Journal of Scientific Research & Reports

15(4): 1-15, 2017; Article no.JSRR.35219
ISSN: 2320-0227

Efficacy of Electrochemical Treatment Method in Removing Pollutants from Restaurant Wastewater

Paul Ngozi Ojukwu[1*] and Kamar Taiwo Oladepo[1]

[1]Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Author PNO designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. Author KTO supervised the study and vetted the draft. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2017/35219
Editor(s):
(1) Luigi dell'Olio, School of Civil Engineering, Channels and Ports, University of Cantabria, Cantabria, Spain.
Reviewers:
(1) Arnaldo Sarti, Instituto de Quimica (Unesp, Araraquara-SP), Brazil.
(2) C. R. Ramakrishnaiah, Visvesvaraya Technological University, India.
(3) Narcis Barsan, "Vasile Alecsandri" University of Bacău, Romania.
(4) Saima Fazal, South China University of Technology, China.
Complete Peer review History: http://www.sciencedomain.org/review-history/20545

Original Research Article

Received 1st July 2017
Accepted 9th August 2017
Published 18th August 2017

ABSTRACT

This study characterized restaurant wastewater and investigated the treatment of restaurant wastewater electrochemically. It also examined the effects of selected factors on the performance of the electrochemical process. This was with a view to evaluating the performance of the electrochemical process. Wastewater from student canteen and a fast-food restaurant were collected into polyethylene bags and treated using electrochemical method in a batch reactor. After addition of wastewater to the reactor, the experiments were carried out separately varying the following factors: voltage, separation distance between electrodes, and volume of wastewater. 2^3 factorial experiments were used to identify factors that influence the efficacy of the electrochemical method. The efficiency of the method was evaluated using Yates' algorithm. The results showed that restaurant wastewater is acidic and polluted with high oil and grease content, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and conductivity. Applied voltage and distance between electrodes had a positive and negative effect respectively on the performance of the electrochemical treatment process while volume of the wastewater had a negative effect on pH increase and a varied effect on the removal of other

**Corresponding author: E-mail: ojukwu213@yahoo.com;*
E-mail: koladepo1@yahoo.com;

pollutants. Electrochemical treatment process can neutralize pH of restaurant wastewater and is efficient in removing oil and grease, BOD, COD, TSS and conductivity from restaurant wastewater with results yielding greater than 90% removal. The significant factors at 95% confidence level were applied voltage (F = 20.33), separation distance between electrodes (F = 20.64), and volume of wastewater (F = 39.57).The study concluded that electrochemical treatment method has the potential to treat restaurant wastewater in a rectangular batch reactor.

Keywords: Electrochemical method; wastewater; reactor; chemical oxygen demand; conductivity.

1. INTRODUCTION

Man's need for food at the time required has made restaurants one of the fastest growing industries. The wastewater discharged by restaurants has become an environmental concern, in particular the high concentration of soluble organics and vegetable fats and oil. The presence of oil and grease is a major concern when discharged directly to bodies of water or to sewer systems as they clog the pipe and produce foul odours [1].

Restaurant wastewater treatment facilities must be highly efficient in removing oil and grease, cause no food contamination, and be compact in size. In addition, the technology has to be simple so that it can be operated easily either by a chef or a waiter. Conventional biological processes are therefore ruled out due to the requirement of large space and skilled technicians. Chemical coagulation/settlement is not practicable because of the low efficiency in removing light and finely dispersed oil particles and possible contamination of foods by chemicals. The G-bag approach, which used a bag of adsorbent to capture the pollutants and degrade the pollutants with the immobilized microorganism on the adsorbent, seems to be a good alternative only if the system can be designed simple and free from fouling [2].

Electrochemical treatment may be considered as an alternative process under the conditions when conventional treatment methods fail to reduce pollution. The electrochemical treatment is considered as one of the advanced oxidation processes, potentially a powerful method of pollution control, offering high removal efficiencies. Electrochemical processes generally have lower temperature requirement than those of other equivalent non-electrochemical treatments and usually there is no need for addition of chemicals. Electrochemical treatment generally requires compact reactors and simple equipment for control and operation of the process. The process would be relatively non-specific, that is, applicable to a variety of contaminants but capable of preventing the production of unwanted side-products. In recent years there has been an increasing interest in the treatment of industrial effluents by electrochemical methods as an alternative to traditional biological treatments.

Several literatures have been published on wastewater treatment [3,4]. [5] examined the removal of phenolic compounds from oil refinery waste effluent using an electro-chemical reactor with a fixed bed anode that has been made of randomly oriented Al. raschig rings packed in a perforated plastic basket located above the horizontal cathode. The phenolic compounds removal was investigated in terms of various parameters in a batch mode namely: pH, operating time, current density, initial phenol concentration, the addition of NaCl, temperature and the effect of phenol structure (effect of functional groups). The chemical oxygen demand (COD) was measured as well. The study revealed that the optimum conditions for the removal of phenolic compounds were achieved at current density = 8.59 mA/cm^2, pH = 7, NaCl concentration = 1 g/L and temperature of 25℃. Remarkable removal of 100% of the phenol compound after 2 hrs can be achieved for 3 mg/L phenol concentration of real refinery wastewater. The new anode design of electrocoagulation cell permits high efficiencies with lower energy consumption in comparison with the other cell design used in previous studies. [6] argued that an effective electrochemical approach for simultaneous silver recovery and cyanide removal from electroplating wastewater was presented. Accordingly, pulse current (PC) electrolysis with parameters including voltage (4.0 V), frequency (800 Hz), and duty cycle (50%) were settled using static cylinder electrodes. Then the influences of technological conditions on the electroplating wastewater treatment process has been widely investigated, which manifested that the concentration of silver ions in electroplating wastewater could be reduced from 221 to 0.4 mg L^{-1} and cyanide could be simultaneously removed from 157 to 4.9 mg L^{-1} after 3.0 h of PC electrolysis at pH 9.5 ± 0.5, aeration rate of 100 L h^{-1}, and stirring speed of 1000 rpm with NaCl addition of 0.05 mol L^{-1} at room temperature. The results of XRD and EDX analysis showed that the silver deposits on the cathode were crystalline in face centered cubic structure and had a high purity. [7] highlighted the electrocoagulation using aluminum electrodes achieved a high removal efficiency of chemical oxygen demand (≥80%) from aqueous solutions containing 0.51 $g \cdot L^{-1}$ tannic acid. The primary mechanism implicated in eliminating tannic acid from water by electrocoagulation using Al. electrodes involves the adsorption of tannic acid molecules on the aluminium hydroxide surface. The results of the treatment of real wastewater obtained from the pulp and paper industry with an initial chemical oxygen demand (COD) concentration of 1450 $mg \cdot L^{-1}$ have shown that more than 60% of COD can be removed by electrocoagulation using Al electrodes under optimized experimental conditions. The specific energy required for the electrochemical process with Al electrodes was estimated to range from 1 to 2 $kWh \cdot m^{-3}$. [8] preliminary work on POME samples were collected from Sri Ulu Langat Palm Oil Mill with COD, turbidity and pH around 50,000 mg/L, 2800 NTU and 4 respectively. Water samples were collected from usual tap water in the laboratory, the pH of tap water was 6 to 8.5. The pH of the water was adjusted to pH 4 by using 1N HCl. The production of hydrogen gas from POME during electrocoagulation was also compared with hydrogen gas production from tap water at pH 4 and tap water without pH adjustment under the same conditions to highlight the advantageous aspects of hydrogen production and wastewater treatment simultaneously. Production of hydrogen gas while treating POME with EC to reduce COD and turbidity effectiveness is the main advantage of this study. Electrocoagulation was performed at different voltage (2, 3 and 4 volts). A reactor containing a volume of 20 litres of POME or water was used to conduct the EC experiments. The maximum hydrogen gas produced was about 22.68 litres/hour and an efficient reduction of COD and turbidity of POME by as much as 57% and 62% was achieved respectively.

The objectives of the present study are to characterize restaurant wastewater, determine the effects of selected factors on the performance of the electrochemical treatment process, and evaluate the performance of the electrochemical treatment process.

2. MATERIALS AND METHODS

2.1 Materials

The materials that were used for the electrochemical process in this study includes aluminum electrodes, copper wire, batch reactor, wastewater, DC power supply, a multimeter, a drying cabinet, desiccator, and a weighing balance. Electricity source in Environmental Laboratory of Civil Engineering Department (Obafemi Awolowo University, Ile-Ife, Nigeria) was used as alternating current source from where the flow of direct current through the laboratory setup was obtained. The procedure flow of the study can be seen in Fig. 1. Fig. 2 displays the experimental set-up of the batch-process.

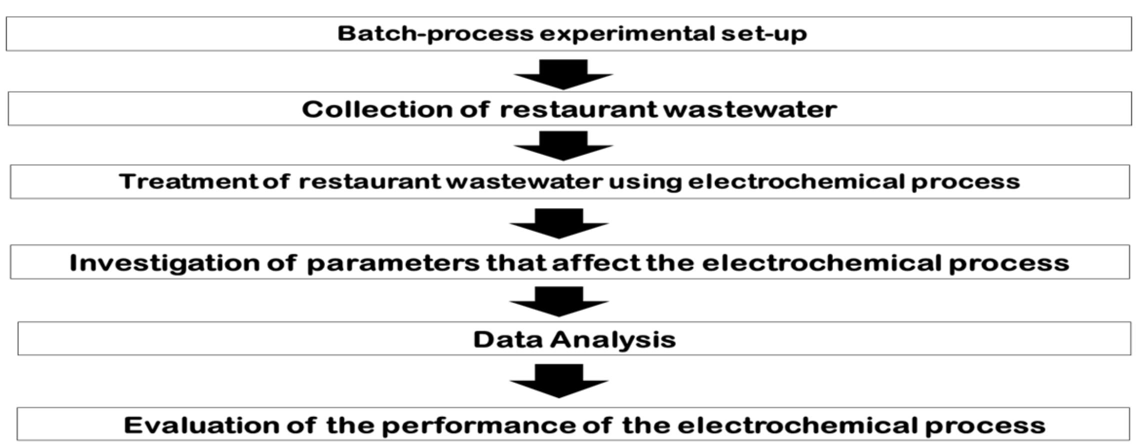

Fig. 1. Procedure flow of the study

Fig. 2. Laboratory set-up of the batch electrochemical process

2.2 Methods

The wastewater from student canteen located at Obafemi Awolowo University, Ile-Ife in Osun State and a fast-food restaurant also located at Ile-Ife in Osun State were collected into polyethylene bags according to Standard Methods for Water and Wastewaters Examination [9]. The wastewaters collected were characterized then investigation of the effects of applied voltage, separation distance between electrodes, and volume of wastewater on electrochemical treatment process was carried out.

2.2.1 Investigation of parameters that affect the batch electrocoagulation process

The influence of three variables on the performance of the electrocoagulation reactor was investigated with the aid of 2^3 factorial experiment. The three factors were: Applied voltage (V), separation distance between the electrodes (D), and volume of wastewater (W_v). The low level and high level of each of the factors were 10 V and 20 V for V, 10 mm and 40 mm for D, and 1.5 L and 3.0 L for W_v respectively. The initial pH, oil and grease, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and conductivity of the wastewater were determined according to APHA [9] standards. The electrodes were cleaned in order to wash away any surface contaminants or dirt present before they were submerged into the wastewater. The cleaning process used by Umlas et al. [1] was applied in this study and consisted of the use of sand paper for polishing and the application of 3 M HCl and distilled water for rinsing. The electrodes were then air-dried before they were mounted to the EC reactor. To operate the reactor, the aluminum electrodes were fixed in the grooves of the spacer at the bottom of the reactor. The electrodes were connected to the power supply with the aid of cables with clip at their ends. A measured amount of the restaurant wastewater was poured into the reactor then the multimeter was connected for voltage measurements. The DC power supply units were switched on and the control knobs were turned in order to set the voltage to predetermined level. The reactor was left to run for 30 minutes. The power supply unit was switched on and the reactor was operated for 30 minutes. Each experiment was repeated three times, so there were 24 experimental runs. At the end of each run, the final COD, BOD, TSS, oil and grease, conductivity, and pH were determined. This procedure was repeated for all the experimental runs. The order of the running of the experiments were randomized with the aid of random numbers obtained from [10].

The data collected were subjected to Yates' algorithms and significance analysis. The total and mean response of each experimental condition were the sum and average respectively of the replicates. Yates' algorithms were obtained using procedures stated in [11,12]. Degrees of freedom were obtained using methods stated in literatures [13,14]. Divisors, effects, sum of squares, mean of squares, and F-values were obtained using methods stated in [15-17].

3. RESULTS AND DISCUSSION

3.1 Characteristics of Restaurant Wastewater

It is very difficult to have one meaningful characterization for each restaurant due to the variation of wastewater composition from time-to-time for a particular restaurant. The wastewater composition of student canteen restaurant is expected to be different from that of fast-food restaurant due to the difference in cuisines prepared. This can be also attributed to the unavailability of wastewater collection system. Thus, waste samples have to be scooped from the entrance of the drains at representative time. 24 samples were collected from each restaurant for the characterization purpose. The results are listed in Table 1. Oil and grease content was higher in wastewater samples from the fast-food restaurant. The pollutant concentration varied in a wide range. It was recorded that the highest COD, oil and grease, total suspended solids, BOD, and conductivity values were found from wastewater discharged by the fast-food restaurant. The highest pH values was found from wastewater discharged by student canteen. However, it should be pointed out that the pollutant concentration variations are comparable for all the restaurants. In comparison with [18], the parameters consistently exceeded the standard although oil and grease and BOD values from wastewater discharged by student canteen were lower than values obtained from the fast-food restaurant.

3.2 Treatment of Wastewater

The results and discussion of student canteen and fast-food wastewater treated electrochemically are based on pollutant (BOD, COD, oil and grease, TSS, conductivity) removal and pH increase. Table 2 shows standard matrix, total and mean response of BOD removal (in percentage) from student canteen wastewater, Yates' analysis, divisors, effects, sum of squares, degree of freedom, mean of sum of squares and F-values of the factors (V, D, W_v) and their interactions. Table 3 shows standard matrix, total and mean response of pH increase and removal of oil and grease, COD, TSS, and Conductivity (in percentage) from student canteen wastewater, Yates' analysis, divisors, effects, sum of squares, degree of freedom, mean of sum of squares and F-values of the factors (V, D, W_v) and their interactions. Table 4 shows standard matrix, total and mean response of pH increase and removal of oil and grease, COD, TSS, and Conductivity (in percentage) from fast-food restaurant wastewater, Yates' analysis, divisors, effects, sum of squares, degree of freedom, mean of sum of squares and F-values of the factors (V, D, W_v) and their interactions.

3.2.1 <u>Removal of BOD from restaurant wastewater</u>

From Table 2, it can be seen that when only the applied voltage was high, it had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). When only separation distance between electrodes was high, it had negative effect with significance at 95% confidence level ($F > F_c = 4.49$). The positive interaction between applied voltage and separation distance between electrodes had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). When only volume of wastewater was high, it had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). Interaction between high applied voltage and high volume of wastewater had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). The positive interaction between separation distance between electrodes and volume of wastewater had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). Finally, the interaction between all the factors (applied voltage - V, separation distance between electrodes - D, volume of wastewater - W_v) had negative effect with no significance at 95% confidence level ($F < 1 < F_c$).

From Table 4, it can be seen that when only the applied voltage was high, it had a positive effect with significance at 95%confidence level ($F > F_c = 4.49$). When only separation distance between electrodes was high, it had negative effect with significance at 95% confidence level ($F > F_c = 4.49$). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). Increase in volume of wastewater with other factors low (-) had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). Interaction between high applied voltage and high volume of wastewater had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). The positive interaction between separation distance between electrodes and volume of wastewater had negative effect with no significance ($F < 1 < F_c$). Finally, the interaction between all the factors had a positive effect with no significance at 95% confidence level ($F<1<F_c$).

3.2.2 Increase in pH of restaurant wastewater

From Table 3, it can be seen that when only the applied voltage was high, it had negative effect with no significance at 95% confidence level ($F < 1 < F_c$) at F_c = 4.49. When only separation distance between electrodes was high, it had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had a neutral effect with no significance at 95% confidence level ($F < 1 < F_c$). Increase in volume of wastewater with other factors low (-) had negative effect with significance at 95% confidence level ($F > F_c$ = 4.49). Interaction between high applied voltage and high volume of wastewater had a positive effect with no significance at 95% confidence level ($1 < F < F_c$). The positive interaction between separation distance between electrodes and volume of wastewater had neutral effect with no significance at 95% confidence level ($F < 1 < F_c$). Finally, the interaction between all the factors had negative effect with no significance at 95% confidence level ($1 < F < F_c$).

From Table 4, it can be seen that when only the applied voltage was high, it had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$) at Fc = 4.49. When separation distance between electrodes was high, it had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance ($1 < F < F_c$). Increase in volume of wastewater with other factors low (-) had negative effect with significance at 95% confidence level ($F > F_c$ = 4.49). Interaction between high applied voltage and high volume of wastewater had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). The positive interaction between separation distance between electrode and volume of wastewater had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). Finally, the interaction between all the factors had negative effect with no significance at 95% confidence level ($F < 1 < F_c$).

3.2.3 Removal of oil and grease from restaurant wastewater

From Table 3 it can be seen that when only the applied voltage was high, it had a positive effect with significance at 95% confidence level ($F > F_c$ = 4.49). When only separation distance between electrodes was high, it had negative effect with significance at 95% confidence level ($F > F_c$ = 4.49). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). Increase in volume of wastewater with other factors low (-) had a positive effect with significance at 95% confidence level ($F > F_c$ = 4.49). Interaction between high applied voltage and high volume of wastewater had a positive effect with no significance at 95% confidence level ($1 < F < F_c$). The positive interaction between separation distance between electrodes and volume of wastewater had negative effect with significance at 95% confidence level ($F > F_c$ = 4.49). Finally, the interaction between all the factors had negative effect with significance at 95% confidence level ($F > F_c$ = 4.49).

From Table 4, it can be seen that when only the applied voltage was high, it had a positive effect with significance at 95% confidence level ($F > F_c$ = 4.49). When only separation distance between electrodes was high, it had negative effect with significance at 95% confidence level ($F > F_c$ = 4.49). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had a positive effect with no significance at 95% confidence level ($1 < F < F_c$). Increase in volume of wastewater with other factors low (-) had a positive effect with significance at 95% confidence level ($F > F_c$ = 4.49). Interaction between high applied voltage and high volume of wastewater had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). The positive interaction between separation distance between electrode and volume of wastewater had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). Finally, the interaction between all the factors had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$).

Table 1. Characteristics of student canteen and fast-food restaurant wastewaters

Restaurant	Student canteen				Fast-food restaurant				FEPA (1992) Standard	
Number of samples	24				24				Limit for discharge into surface water	Limit for land application
	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Less than 40^0C within 15 meter of outfall	less than 40^0C
PH	5.19	5.31	5.24	0.03	5.08	5.17	5.14	0.02	6 - 9	6 -9
BOD (MG/L)	328.00	380.00	346.50	11.46	3108.00	3510.00	3302.75	136.29	50	500
TSS (MG/L)	4709.00	5786.00	5395.17	374.26	35076.00	37964.00	36376.33	847.29	30	-
COD (MG/L)	4173.00	4550.00	4373.00	117.62	4704.00	5130.00	4807.63	124.042	-	-
CONDUCTIVITY (µS/CM)	2309.52	2720.74	2516.61	2516.61	4573.43	4925.14	4752.18	109.38	-	-
OIL AND GREASE (MG/L)	8.02	9.54	8.72	0.51	780.00	920.00	805.00	34.77	10	30

Table 2. Standard matrix, response, Yates' algorithms and significance analysis of results of BOD removal from student canteen wastewater

Experiment No.	Standard matrix and factors				Total BOD removed (in %) from 3 replicates	BOD removed (%)	Statistical Analysis						
	V	D	W_v	Code		Mean	Final values of Yates' algorithms	Divisor	Effects	Sum of squares	Degree of freedom	Mean of sum of squares	F-values
1	-	-	-	1	268.23	89.41	2084.87	24	86.87	45277.93			
2	+	-	-	V	266.52	88.84	118.26	12	9.86	582.73	1	582.73	*6.21
3	-	+	-	D	189.57	63.19	-140.87	12	-11.74	826.84	1	826.84	*8.81
4	+	+	-	VD	257.22	85.74	104.00	12	8.67	450.67	1	450.67	*4.80
5	-	-	+	W_v	284.64	94.88	121.80	12	10.15	618.11	1	618.11	*6.58
6	+	-	+	VW_v	293.48	97.83	-13.62	12	-1.14	7.73	1	7.73	0.08
7	-	+	+	DW_v	240.87	80.29	35.07	12	2.92	51.25	1	51.25	0.55
8	+	+	+	VDW_v	284.35	94.78	-34.72	12	-2.89	50.24	1	50.24	0.54
Error										1502.02	16	93.88	
Total of sum squares										3529.70	23	153.47	

†*significant at 90% confidence level ($F_{16,1} = 3.05$)*
**significant at 95% confidence level ($F_{16,1} = 4.49$)*

Table 3. Standard matrix, response, Yates' algorithms and significance analysis of results of pH increase and removal of Oil and Grease, COD, TSS, and Conductivity from student canteen wastewater

Experiment Code	pH increase			Oil and grease			COD			TSS			Conductivity		
	(%) increase	Statistical analysis		(%) decrease	Statistical analysis		(%) decrease	Statistical analysis		(%) decrease	Statistical analysis		(%) decrease	Statistical analysis	
	Mean	Effect	F-value	Mean	Effect	F-value	Mean	Effect	F-value	Mean	Effect	F-value	Mean	Effect	F-value
1	2.45	1.68		82.34	85.31		91.21	94.62		85.38	88.17		90.92	90.98	
V	1.46	-0.02	0.00	83.22	5.26	*20.33	90.65	1.41	1.90	90.21	2.70	0.78	90.90	0.32	†3.43
D	2.10	0.23	0.43	79.63	-3.23	*7.68	96.21	3.11	*9.29	83.77	-4.51	2.18	90.82	-0.22	1.59
VD	2.28	0.00	0.00	84.79	-0.59	0.26	94.85	-1.94	†3.60	79.24	-1.31	0.18	91.00	-0.22	1.63
W_v	0.69	-0.79	*4.88	85.67	5.64	*23.40	91.58	2.78	*7.40	91.45	7.03	*5.30	90.71	0.14	0.64
VW_v	1.65	0.39	1.19	96.48	2.24	†3.68	98.82	2.37	*5.38	94.64	2.55	0.70	91.81	0.24	2.02
DW_v	1.51	0.00	0.00	83.10	-2.66	*5.19	96.67	-1.49	2.13	86.66	1.78	0.34	90.82	-0.21	1.56
VDW_v	1.29	-0.59	2.70	87.27	-2.73	*5.50	96.97	-1.53	2.26	93.97	3.37	1.21	90.84	-0.32	†3.50

†*significant at 90% confidence level ($F_{16,1}$ = 3.05)*

**significant at 95% confidence level ($F_{16,1}$ = 4.49)*

Table 4. Standard matrix, response, Yates' algorithms and significance analysis of results of pH increase and removal of Oil and Grease, COD, TSS, and Conductivity from fast-food restaurant wastewater

Experiment code	pH increase			Oil and grease			BOD			COD			TSS			Conductivity		
	(%) increase	Statistical analysis		(%) decrease	Statistical analysis		(%) decrease	Statistical analysis		(%) decrease	Statistical analysis		(%) decrease	Statistical analysis		(%) decrease	Statistical analysis	
	Mean	Effect	F-value	Mean	Effect	F-value	Mean	Effect	F-value	Mean	Effect	F-value	Mean	Effect	F-value	Mean	Effect	F-value
1	1.85	1.44		81.25	83.92		88.48	89.49		97.74	96.31		97.86	98.81		88.55	89.62	
V	1.88	0.02	0.00	85.83	6.79	*11.54	88.48	6.22	*13.43	93.89	0.77	0.59	99.43	0.54	*5.25	90.17	2.19	*10.37
D	1.75	-0.09	0.60	76.67	-5.13	*6.57	77.63	-7.71	*20.64	96.67	0.76	0.57	98.20	-0.60	*6.57	89.67	-0.63	0.87
VD	1.81	-0.14	1.43	83.13	2.38	1.41	87.27	5.90	*12.09	95.25	-0.43	0.18	98.24	-0.26	1.18	90.23	-1.15	2.84
W_v	0.97	-0.76	*39.57	87.29	4.40	*4.83	97.88	8.04	*22.43	92.92	0.84	0.71	99.58	0.76	*10.47	87.99	-0.06	0.01
VW_v	1.27	-0.03	0.00	91.54	1.27	0.40	98.52	1.40	0.68	99.17	3.41	*11.51	99.60	-0.26	1.26	93.05	1.10	2.63
DW_v	1.17	-0.01	0.00	76.88	-1.48	0.55	81.52	-1.67	0.97	96.36	0.61	0.37	98.53	-0.19	0.62	87.90	-1.22	†3.23
VDW_v	0.86	-0.16	1.70	88.75	1.44	0.52	96.11	1.08	0.40	98.47	-1.64	2.68	99.07	0.51	*4.71	89.43	-0.62	0.82

†*significant at 90% confidence level* ($F_{16,1}$ = 3.05)

**significant at 95% confidence level* ($F_{16,1}$ = 4.49)

3.2.4 Removal of COD from restaurant wastewater

From Table 3, it can be seen that when only the applied voltage was high, it had a positive effect with no significance at 95% confidence level ($1 < F < F_c$) at Fc = 4.49. When only separation distance between electrodes was high, it had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). The interaction between high applied voltage and high separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance at 95% confidence level ($1 < F < F_c$). Increase in volume of wastewater with other factors low (-) had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). Interaction between high applied voltage and high volume of wastewater had a positive effect with significance 95% confidence level ($F > F_c = 4.49$). The positive interaction between separation distance between electrodes and volume of wastewater had negative effect with no significance at 95% confidence level ($1 < F < F_c$). Finally, the interaction between all the factors had negative effect with no significance at 95% confidence level ($1 < F < F_c$).

From Table 4, it can be seen that when only the applied voltage was high, it had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$) at Fc = 4.49. When only separation distance between electrodes was high, it had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). The interaction between high applied voltage and high separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). Increase in volume of wastewater with other factors low (-) had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). Interaction between high applied voltage and high volume of wastewater had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). The positive interaction between separation distance between electrodes and volume of wastewater had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). Finally, the interaction between all the factors had negative effect with no significance at 95% confidence level ($F < 1 < F_c$).

3.2.5 Removal of TSS from restaurant wastewater

From Table 3, it can be seen that when only the applied voltage was high, it had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$) at Fc = 4.49. When only separation distance between electrodes was high, it had negative effect with no significance at 95% confidence level ($1 < F < F_c$). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance ($F < 1 < F_c$). Increase in volume of wastewater with other factors low (-) had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). Interaction between high applied voltage and high volume of wastewater had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). The positive interaction between separation distance between electrodes and volume of wastewater had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). Finally, the interaction between all the factors had a positive effect with no significance at 95% confidence level ($1 < F < F_c$).

From Table 4, it can be seen that when only the applied voltage was high, it had a positive effect with no significance at 95% confidence level ($F > F_c = 4.49$). When only separation distance between electrodes was high, it had negative effect with significance at 95% confidence level ($F > F_c = 4.49$). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance at 95% confidence level ($F < 1 < Fc$). Increase in volume of wastewater with other factors low (-) had a positive effect with significance at 95% confidence level ($F > Fc = 4.49$). Interaction between high applied voltage and high volume of wastewater had a negative effect with no significance ($F < 1 < F_c$). The positive interaction between separation distance between electrodes and volume of wastewater had negative effect with no significance ($F < 1 < F_c$). Finally, the interaction between all the factors (V, D, W_v) had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$).

3.2.6 Removal of conductivity from restaurant wastewater

From Table 3, it can be seen that when only the applied voltage was high, it had a positive effect with no significance at 95% confidence level ($1 < F < F_c$) at $F_c = 4.49$. When only separation distance between electrodes was high, it had negative effect with no significance at 95% confidence level ($1 < F < F_c$). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance at 95% confidence level ($1 < F < F_c$). Increase in volume of wastewater with other factors low (-) had a positive effect with no significance at 95% confidence level ($F < 1 < F_c$). Interaction between high applied voltage and high volume of wastewater had a positive effect with no significance at 95% confidence level ($1 < F < F_c$). The positive interaction between separation distance between electrodes and volume of wastewater had negative effect with no significance at 95% confidence level ($1 < F < F_c$). Finally, the interaction between all the factors had negative effect with no significance at 95% confidence level ($1 < F < F_c$).

From Table 4, it can be seen that when only the applied voltage was high, it had a positive effect with significance at 95% confidence level ($F > F_c = 4.49$). When only separation distance between electrodes was high, it had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). The interaction between high applied voltage and separation distance between electrodes with volume of wastewater low (-) had negative effect with no significance at 95% confidence level ($1 < F < F_c$). Increase in volume of wastewater with other factors low (-) had negative effect with no significance at 95% confidence level ($F < 1 < F_c$). Interaction between high applied voltage and high volume of wastewater had a positive effect with no significance at 95% confidence level ($1 < F < F_c$). The positive interaction between separation distance between electrode and volume of wastewater had negative effect with no significance at 95% confidence level ($1 < F < F_c$). Finally, the interaction between all the factors had negative effect with no significance at 95% confidence level ($F < 1 < F_c$).

3.3 Factors Influencing the Performance of the Electrochemical Process

The influence of the factors on the electrochemical process were determined based on the effects obtained from the statistical analysis. From the statistical analysis (presented in Tables 1, 2, and 3), the effects of factors and interactions can be grouped into two, namely:

i. Factors and interactions with negative coefficients, and
ii. Factors and interactions with positive coefficients.

The factors and interactions with negative effects suggest that better efficiency of the electrochemical process can only be achieved at their low levels (-). On the other hand, factors and interactions with positive effects suggest that efficiency of the electrochemical process can only be achieved at their high levels (+).

The F-values obtained from the statistical analysis (presented in Tables 1, 2, and 3) can be categorized into three as follows:

i. Those interactions with F-values less than one (1),
ii. Those factors and interactions with F-values greater than one but less than the critical F-value at 95% confidence level, and
iii. Those factors with F-values greater than the critical value at 95% confidence level.

The grouping indicates interactions with negligible effects ($F<1$), factors and interactions with little effects ($1 < F < F_c$) and factors with significant effects ($F > F_c = 4.49$). Factors with significant effects should be given priority in the design of the electrochemical unit.

3.3.1 Effect of applied voltage

Applied voltage had an overall positive effect on the performance of the electrochemical treatment process. When only the applied voltage was at high level, the bubble density increased which led to greater upwards momentum flux and thus more likely removal by flotation. Similar observation was made by Holt et al. [19]. This implies that when the applied voltage was at high level, the efficiency of the electrochemical process was increased.

3.3.2 Effect of separation distance between electrodes

Inter-electrode distance had a negative effect on the performance of the electrochemical treatment process. Inter-electrode distance affects the amount of coagulants dosed throughout the rectangular reactor. If inter-electrode distance is too close, the coagulants may be concentrated in the immediate dosing area while if it is too large, destabilization may occur at longer period of time because as the separation between the electrodes increases, the resistance offered by the electrolyte to the applied voltage increases. Similar observations were made by [20,21]. This suggests that a closer inter-electrode distance was able to promote coagulant and pollutant interaction with little interference from electrostatic field which occurs at wider distances [20,21].

3.3.3 Effect of volume of wastewater

The volume of the wastewater had a negative effect on pH increase. This suggests that when the volume of wastewater was at low level the pH neutralization efficiency of the process was increased. The volume of wastewater had varied effect on other pollutants depending on the pollutant treated due to the geometry of the reactor. Similar observation was made by [22].

3.4 Efficiency of the System

The removal efficiency of the electrochemical process was determined by analyzing the effect of the electrochemical process on pH and on the removal of other pollutants from the wastewater. Figs. 3 – 6 present the pollutant removal efficiency of the electrochemical process at different treatment combinations.

Fig. 3 shows efficiency of the electrochemical treatment in the reduction of BOD, COD, TSS, conductivity, and oil and grease from student canteen wastewater at different treatment combinations. The highest average reduction of BOD obtained was 97.83% while lowest average % reduction of BOD obtained was 63.19%. The highest average reduction of COD obtained was 98.82% while the lowest average % reduction of COD obtained was 90.65%. The highest average reduction of TSS obtained was 94.64% while the lowest average % reduction of TSS obtained was 79.24%. The highest average reduction of conductivity obtained was 91.81% while the lowest average % removal of conductivity obtained was 90.71%. The highest average reduction of oil and grease obtained was 96.48% while the lowest average % reduction of oil and grease obtained was 79.63%.

Fig. 4 shows pH value of electrochemically treated student canteen wastewater at different treatment combinations. It can be seen from Fig. 4 that when volume of wastewater was at low level the pH was increased by an average of 2.07 whereas when volume of wastewater was at high level the pH was increased by an average of 1.29 and the highest average pH obtained was 7.69 while the lowest average pH obtained was 5.93.

Fig. 5 shows efficiency of the electrochemical treatment in the reduction of BOD, COD, TSS, conductivity, and oil and grease from fast-food restaurant wastewater at different treatment combinations. The highest average removal of BOD obtained was 98.52% while the lowest average % removal of BOD obtained was 77.63%. The highest average removal of COD obtained was 99.17% the lowest average % removal of COD obtained was 92.92%. The highest average removal of TSS obtained was 99.60% while the lowest average % removal of

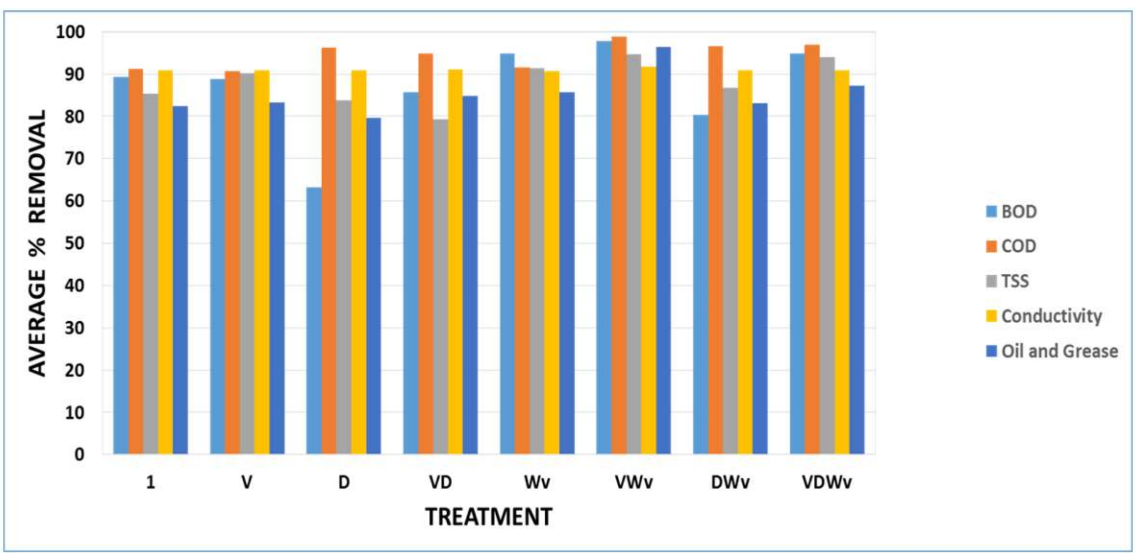

Fig. 3. Average % pollutant removal efficiencies of electrochemical treatment of student canteen wastewater using factorial experiments

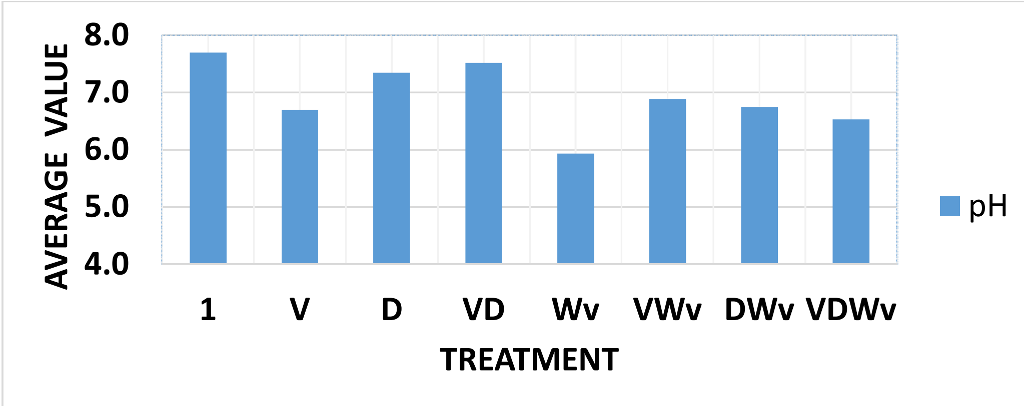

Fig. 4. Average pH value of electrochemically treated student canteen wastewater using factorial experiments

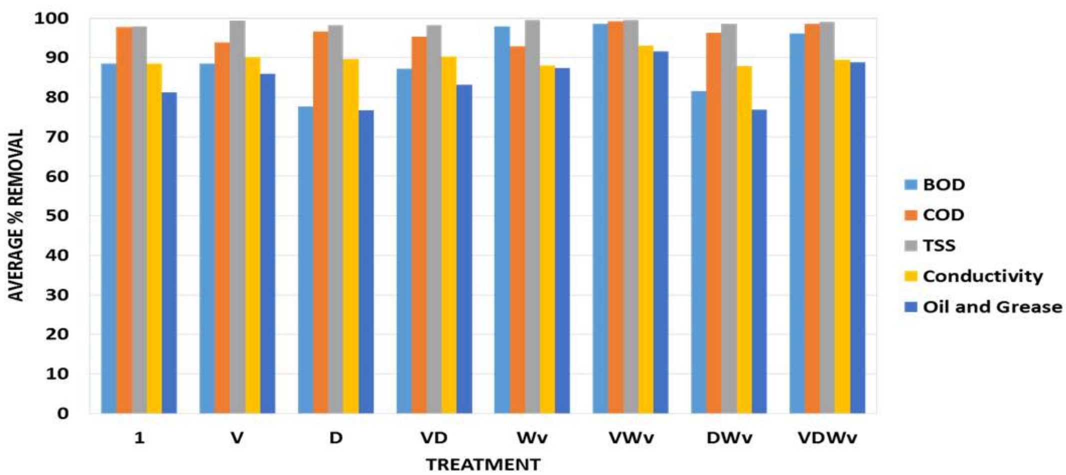

Fig. 5. Average % pollutant removal efficiencies of electrochemical treatment of fast-food restaurant wastewater using factorial experiments

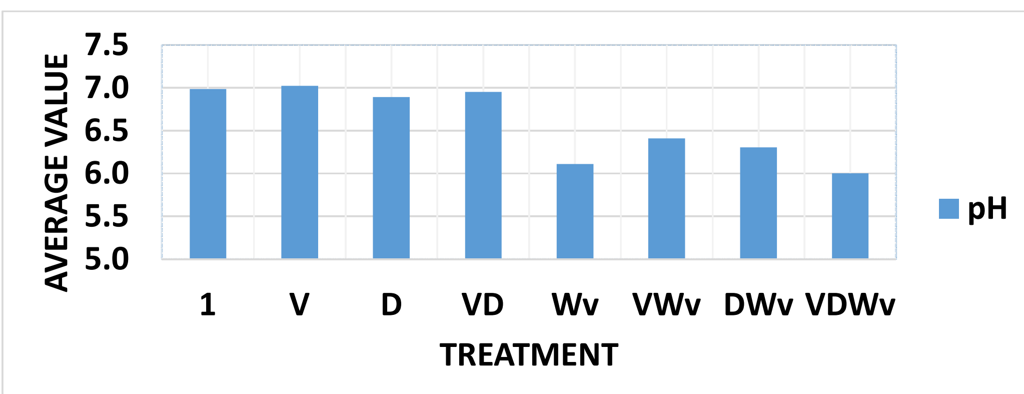

Fig. 6. Average pH value of electrochemically treated fast-food restaurant wastewater using factorial experiments

TSS obtained was 97.86%. The highest average removal of conductivity obtained was 93.05% while lowest average % removal of conductivity obtained was 87.99%. The highest average removal of conductivity obtained was 91.54% while the lowest average % removal of oil and grease obtained was 76.67%.

Fig. 6 shows pH value of electrochemically treated fast-food restaurant wastewater at different treatment combinations. It can be seen from Fig. 6 that when volume of wastewater was at low level the pH was increased by an average of 1.82 whereas when volume of wastewater was at high level the pH was increased by an average of 1.07 and the highest average pH obtained was 7.02 while the lowest average pH obtained was 6.00.

4. CONCLUSION

Based on the results obtained from the study, it can be concluded that restaurant wastewater is acidic and polluted with high oil and grease content, BOD, COD, TSS, and conductivity. Applied voltage had a positive effect on the performance of the electrochemical treatment process. Distance between electrodes had a negative effect on the performance of the electrochemical treatment process. Volume of the wastewater had a negative effect on pH increase and a varied effect on other pollutants depending on the pollutant treated. Electrochemical treatment process can neutralize pH of restaurant wastewater and is efficient in removing oil and grease, BOD, COD, TSS and conductivity from restaurant wastewater with results yielding greater than 90% removal. This shows that the electrochemical treatment method has the potential to treat restaurant wastewater in a rectangular batch reactor.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Umlas NGA, Baraoidan MJA, Leonco GP, Mission EG, Gaspillo PD. Electrocoagulation of simulated quick service restaurant wastewater using aluminium-iron electrode pair. DLSU Research Congress, De La Salle University, Manila, Philippines; 2014
2. Chen XM, Chen G, Yue PL. Separation of pollutants from restaurant wastewater by electrocoagulation. Separation and Purification Technology. 2000;19(1-2):65-76.
3. Naje AS, Abbas SA. Electrocoagulation Technology in Wastewater Treatment: A Review of Methods and Applications. Civil and Environmental Research. 2013;3(11). ISSN: 2224-5790 ISSN: 2225-0514
4. Oke IA, Oladepo KT, Fehintola EO, Adekanunbi EA, Obijole AO, Basil ON, Mohammed H. An overview of electrochemical treatment processes in environmental engineering: Modern studies on electrochemical treatment processes (2005 – 2010). In: Water Treatment Processes: Kostas Demadis, ed,. Nova Science Publishers Inc.; 2012. ISBN: 978-1-62100-352-6
5. El-Ashtoukhy~~,~~ EZ, El-Taweel~~,~~ YA, Abdelwahab~~,~~ O, Nassef~~,~~ EM. Treatment of petrochemical wastewater containing phenolic compounds by electrocoagulation using a fixed bed electrochemical reactor. Int. J. Electrochem. Sci. 2013;8:1534–1550.
6. Gao Y, Zhou Y, Wang H, Lin W, Wang Y, Sun D, Hong J, Li Q. Simultaneous silver recovery and cyanide removal from electroplating wastewater by pulse current electrolysis using static cylinder electrodes. Ind. Eng. Chem. Res, AI; 2013.
7. Mansouri K, Hannachi A, Abdel-Wahab A, Bensalah N. Electrochemically Dissolved Aluminum Coagulants for the Removal of Natural Organic Matter from Synthetic and Real Industrial Wastewaters. Ind. Eng. Chem. Res. 2013;51:2428-2437.
8. Ali, E, Yaakob, Z. Electrocoagulation for treatment of industrial effluents and hydrogen please delete this space production. INTECH O.S Publishing, Kulalumpur: Malaysia. 2012;227-242.
9. APHA. Standard methods for the examination of water and wastewater. American Public Health Association, Washington; 1998.
10. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2^{nd} ed. New York: John Wiley & Sons, Inc; 1983.
11. Guttman I, Wilks SS, Hunter JS. Introductory Engineering Statistics, 2^{nd} ed. New York: John Wiley & Sons, Inc; 1971.
12. Devore JL, Farnum NR. Applied statistics for engineers and scientists, 1^{st} ed. Toronto: Duxubury Press; 1999.
13. Montgomery DC, Runger GC. Applied Statistics and Probability for Engineers 6^{th}

ed. New York: John Wiley & Sons, Inc; 2013.
14. Montgomery DC. Design and analysis of experiments, 7th ed. New York: John Wiley & Sons, Inc; 2009.
15. Gardiner WP, Gettinby G. Experimental design techniques in statistical practice, 2nd ed. Chichester: Harwood Publishing; 1998.
16. Devore JL. Introduction to Probability and Statistics for Engineering and Scientists. 1st ed. Spain: Duxury Thomas Learning; 2000.
17. Oke IA, Oladepo KT, Ogedengbe MO. Utilization of 2^k factorial experiments for the determination of factors that influence electrochemical process. Ife Journal of Technology. 2010;19(2):48–54.
18. Federal Environmental Protection Agency. National interim guidelines and standards for industrial effluents, gaseous emissions and hazardous wastes management in Nigeria; 1992.
19. Holt PK, Barton GW, Mitchell CA. The future for electrocoagulation as a localized water treatment technology. Chemosphere. 2005;59:355–367.
20. Oladepo KT. Development of an electrochemical method of coagulation for water treatment. Unpublished Ph.D. thesis, Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife; 2009.
21. Lieu UT. The effects of operational parameters on the removal of pollutants from a simulated tannery wastewater by electrocoagulation process. Unpublished Masters Dissertation, De La Salle University – Manila; 2012.
22. Mohta A. Electro-chemical treatment of wastewater. M.Sc. Thesis. Department of Biotechnology & Environmental Sciences, Thapar University; 2007.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/20545