The University of Tehran Press

Pollution

https://jpoll.ut.ac.ir/

Print ISSN: 2383-451X
Online ISSN: 2383-4501

Purification of Heavy Metals Contaminated Groundwater by Electro-Coagulation Process Using Graphite Electrodes

Muhibbu-Din Eniola Ismail✉ | Jimoh Heekmah Oiza | Kehinde David Pelumi | Tinuoye Ifeoluwa Agnes

Clean Energy/Environmental Research Laboratory, Department of Chemical Engineering, University Of Ilorin, Nigeria.

Article Info

Article type:
Research Article

Article history:
Received: 15 June 2023
Revised: 31 August 2023
Accepted: 13 December 2023

Keywords:
Electrolysis
Process Cost Raw Well Water
Operation Parameter
Laboratory scale

ABSTRACT

The application of the electro-coagulation process to the identified contaminated groundwater at Abala community, a suburb of Ilorin metropolis in Kwara state, Nigeria, is the subject of this study. The groundwater samples were electro-coagulated in a batch reactor of 2.5L containing 1 litre volume of contaminated groundwater for 1 hour per run using a DC power supply ranging from 10v to 20v at constant current 5amp and 2amp to 6amp at constant voltage 10v using graphite electrodes. The results revealed that electro-coagulation process can reduce turbidity, TDS, Electrical Conductivity, BOD, TOC, COD, and color by 97.3 %, 91.2 %, 91.1 %, 96 %, 99.7%, 99.7%, 79.9%, and 82.96 %, respectively. Through Atomic Absorption spectroscopy analytical study, the process also shows removal efficiency of Manganese, Iron, and Zinc of 82.96 percent, 70.0 percent, and 95.30 percent, respectively. The outcome of the electro-coagulation process met the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), and the Water Environment Partnership In Asia (WEPA) criteria for both drinking water and general industrial wastewater discharge guidelines. The electro-coagulation treatment for contaminated groundwater was efficient and effective, therefore it is recommended in this study for Nigerians.

Cite this article: Eniola Ismail, M. D., Heekmah Oiza, J., David Pelumi, H., & Ifeoluwa Agnes, T. (2024). Purification of Heavy Metals Contaminated Groundwater by Electro-Coagulation Process Using Graphite Electrodes. *Pollution*, 10 (1), 32-44.
https://doi.org/10.22059/poll.2023.360784.1949

 Publisher: The University of Tehran Press.
DOI: https://doi.org/10.22059/poll.2023.360784.1949

INTRODUCTION

In Nigeria and around the world, groundwater is the primary source of portable water. Groundwater bodies are contaminated by a variety of causes including geological formations from the earth's crust, indiscriminate industrial and household waste discharge, leaky landfills, underground storage tanks and pipelines. Effluents are being released directly or indirectly into the aquifers of groundwater due to advent of industrial revolutions and wash down of numerous transportations air pollutants (Muhibbudin et al., 2021).

Heavy metals found in underground water bodies, which are major cause of pollution and have a density of more than 5 milligrams per litre (mg/l), are among these effluents (Babel and Kurniawan, 2004) The solubility of heavy metals in groundwater causes significant environmental problems and human health risks. Although some heavy metals are needed nutrients in very small concentrations, all heavy metals at elevated levels are harmful to human health (Borba et al., 2006). Heavy metals can infiltrate the food chain and accumulate in live organisms when they are consumed. Heavy metals such as iron, manganese, and zinc have

*Corresponding Author Email: *muhibbudin.ei@unilorin.edu.ng*

been found in contaminated groundwater in Abala, Osin, Ita-elepa, Ilorin-west local government, Nigeria. To maintain good health and wellness for the people of Ilorin, the contaminated groundwater must be treated exclusively for drinking and domestic use, free of toxins and other dangerous components. The treatment of groundwater free from heavy metals has become an imperative necessity. The need to identify the most cost-effective and efficient solutions to clean groundwater without polluting it has become an urgent priority.

To address this issue, a variety of conventional treatment of contaminated groundwater are available, these include Nano-materials (Abdulkhaleq et al., 2022; Mohammed et al., 2022), Biological Aerated Filters (Kalash,et al., 2022), catalytic oxidation, adsorption processes (Mohammed et al., 2022), ion exchange, biological processes, ultra-filtration, photo catalysis, and chemical coagulation (Tahboub, 2000). Each of the waste water treatment processes mentioned necessitates a significant energy commitment, optimization, tailored design to target specific water pollutants rather than all and continuous material adjustments. Conversely, electro-coagulation methods posses the capacity to effectively treat any type of water pollutant with minimal energy and cost requirements, while maintaining high efficiency. The electro-coagulation method received little attention, particularly in African settings. Electro-coagulation (EC) is an electrochemical water treatment process for contaminants/pollutants in water. The process destabilizes and breakdown contaminants through movement of charged ions from the electrical powered electrodes. Because of its superior benefits over other approaches (physical, chemical, and biological) in contaminated water treatment, globally electro-coagulation (EC) processes have recently gotten increased attention around the world.

In contaminated water treatment, EC has capability to removing suspended solids/particles, oil and greases in wastewater. It is very useful in coagulating the colloids found in natural water, reducing the turbidity and color (Can et al., 2003; Daneshvar et al.,2006). It can also be employed in remove iron ions, silicates, humus, dissolved oxygen, virus, fungi and bacteria (Chen, 2004). EC has been applied in treating wastewaters from textile (Can et al., 2006; Phalakornkule et al., 2010), tannery (Benhadji et al., 2011), food industries (Tahboub, M. 2000; Valero et al., 2011), catering (Chen et al., 2000), petroleum, tar sand and oil shale wastewater (Rizzo, L., et al. 2013), municipal sewage (Pouet, and Grasmick, 1995), chemical fiber wastewater (Lai and Lin 2004), oily wastewater (Phalakornkule, et al., 2010), nitrite (Abuzaid, et al., 1999), and dye stuff (Ogutveren and Koparal 1992) from wastewater.

In Nigeria, wastewater treatment for groundwater has played a significant role in increasing the production of safe drinking water. According to the Joint Monitor Program for Water Supply and Sanitation (JMP), 60 percent of Nigerians rely on groundwater point sources for their primary drinking water supply, with 73 percent in rural areas and 45 percent in urban areas (Joint Monitoring Programme, 2019). The treatment and provision of groundwater resources should be done in a way that is sustainable, low-cost and acceptable.

As a result, the goal of this study is to purify heavy metal-contaminated groundwater utilizing an electro-coagulation process using a graphite electrode.

MATERIAL AND METHODS

Description of Study Area and sampling site

Ilorin, the state capital of Nigeria's Kwara State, with a population of 780,000 people [25]. It has a land area of 765 km2 and is located between latitude 8° 29' 47.90" N and longitude 4° 32' 31.70" E. It is centrally positioned in Nigeria, between the densely populous southwestern region and the less populated central belt. Ilorin is located in Nigeria's traditional zone, between the deciduous woodlands of the south and the desert savanna of the north (Ajadi, B., et al. 2011)

The sampling site of the groundwater is located at Abala, Osin, Ita-elepa, Ilorin-west local government, Kwara state Nigeria. It is situated between latitudes 8036′N and 8024′N and

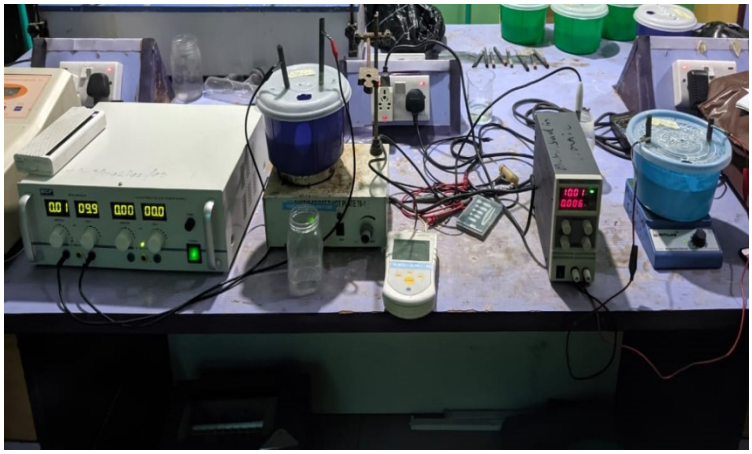

Fig. 1. Set-up of electro-coagulation process.

longitudes 4036′E and 4010′E along Nigeria National Petroleum Corporation pipelines (NNPC) pipelines. This groundwater sampling location has been contaminated, most likely as a result of earth geological formation and leaks from NNPC pipelines installed underground throughout the area. Contaminated water samples were taken from the groundwater (well water) and taken to the laboratory for initial analysis to determine the physicochemical characteristics of the contaminated groundwater, after which the water samples were electro-coagulated and finally, the treated groundwater's physicochemical parameters were then examined.

Electrocoagulation set-up process

Electrocoagulation process set-up consist of batch reactor, magnectic stirrer, graphite electrodes, DC power supply and Ph meter.The batch reactor was set up using a plastic bowl of about 2.5L with perforations on the cover/lid for graphite electrodes and for the pH meter probe. The bowl was filled with 1L contaminated groundwaterand a magnet was placed inside for agitation, the graphite electrodes (used for both anode and cathode) was placed in the electrode hole and the bowl was then placed on the magnetic stirrer that was connected to a power supply. The electrodeswere connected to the positive (anode) and negative (cathode) terminals respectively in the D.C power supply.The D.C power supply was regulated to the desired voltage and current needed for the process. The process was operated for each batch reactor for one hour, and the pH of the water was taken at the interval of 10 minutes.

Determination of Physical Water Quality Parameter:
pH, TDS AND EC

pH, Electrical Conductivity, TDS (Total dissolved solids) were analyzed using Hanna Multi parameter instrument HI 9812-5. The instrument was first calibrated and the reading was taking from the sample. The probe was rinsed twice before subsequent sample reading.

Dissolved Oxygen/ Salinity

The dissolved oxygen was done using Extech heavy duty DO/ Salinity/ Temperature meter model 407510A

Biological Oxygen Demand

The BOD (biological oxygen demand) test took 5 days to complete and was performed using a dissolved oxygen test kit. The BOD level is determined by comparing the DO (dissolved oxygen) level of a water sample taken immediately with the DO level of a water sample that

has been incubated in a dark location for 5 days. The difference between the two DO levels represents the amount of oxygen required for the decomposition of any organic material in the sample and is a good approximation of the BOD level.

Chemical Oxygen Demand (COD)

The Reagents used were Potassium Dichromate, Sulfuric Acid, Ferrous Ammonium Sulfate, Mercuric Sulfate Ferrous Indicator, Organic Free Distilled water. The groundwater samples were preserved with sulfuric acid to a pH less than 2 and maintained at 4ºC until analysis. GroundwaterSamples were not allowed to freeze.3 glass containers (vials) were Taken with stopper or cover lid.2.5ml of the sample was added to the two glass containers and the remaining vial added distilled water.1.5ml of potassium dichromate reagent (Digestion Reagent) was added to all the vials.3.5ml of sulfuric acid reagent (catalyst solution) in the same manner. Cock the vials and place in digester at 150ºC for 2hrs.Theburette wasCooled and filled with the standard Ferrous Ammonium Sulfate prepared. the contents wasTransferred to a conical flask and add two drops of Ferron indicator .The content became bluish green in color and Titrated to a reddish brown end point.Titrate blank from a greenish color to a reddish brown color

Calculation**:**

$$\mathrm{COD}\left(\mathrm{mg/L}\right) = \left(\mathrm{A}-\mathrm{B}\times\mathrm{N}\times 8\times 1000\right)/\mathrm{V}$$

A = Vol.of ferrous ammonium sulfate for blank
B = Vol.of ferrous ammonium sulfate for sample
N = Normality of ferrous ammonium sulfate = 0.1
V = Vol.of sample used
Multiply the results obtained by1000 to convert it to mg / L

$$\text{Residual Chlorine mg/L} = \left\{\left(\mathrm{A}-\mathrm{B}\right)\times 0.1\times 8\times 1000\right\}/\mathrm{V}$$

Atomic Absorption Spectrometry (AAS)

After contaminated groundwater samples were collected from Abala, Osin Ita-Elepa, Ilorin, Kwara state taken to the laboratory. 2ml of concentrated HNO_3 and 5ml of HCL were added to 100ml contaminated groundwater samples before digestion. 100 ml aliquot of the well mixed sample each was transferred to a beaker. 2ml of concentrated HNO_3 and 5ml of HCLwere added. The sample each were covered with a watch glass and heat on a steam bath, hot plate at 90 to 95^0C until the volume has been reduced to 20ml by evaporation. Each beaker was removed and allowed to cool down. Each beaker and the wash glass were washed with water and the samples were filtered to remove insoluble materials that could clog the nebulizer. The filtered paper and filtering apparatus were thoroughly cleaned and pre-rinsed with diluted HNO_3. The final volume were adjusted to 100ml with deionised water and analysed by AAS. This was carried out for both contaminated (untreated) groundwater and electro-coagulated (treated) groundwater.

RESULTS AND DISCUSSION

Having carried out batch electrocoagulation process experiment considering various variables such as voltage, current, pH and electrode distance. Table 1 summarised how the experiment was carried out using six different batch reactorsfor one hour at constant/varying voltage and current.

Results for physical water quality parameters on the treated groundwater.
*Results obtained for removal efficiency of identified heavy metals (Manganese, Iron and Zinc)***.**
Cost of Electrocoagulation Process

Electrical energy consumption is a very essential in determining the economical parameter

of electro coagulation process and it can be calculated using the below equation (Bazrafshan, E., et al. 2012).

$$E = \left[UIt / 1000V \right]$$

Where U is applied voltage, I is current flow, t is time (hour), V is volume of water used.

Effects of pH on the electrocoagulaion process

From Table 2 to Table 7 indicated trends of the pH during the treatment of contaminated groundwater.The pH eletrocoagulated groundwater tends to neutrality in all the batch reactors. It was observed that the pH was more effective at constant current 5amps with varing voltage 10 - 20 v. The best pH result was obtained at batch reactor A with pH 7.01. At varying current ,constant voltage the best pH was at batch reactor D, with pH 7.06. The movement of charged ion from the cathode (reduction) to anode (oxidation) ensued to neutralization of the charged pollutants (

Table 1. Electrocoagulation Experimental Design for the contaminated groundwater

Water Sample	Electrode Distance (cm)	Voltage (V)	Current (A)
A	2	10	5
B	4	15	5
C	6	20	5
D	2	10	2
E	4	10	4
F	6	10	6

Table 2. Effect of time on pH during electrocoagulationprocess for batch reactor A

Time (mins)	pH values	Electrode Distance (cm)
10	6.55	2
20	7.09	2
30	7.08	2
40	7.04	2
50	7.04	2
60	7.03	2

Table 3. Effect of time on pH during electrocoagulation process for batch reactor B

Time (mins)	pH values	Electrode Distance (cm)
10	6.97	4
20	7.05	4
30	7.05	4
40	7.03	4
50	7.05	4
60	7.07	4

Table 4. Effect of time on pH during electrocoagulation process for batch reactor C

Time (mins)	pH values	Electrode Distance (cm)
10	6.9	6
20	6.65	6
30	6.68	6
40	6.76	6
50	7.03	6
60	7.01	6

Table 5. Effect of time on pH during electrocoagulation process for batch reactor D

Time (mins)	pH values	Electrode Distance (cm)
10	7.07	2
20	7.02	2
30	7.03	2
40	7.06	2
50	7.05	2
60	7.06	2

Table 6. Effect of time on pH during electrocoagulation process for batch reactor E

Time (mins)	pH values	Electrode Distance (cm)
10	6.22	4
20	6.3	4
30	6.38	4
40	6.57	4
50	7.17	4
60	7.35	4

Table 7. Effect of time on pH during electrocoagulation processfor batch reactor F

Time (mins)	pH values	Electrode Distance (cm)
10	7.57	6
20	7.56	6
30	7.38	6
40	7.3	6
50	7.17	6
60	7.17	6

Table 8. Result obtained for efficiency reduction of TOTAL DISSOLVED SOLIDS (TDS)

Sample	TDS (ppm)	Average Value	%
A	16:16	16	90.6
B	15:15	15	91.2
C	16:16	16	90.6
D	16:16	16	90.6
E	16:16	16	90.6
F	16:16	16	90.6
Initial Value	170:170	170	

heavy metals or any other contaminants) with charged ions.This implies that electrocoagulation process is excellent to achieve good pH in treated of contaminated groundwater.

Effects of Inter-Electrode Distance

The inter-electrode spacing and effective surface area of electrodes are very important factors to calculate the operational cost needed (Bukhari, A. A. 2008).

The distance between the electrodes (anode and cathode) are important in the electrocoagualtion process as they play a great role on the region of electrostatic field.

From Table 1 to Table 7 shows the electrode distance while From Table 16 shows effects of electrode distance of the batch reactors in the removal of heavy metals from contaminated ground water. It was observed that at a lower distance (2cm) the effects of heavy metal removal

Table 9. Result obtained for efficiency reduction of Electrical Conductivity

Sample	EC (µs/cm)	Average Value	%
A	32:32	32	90.9
B	31:31	31	91.1
C	32:32	32	90.9
D	32:32	32	90.9
E	32:32	32	90.9
F	33:33	33	90.6
Initial Value	350:350	350	

EC: ELECTRICALCONDUCTIVITY

Table 10. Result obtained for efficiency reduction of Biological Oxygen Demand (BOD)

Sample	BOD (mg/L)	Average Value	%
A	0.5:0.33	0.4	92
B	0.4:0.1	0.25	95
C	0.4:0.4	0.4	92
D	0.3:0.1	0.2	96
E	0.3:0.2	0.25	95
F	0.4:0.2	0.3	94
Initial Value	9:1	5	

Table 11. Result obtained for efficiency reduction of Total Organic Carbon

Sample	TOC	Average Value	%
A	1.2:0.8	1.0	98.3
B	2.0:2.4	2.2	96.3
C	1.6:2.0	1.8	97
D	1.6:2.4	2.0	96.7
E	0.4:0.8	0.6	99.7
F	3.2:3.6	3.4	94.3
Initial Value	40:80	60	

Table 12. Result obtained for efficiency reduction of Chemical Oxygen Demand (COD)

Sample	COD (mg/L)	Average Value	%
A	72:68	70	91
B	80:76	78	90
C	80:76	78	90
D	76:80	78	90
E	60:50	58	92.6
F	76:80	78	90
Initial Value	800:760	780	

Table 13. Result Obtained For efficiency reduction of Turbidity

Sample	TURBIDITY (NTU)	Average Value	%
A	12:16	14	97.3
B	76:74	75	85.7
C	74:72	73	86.1
D	28:27	27.5	94.8
E	18:16	17	96.8
F	15:18	16.5	96.9
Initial Value	523:526	525	

Table 14. Result Obtained For efficiency reduction of Colour

ample	COLOUR (TCU)	Average Value	%
A	1.2:1.23	1.22	62.8
B	0.97:0.96	0.97	70.43
C	0.96:0.96	0.96	70.7
D	0.65:0.67	0.66	79.9
E	0.92:0.96	0.94	70.1
F	0.72:0.72	0.72	78
Initial Value	3.27:3.29	3.28	

Table 15. Result Obtained For efficiency reduction of Turbidity

Sample	COLOUR (TCU)	Average Value	%
A	12:16	14	97.3
B	76:74	75	85.7
C	74:72	73	86.1
D	28:27	27.5	94.8
E	18:16	17	96.8
F	15:18	16.5	96.9
Initial Value	523:526	525	

Table 16. Effect of The Electrocoagulation process on Weight of Electrodes.

S/N	Electrode Charge	Electrode Distance (cm)	Initial Weight(g)	Final Weight(g)	Weight Difference
1	Anode	4	22	22.104	0.104
2	Cathode	4	19	18.744	-0.256
3	Anode	4	13.955	15	1.045
4	Cathode	4	14.564	14	-0.564
5	Anode	6	13.991	14	0.009
6	Cathode	6	14	13.457	-0.543
7	Anode	6	13	13.604	0.604
8	Cathode	6	12.501	12	-0.501
9	Anode	2	13.668	14	0.332
10	Cathode	2	14.053	14	-0.053
11	Anode	2	13	13.525	0.525
12	Cathode	2	14.082	14	-0.082

in the groundwater was minimal while at a higher distance of 4cm and 6cm the removal effects was maximum most especially for Iron and Zinc. It was also observed that physical water quality parameters were improved at high distance of the electrodes. This phenomenon was possible at longer distance because there was larger room of movement charged ions from the cathode to anode (electrostatic field) which empowered electrocoagulation process.

Effect of Voltage And Current

Operation of electrocoagulation process at varying voltage with constant current as well as operating at varying current with constant voltage has brought about purification of contaminated groundwater. From Table 2 to Table 18, Optimal results were achieved for pH, TDS, EC, and removal efficiency for Iron and Zinc at constant current of 5 amps with varing voltage 20v,15v

Table 17. Results obtained for removal efficiency of Manganese (M), Iron (I) and Zinc (Z)

Sample	MC_O	MC_E	R%= MC_O-MC_E/MC_O	IC_O	IC_E	R%= IIC_O -IC_E/IC_O	ZC_O	ZC_E	R%= ZC_O - ZC_E/ZC_O
A	2.7	1.49	44.81	0.2	0.12	40	1.3	0.06	95.35
B	2.7	1.38	48.89	0.2	0.06	70	1.3	0.63	51.54
C	2.7	0.49	81.76	0.2	0.13	35	1.3	0.66	50.77
D	2.7	0.46	82.96	0.2	0.07	65	1.3	0.65	50.00
E	2.7	1.56	43.1	0.2	0.06	66	1.3	0.06	95.38
F	2.7	1.38	48.89	0.2	0.06	66	1.3	0.25	80.77

C_O = intial concentration; C_E = final concentration after electro-coagulation

Table 18. Comparison of Results Obtained with the Water Quality Guidelines for heavy metals

S/N	HEAVY METALS	WHO (mg/L)	USEPA (mg/L)	WEPA1 (mg/L)	WEPA2 (mg/L)	UNTREATED WATER (mg/L)	TREATEDWATER (mg/L)					
							A	B	C	D	E	F
1	Manganese	0.5	1.5	0.5	1	2.7	1.49	1.38	0.49	0.46	1.54	1.38
2	Iron	0.3	2	1	2	0.2	0.12	0.06	0.13	0.07	0.06	0.06
3	Zinc	3	5	15	1	1.3	0.06	0.63	0.66	0.65	0.06	0.25

WHO: World Health Organization; USEPA: United States Environmental Protection Agency; WEPA: Water Environment Partnership In Asia. $WEPA^1$: Groundwater Standards for Drinking Purposes By WEPA ; $WEPA^2$: General Indusrial Wastewater Discharge Standards by WEPA

Table 19. Comparison of Results Obtained with the Water Quality Guidelines for physical Water Quality Parameters.

S/N	WATER QUALITY PARAMETERS	WHO	USEPA	$WEPA^1$	$WEPA^2$	UNTREATED WATER	TREATED WATER					
							A	B	C	D	E	F
1	T D S (ppm)	500	1500		40	170	16	15	16	16	16	16
2	E C (µs/cm)	200	750			350	32	31	32	32	32	32
3	BOD (mg/L)	2	50		40	5	0.4	0.25	0.4	0.2	0.25	0.3
4	TOC (%)					0.6	1	2.2	1.8	2	0.6	3.4
5	COD (mg/L)	80	250			78	70	78	78	78	58	78
6	Turbidity (NTU)	25	75	20		5.25	14	75	73	27	17	16.5
7	Colour (TCU)			15			1.22	1.93	0.96	0.66	0.94	0.72

WHO: World Health Organization; USEPA: United States Environmental Protection Agency; WEPA: Water Environment Partnership In Asia. $WEPA^1$: Groundwater Standards for Drinking Purposes By WEPA ; $WEPA^2$: General Indusrial Wastewater Discharge Standards by WEPA

and 10v respectively. Most desirable water quality parameters were obtained BOD, TOC, COD, Colour, removal efficiency for Manganese and Zinc at constant voltage of 10 volts with varing current of 2amps, 4amps and 6amps respectively.The best water quality may be achieve through restrictions of voltage and current over a long time in electrocoagulation process.

Effect of the cost On Electrocoagulation Process

From Table 20, the maximum cost of electrocoagulation process was calculated to be #400 per liter of wastewater treated while the minimum cost was calculated to be #80 per litre of treated water. This implies that operation of electrocoagulation process is economical, affordable and could be sustained. This is due to low energy consumption; as a result of low current and low

Table 20. Result obtained for energy consumption and cost of each batch process.

Sample	Voltage (V)	Current (A)	Time (hr)	Volume (m^3)	E= [UIt/1000V] (kWh/m^3)	COST@ #4.00/kWh
A	10	5	1	0.001	50	200
B	15	5	1	0.001	75	300
C	20	5	1	0.001	100	400
D	10	2	1	0.001	20	80
E	10	4	1	0.001	40	160
F	10	6	1	0.001	60	240

voltage. In economic of scale, the process would be much more cheaper in energy consumption in a large scale water treatment.

Effect on Electrodes

From Table 16, It was observed that the weight of the anodes (positive terminal) electrode was increasing while that of the cathode electrode (negative terminal) were reducing (reduction) allowing for redoxreaction. As shown equation (1), oxidation occurs at anode, where negative ions were force by electrical potential to react chemically and produce (give up) electrons. According to equation (2),reduction occurs at cathode. where positive ions gained or acquired electrons are used up in the process of electrocoagulation and were supplied to anode to get oxidized.

Oxidation (Anode) : $2H_2O \longrightarrow O_2 + 4H^+ + 4e^-$ (1)

Reduction (cathode) : $4H_2O + 4e^- \longrightarrow 4OH^- + 2H_2$ (2)

Net reaction: $6H_2O \longrightarrow 4OH^- + 4H^+ + 2H_2 + O_2$ (3)

Comparison of the treated groundwater with water quality standard

From Table 18 to Table 19 give comparative account of quality of treated groundwater by electrocoagulation process with water quality standards of World Health Organization, United States Environmental Protection Agency,Water Environment Partnership In Asia for both drinking purposes and General Indusrial Wastewater Discharge guidelines.

Comparing water quality parameters of treated groundwater with the Water Quality Guidelines for physical and chemical Parameters of water,the treated groundwater is lower than the water quality standards thereby suitable for drinking purposes and industrial effluent discharge. This indicate that electrocoagulation process on conterminated groundwater is appropiate for wastewater treatment and industrial effluents.

CONCLUSION

The application of electrocoagulation process to purify contaminated groundwater was demostrated to be efficient and improve water quality parameters of the contaminated groundwater. The findings from the study revealed 97.3 % efficiency reduction for Turbidity, 91.2% efficiency reduction for TDS, 91.1% efficiency reduction for Electrical Conductivity, 96 % efficiency reduction for BOD, 99.7 % efficiency reduction for TOC, 92.6% efficiency reduction for COD, 79.9% efficiency reduction for Colour, 82.96 % efficiency removal for Manganese, 70.0 % efficiency removal for Iron and 95.30 % efficiency removal for Zinc in its best configuration of the electrocoagulation process. The process brought the pH of water to nuetrality of 7.01. Electrocoagulation process is economical with low operating cost, therefore

it could be sustained.The quality of treated groundwater exceed the limit for water quality guidelines by World Health Organization(WHO), United States Environmental Protection Agency (USEPA) and Water Environment Partnership In Asia (WEPA) for both drinking purposes and General Indusrial Wastewater Discharge guidelines.

ACKNOWLEDGEMENT

Many thanks to the staff and management of Central Research Laboratory , Tanke, Ilorin for their analysis.

GRANTSUPPORT DETAILS

This study was supported by Clean Energy/Environmental Research Laboratory, Department of Chemical Engineering, and University Of Ilorin, Nigeria.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research

REFERENCES

Abdulkhaleq Alalwan, H., Alminshid, A. H., Mustafa Mohammed, M., Mohammed, M. F., & Hatem Shadhar, M. (2022). Reviewing of using nanomaterials for wastewater treatment. *Pollution*, *8*(3), 995-1013. doi: 10.22059/poll.2022.337436.1329

Abuzaid, N. S., Al-Hamouz, Z., Bukhari, A. A., & Essa, M. H. (1999). Electrochemical treatment of nitrite using stainless steel electrodes. Water, Air, and Soil Pollution, 109(1), 429-442. https://doi.org/10.1023/A:1005024012610

Ajadi, B. S., Adeniyi, A., & Afolabi, M. T. (2011). Impact of climate on urban agriculture: case study of Ilorin City, Nigeria. *Global Journal of Human Social Science*, *11*(1), 12.

Babel, S., & Kurniawan, T. A. (2004). Cr (VI) removal from synthetic wastewater using coconut shell charcoal and commercial activated carbon modified with oxidizing agents and/or chitosan. Chemosphere **54**(7): 951-967 . https://doi.org/10.1016/j.chemosphere.2003.10.001

Bazrafshan E, Ownagh K.A., & Mahvi AH. (2012) Application of electrocoagulation process using iron and aluminum electrodes for fluoride removal from aqueous environment. E-Journal of Chemistry **9**(4): 2297-2308. https://doi.org/10.1155/2012/102629

Behbahani, M., Bagheri A, Amini M.M., Sadeghi O, Salarian M, Najafi F., & Taghizadeh M. (2013). Application of multiwalled carbon nanotubes modified by diphenylcarbazide for selective solid phase extraction of ultra traces Cd (II) in water samples and food products. Food chemistry **141**(1): 48-53.

doi: 10.1016/j.foodchem.2013.03.011

Benhadji, A., Ahmed, M. T., & Maachi, R. (2011). Electrocoagulation and effect of cathode materials on the removal of pollutants from tannery wastewater of Rouïba. *Desalination*, *277*(1-3), 128-134.

Borba, C. E., Guirardello, R., Silva, E. A., Veit, M. T., & Tavares, C. R. G. (2006). Removal of nickel (II) ions from aqueous solution by biosorption in a fixed bed column: experimental and theoretical breakthrough curves. Biochemical Engineering Journal, *30*(2), 184-191.

Bukhari, A. A. (2008). Investigation of the electro-coagulation treatment process for the removal of total suspended solids and turbidity from municipal wastewater. Bioresource technology **99**(5): 914-921.

Can, O.T., & Bayramoglu, M. (2010). The effect of process conditions on the treatment of benzoquinone

solution by electrocoagulation. Journal of Hazardous Materials, 173 (1-3)*, 731-736*
Can, O.T., Kobya, M., Demirbas, E., & Bayramoglu, M., (2006). Treatment of the textile wastewater by combined electrocoagulation.Chemosphere 62 (2), 181-7.
Chen, G. (2004). Electrochemical technologies in wastewater treatment. Separation and purification Technology **38**(1): 11-41.
Chen, G., Chen, X., & Yue, P. L. (2000). Electrocoagulation and electroflotation of restaurant wastewater. *Journal Of Environmental Engineering*, *126*(9), 858-863.
Chen, X., & Deng, H., (2012). Removal of humic acids from water by hybrid titanium-based electrocoagulation with ultrafiltration membrane processes. Desalination 300, 51- 57.
Chen, X., Chen, G., & Yue, P.L. (2000). Separation of pollutants from restaurant wastewater by electrocoagulation. *Separation and Purification Technology, 19*, 65-76.
Daneshvar, N., Ashassi-Sorkhabi, H., & Tizpar, A., (2003). Decolorization of Orange II by electrocoagulation method. Separation and Purification Technology, 31(2)*, 153-162.*
Daneshvar, N., Khataee, A. R., Ghadim, A. A., & Rasoulifard, M. H. (2007). Decolorization of CI Acid Yellow 23 solution by electrocoagulation process: Investigation of operational parameters and evaluation of specific electrical energy consumption (SEEC). Journal of Hazardous Materials, *148*(3), 566-572.
Daneshvar, N., Oladegaragoze A. & Djafarzadeh N (2006). Decolorization of basic dye solutions by electrocoagulation: an investigation of the effect of operational parameters. Journal of Hazardous Materials **129**(1-3): 116-122. doi: 10.1016/j.jhazmat.2005.08.033.
Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (2019). Estimates on the use of water, sanitation and hygiene in Nigeria. www.washdata.org/household.hmlt Accessed on May 25, 2022.
Kalash, K. R., Al-Furaiji, M., & Ahmed, N. (2022). Kinetic Characteristics and the Performance of Up-Flow Biological Aerated Filters (UBAF) for Iraqi Municipal Wastewater. *Pollution*, *8*(2), 621-636. doi: 10.22059/poll.2021.333654.1240
Lai, C.L., & Lin, S.H., (2004). Treatment of chemical mechanical polishing wastewater by electrocoagulation: system performances and sludge settling characteristics. Chemosphere 54 (3), 235 -242. doi: 10.1016/j.chemosphere.2003.08.014.
Lai, C.L., & Lin, S.H., (2003). Electrocoagulation of Chemical Mechanical Polishing (CMP) wastewater from semiconductor fabrication. Chemical Engineering Journal, Vol. 95, No. 1-3, 2003, pp. 205-211. http://dx.doi.org/10.1016/S1385-8947(03)00106-2
Mohammed Ali, N. S., Alalwan, H. A., Alminshid, A. H., & Mohammed, M. M. (2022). Synthesis and Characterization of Fe3O4- SiO2 Nanoparticles as Adsorbent Material for Methyl Blue Dye Removal from Aqueous Solutions. *Pollution*, *8*(1), 295-302. doi: 10.22059/poll.2021.328697.1157
Muhibbudin, I., Ebube, O., Asuquo, B., Adepoju, M., Mubarak, S., Adebanjo, S., & Ayodele, I. (2021). Assessment of an atmospheric heavy metal from a transport pool within the Ilorin Metropolis, Nigeria. *Journal of Particle Science & Technology*, 7(1), 11-21. doi: 10.22104/jpst.2021.5107.1191
National Bureau of Statistics, (2017), https://nigerianstat.gov.ng/elibrary.htmlAccessed on May 28, 2022.
Ögütveren, Ü. B., Gönen, N., & Koparal, S. (1992). Removal of dye stuffs from waste water: Electrocoagulation of Acilan Blau using soluble anode. *Journal of Environmental Science & Health Part A*, *27*(5), 1237-1247. https://doi.org/10.1080/10934529209375794
Phalakornkule, C., Sukkasem, P., & Mutchimsattha, C. (2010). Hydrogen recovery from the electrocoagulation treatment of dye-containing wastewater. International Journal of Hydrogen Energy, 35(20), 10934-10943.
Phalakornkule, C., Polgumhang, S., & Tongdaung, W. (2009). Performance of an electrocoagulation process in treating direct dye: batch and continuous upflow processes. *World Academy Sci. Technol*, *57*, 277-282. https://doi.org/10.5281/zenodo.1080179
Phalakornkule, C., Polgumhang, S., Tongdaung, W., Karakat, B., & Nuyut, T. (2010). Electrocoagulation of blue reactive, red disperse and mixed dyes, and application in treating textile effluent. J. Environ. Manage. 91 (4), 918- 926 .doi: 10.1016/j.jenvman.2009.11.008.
Pouet, M.F. & Grasmick A. (1995). Urban wastewater treatment by electrocoagulation and flotation. Water Science and Technology **31**(3-4): 275-283.
Rizzo, L., Manaia, C., Merlin, C., Schwartz, T., Dagot, C., Ploy, M. C., ... & Fatta-Kassinos, D. (2013). (2013). Urban wastewater treatment plants as hotspots for antibiotic resistant bacteria and genes

spread into the environment: a review. Science of the Total Environment **447**: 345-360. doi: 10.1016/j.scitotenv.2013.01.032.

Siringi, D. O., Home, P., Chacha, J. S., & Koehn, E. (2012). Is electrocoagulation (EC) a solution to the treatment of wastewater and providing clean water for daily use. ARPN Journal of Engineering and Applied Science 7(2):197–204

Tahboub, M. (2000). Evaluation of wastewater treatment alternatives for Hebron City. Hebron, West Bank, Palestine . Thesis (M.S.) (Water Engineering). Birzeit University .

United States Environmental Protection Agency (USEPA), 2010. Regional approaches to improving water quality. www.epa.gov/waterqualityguidelines.html Acessed on May 28,2022

Valero, D., Ortiz, J.M., Garcia, V., Exposito, E., Montiel, V., & Aldaz, A., (2011). Electrocoagulation of wastewater from almond industry. Chemosphere 84 (9), 1290 - 1295. DOI: 10.1016/j. chemosphere.2011.05.032

Water Environment Partnership In Asia (WEPA) (2018).Outlook on Water Environmental Management in Asia.www.wepa-db.net/en/publication/2018_outlook/index.html. Acessed on May 28,2022.

World Health Organization(WHO), (2022), Water qualitu guildelines for Europe. Europeans series No 23, WHO Regional publications, Copenhagen.