

Studying the effectiveness of treating waste water using the electro coagulation process at Sewage Treatment Plants

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Abstract

Sewage has become a major point-source pollutant on a global scale. The management and treatment of wastewater is important to ensure that it is processed to a safe quality before re-use or disposal. The purpose of this study is to investigate the effectiveness of the electrocoagulation process in treating wastewater as an alternative to conventional methods to treat sewage. A 2 litre batch electrocoagulation unit was set up consisting of 4 monopolar electrodes connected to a DC power supply and the process was investigated for chemical oxygen demand, ammonia, and phosphates reduction. Iron and aluminium were comparatively used as the treatment electrodes, and effects of operating conditions like applied voltage and treatment time were investigated. Voltage was varied from 5V, 10V and 15V for 30 and 60 minutes treatment duration and aluminium gave better results than iron. The optimum conditions were experimentally determined to be 15V at 30 minutes treatment using aluminium, to give 92% COD removal, 100% phosphate removal and 61% ammonia removal using DC current converted to alternating pulse current by use of a circuit. The experimental results showed electrocoagulation to be a feasible process in the treatment of wastewater.

Keywords: electrocoagulation; wastewater treatment; applied voltage; COD removal; phosphate removal; ammonia removal; monopolar electrodes.

INTRODUCTION

Sewage is the main point-source pollutant on a global scale [1]. The biological and chemical composition of sewage is usually high in Biological Oxygen Demand (BOD), Suspended Solid (SS) and Chemical Oxygen Demand (COD). So, direct discharge of raw or improperly treated sewage into the water body is one of the main sources of pollution on a global scale [1]. Wastewater treatment serves two main objectives, protecting the environment and conserving fresh water resources [2].

Treated municipal wastewater is considered, in many major cities of the world, as a supplementary water source for several uses such as agricultural irrigation, landscaping, industrial activities (cooling and process needs), groundwater recharge, recreational and other uses. The continued dependence on treated municipal wastewater for the previously mentioned uses coupled with emerging stricter policies/guidelines for such uses prompted scientists and researchers to concentrate in improving current treatment technologies and to come up with innovative ideas to treat municipal wastewater in an efficient and cost effective manner [3].

The most common conventional methods of treating sewage include Activated Sludge Process, Aerated Lagoons (Oxidation Ponds), Biological Trickle Filtration systems and Anaerobic Digesters. The major disadvantages of most of the conventional methods is that they consume a lot of space and require long periods to process sewage. Simple and efficient sewage water treatment systems are urgently needed in developing countries [4].

Electrocoagulation is one of a simple method to treat wastewater efficiently [5]. Electrocoagulation (EC) is an emerging technology that combines the functions and advantages of conventional coagulation, flotation, and electrochemistry in water and wastewater treatment [6]. It is a complex process involving chemical and physical mechanisms operating simultaneously to remove pollutants from wastewaters [2]. Therefore the potential of electrocoagulation to treat multiple contaminants must be studied. Wastewater is the main cause for irreversible damages to the environment and also contributes to the reduction of fresh water reserves, creating threats to the next generation [7]. Sewage treatment plants are then setup to manage wastewater disposal from the sewer systems and processing this wastewater to safe quality before re-use or disposal.

The purpose of this study is to investigate the treatment of wastewater using electrocoagulation and study its effectiveness as an alternative treatment system to already existing methods. Eyvaz et al. (2014) states that electrocoagulation (EC) has gained many interest due to providing simple, reliable and cost effective operation for the treatment of wastewaters without and need for additional chemicals, and thus the secondary pollution [8].

Research, in the past few decades, have shown that electrocoagulation is a promising

treatment method and effectively potential to treat variety type of wastewaters including dyes wastewater, tannery wastewater, restaurant wastewater, palm oil mill effluent, food wastewater, potato chip manufacturing wastewater, urban wastewater, and removing heavy metals [9-10]. Hence a multiple contaminant treatment system could prove very beneficial for municipalities and this could lead to advancement in water treatment technology.

METHODS AND MATERIALS

A schematic diagram of the experimental set-up is depicted in Figure 1. The electrochemical circuit unit consists of an electrocoagulation cell, a D.C power supply and the electrodes (aluminum and iron) and is shown in Figure 2. A magnetic stirrer was put in place to keep the composition the sample homogeneous throughout the treatment and set at 100 rpm. All the electrodes were washed with 5% HCl before every experiments conducted. At the beginning of each experiment, 2000 mL of Municipal wastewater was fed into the electrocoagulation cell and current was applied to the circuit for 60 min. The amount of voltage that were applied to the system were 5, 10 and 15 V with maximum treatment time of 60 minutes. Every experiment was performed at room temperature and experimental samples were taken at 5 minute intervals of each run for COD, phosphate and ammonia measurements. Reagent grade of chemicals were used without further purification in every experiment. The pH value was determined by a pH meter (HACH HQ11d). The COD values were measured using a Double Beam UV/VIS Spectrophotometer (PERKIN – ELMER). Conductivity measurements were obtained using a Conductivity meter (Eutech CON 5100). Phosphates and ammonia measurements were obtained using a Single Beam Ultra-Violet Visible Spectrophotometer (HACH-LANGE DR 6000). The system's current was provided by a regulated D.C power with maximum 30V and 3A output volume and current respectively with a 2cm gap between them.

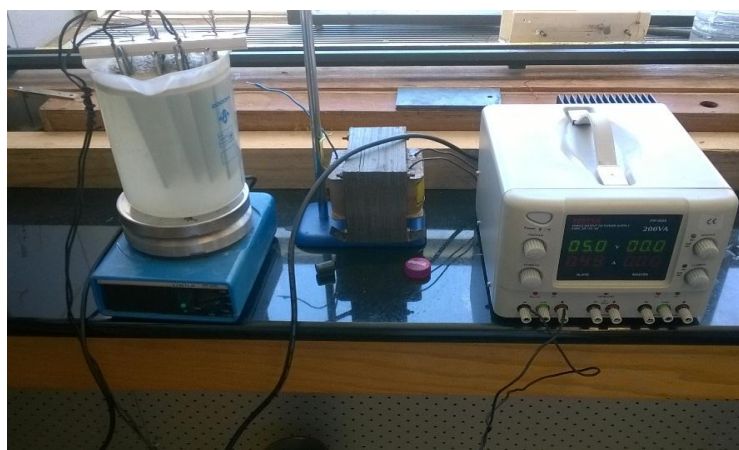


Figure 1: Electrocoagulation unit setup

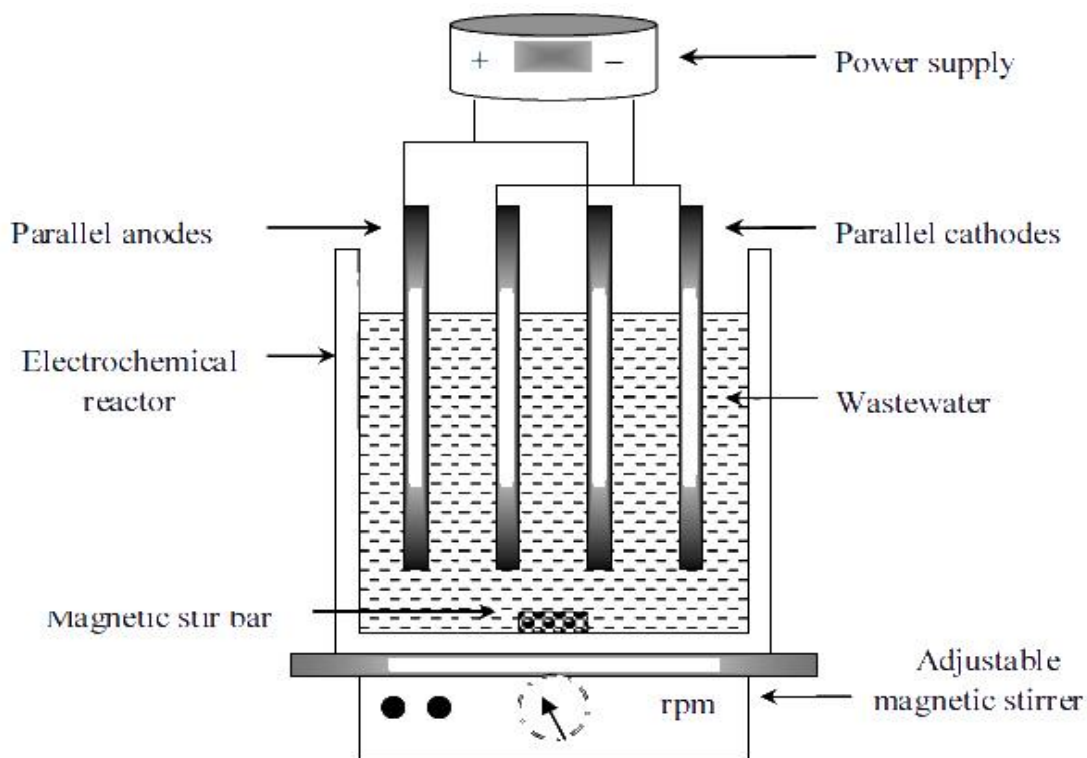


Figure 2: Circuit diagram of electrocoagulation reactor setup

Effect of electrode material

Aluminium and iron were compared for their treatment efficiency. The varied parameters were voltage and treatment time for each electrode.

Effect of Applied Voltage

Voltage was varied from 5V, 10V to 15V. Each voltage was run on a fresh sewage sample. The electrodes were washed with 5% HCl and rinsed with water before and after each treatment in order to remove all dirt from the electrodes [11-12].

Effect of treatment time

50 ml samples were taken after 30 minutes and 60 minutes treatment time. These were filtered and preserved with concentrated H₂SO₄ at 4°C for analysis. The amount of electrode material used up in the treatment was determined using Faraday's Law

$$W = \frac{itM}{zF}$$

RESULTS AND DISCUSSION

pH and conductivity

The effect of pH and conductivity were not subjects of this study, but were analyzed before treatment was carried out to ensure that their values could suffice electrocoagulation. From literature near neutral pH and conductivity in the range >50mS/cm was adequate for electrocoagulation. Domestic wastewater has a fairly good concentration of dissolved salts like NaCl which enable the conduction of current.

Treatment using iron

The EC process was first applied using iron electrodes and the results shown in Table 1.

Table 1: Characteristics of raw and treated wastewater for iron at 5, 10 and 15 volts

5 VOLTS	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	346	242.2	215
Phosphates (mg/L)	10.8	1.3	0.11
Ammonia (mg/L)	56.4	50.1	49.3
10 VOLTS	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	470	222	153
Phosphates (mg/L)	7.51	0.12	0.00
Ammonia (mg/L)	58.6	37.4	30.8
15 VOLTS	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	481	154	96.1
Phosphates (mg/L)	10.33	0.00	0.00
Ammonia (mg/L)	41.7	23.2	19.13

Removal Efficiency was calculated from equation 1:

Taking COD at 5 Volts, Removal efficiency (R %) was calculated from equation 1:

$$R\% (30minutes) = \frac{346-242.2}{346} \times 100 \tag{1}$$

$$= 30\%$$

(Tables showing Removal efficiencies are in the Appendix)

Effect of Time :

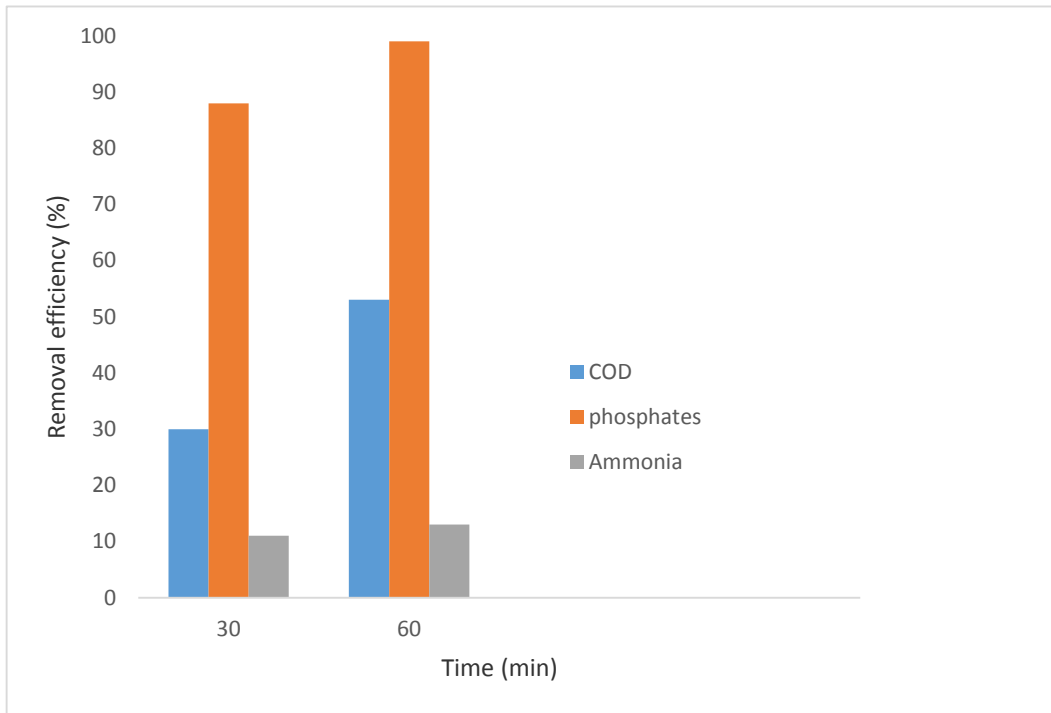


Figure 3: Effect of time at on removal efficiency at 5 volts

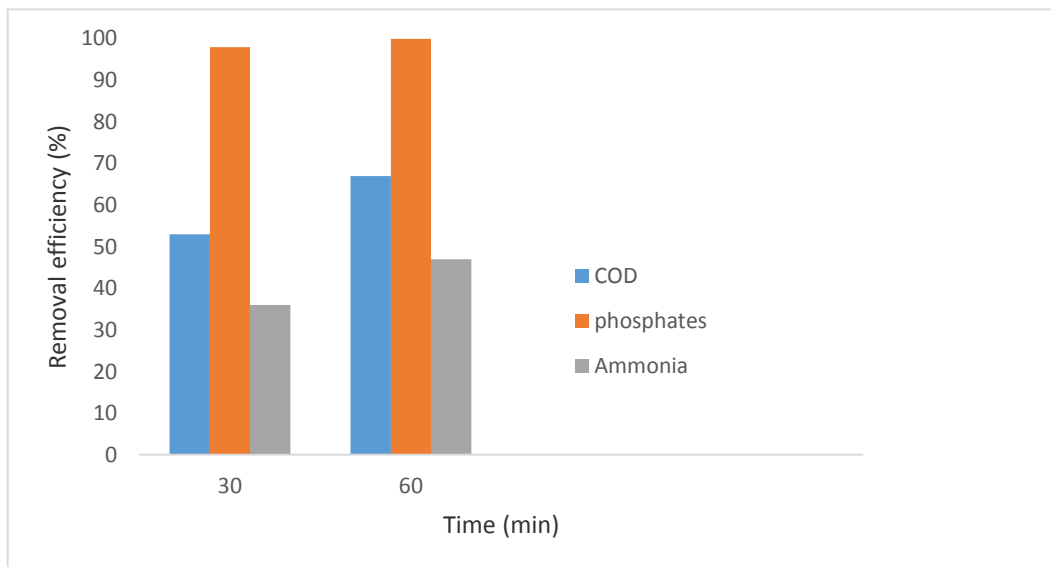


Figure 4: Effect of time on removal efficiency at 10 volts

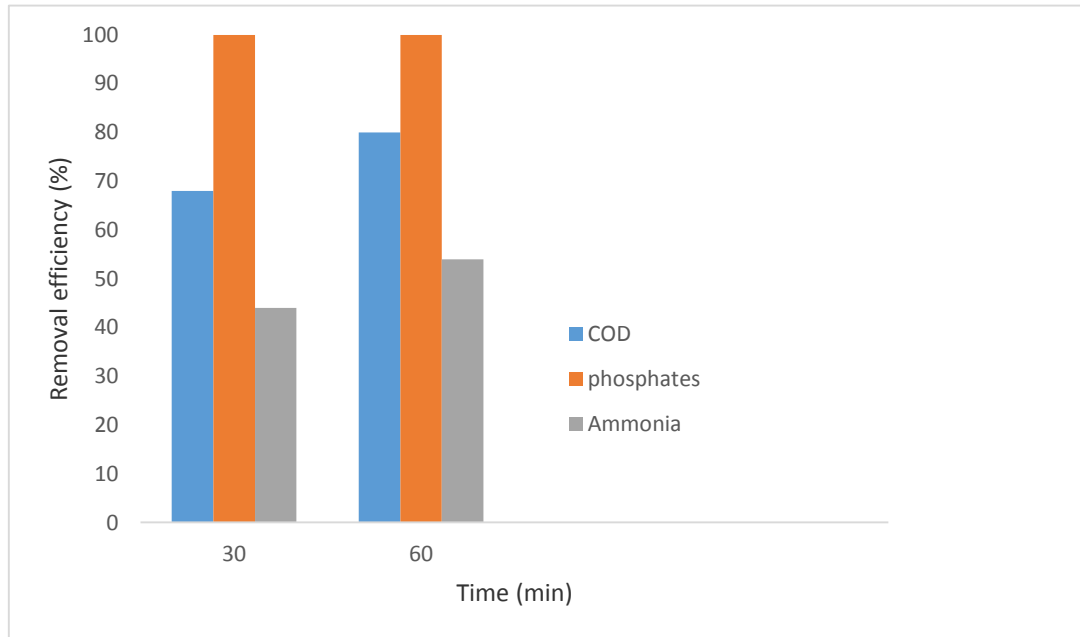


Figure 5: Effect of time on removal efficiency at 15 volts

Effect of Applied Voltage :

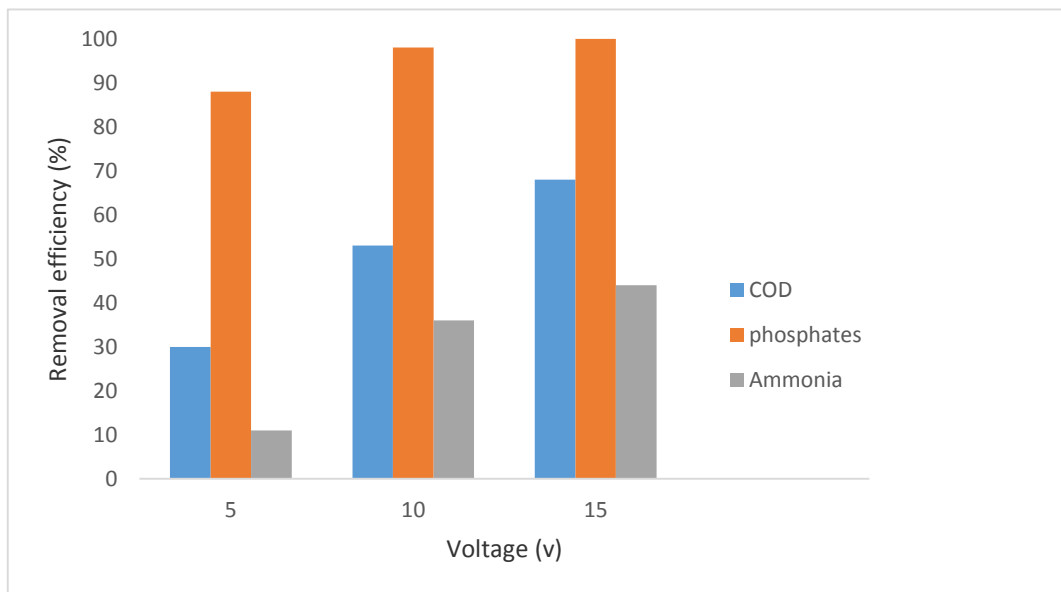


Figure 6: Effect of applied voltage on removal efficiency after 30 minutes treatment

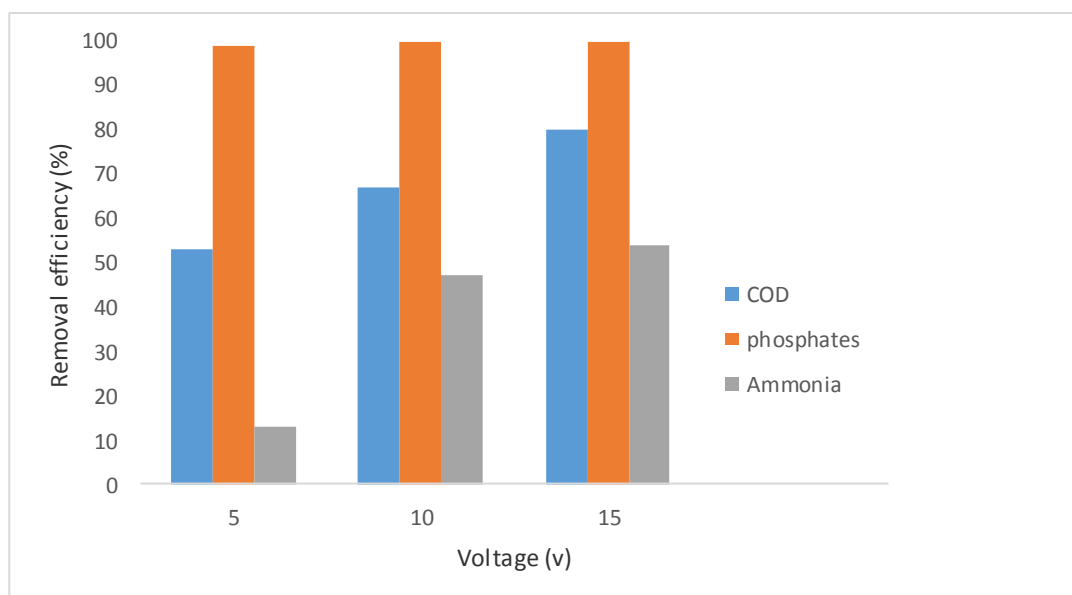


Figure 7: Effect of applied voltage on removal efficiency after 60 minutes treatment

Table 1 shows the results obtained for iron at different voltages and different treatment times. The best result was obtained at 15 volts after 60 minutes treatment. COD, phosphates and ammonia were reduced from 481 mg/L, 10.33 mg/L, and 41.7 mg/L to 96 mg/L, 0.00 mg/L and 19.13 mg/L. Conversely, the lowest result was obtained at 5 volts. Figures 3 to 5 show that increasing treatment time increases removal and Figures 6 and 7 show that increasing voltage had a positive effect on removal efficiency of all pollutants because of the increase in anode dissolution per unit time. 80%, 100% and 54% removal efficiencies were obtained for COD, phosphates and ammonia respectively.

Using iron electrodes, the treating solution began to change into a greenish color after 5 minutes and then switched into brownish color a few minutes later during treatment. These particles are extremely fine and very hard to precipitate, the color was also hard to wash from the vessels. Therefore all subsequent treatments were carried out using aluminium.

TREATMENT USING ALUMINUM

Because of the problems associated with using iron, the results are associated with aluminium

Table 2: Characteristics of raw and treated water at 5 volts

Experiment 1	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	431	243.3	231.7
Phosphates(mg/L)	5.82	0.33	0.01
Ammonia (mg/L)	41.82	32.46	32.10
Experiment 2	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	300	178	162
Phosphates(mg/L)	15.3	0.8	0.01
Ammonia (mg/L)	59.9	48	46
Experiment 3	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	365	207	197
Phosphates(mg/L)	6.71	0.3	0.02
Ammonia (mg/L)	41.34	32.35	31.20

Table 3: Characteristics of raw and treated water at 10 volts

Experiment 1	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	315.1	98.3	52.7
Phosphates(mg/L)	5.65	0.13	0.00
Ammonia (mg/L)	6.37	3.81	2.35
Experiment 2	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	537	197	95.4
Phosphates(mg/L)	10.34	0.00	0.00
Ammonia (mg/L)	3.99	2.47	1.56
COD (mg/L)	481	168.3	60.2
Phosphates(mg/L)	7.6	0.00	0.00
Ammonia (mg/L)	45.7	27.42	20.15

Table 4: Characteristics raw and treated wastewater at 15 volts

Experiment 1	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	360	21.6	2.2
Phosphates(mg/L)	3.70	0.00	0.00
Ammonia(mg/L)	2.75	2.11	1
Experiment 2	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	438	24.6	14.6
Phosphates(mg/L)	8.60	0.00	0.00
Ammonia (mg/L)	38.2	22.50	15.10
Experiment 3	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	273.3	17.3	0.00
Phosphates(mg/L)	13.1	0.00	0.00
Ammonia (mg/L)	11.4	6.56	4.22

The tables show that initial concentration is also an important factor to be considered in electrocoagulation. From Table 2, comparing COD removal, it can be seen that a higher initial COD loading meant a relatively higher COD loading in the final treated

solution. The same is true with ammonia, which exhibits the same trend as COD. Phosphate conversely did not seem to be affected by this factor. COD was in the blue zone, ammonia red and phosphate blue according after 60 minutes treatment at 15 volts. 30 minutes treatment produced similar results.

Effect of Time:

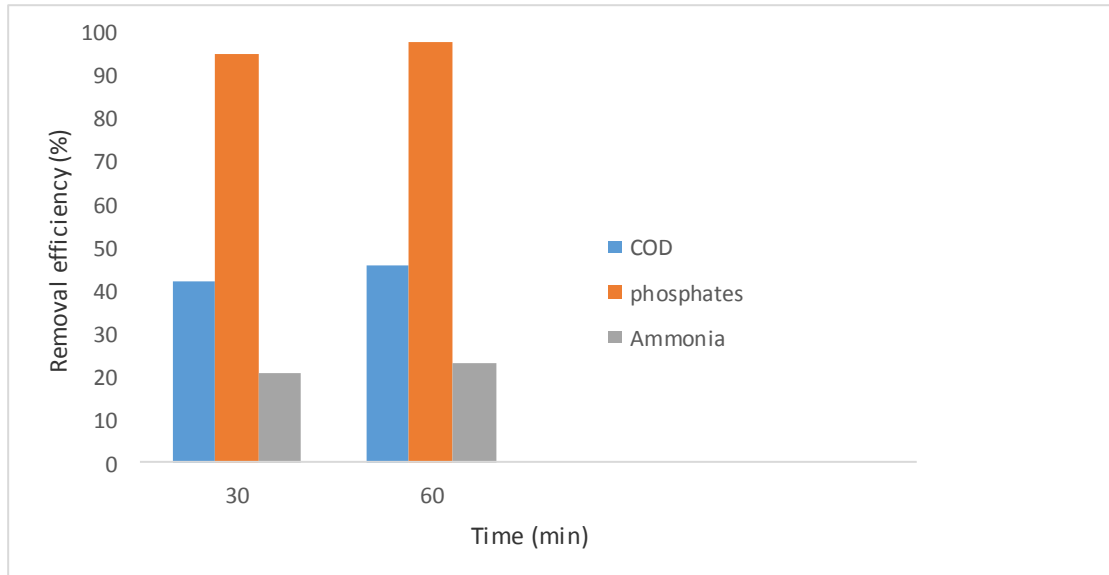


Figure 8: Effect of treatment time on removal efficiency at 5 volts

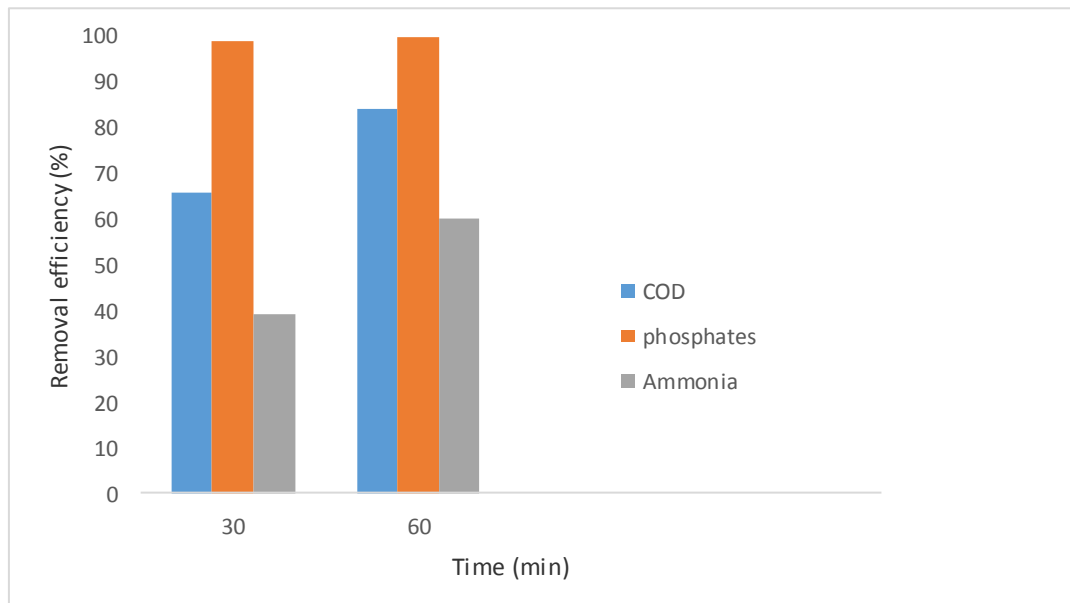


Figure 9: Effect of treatment time on removal efficiency at 10 volts

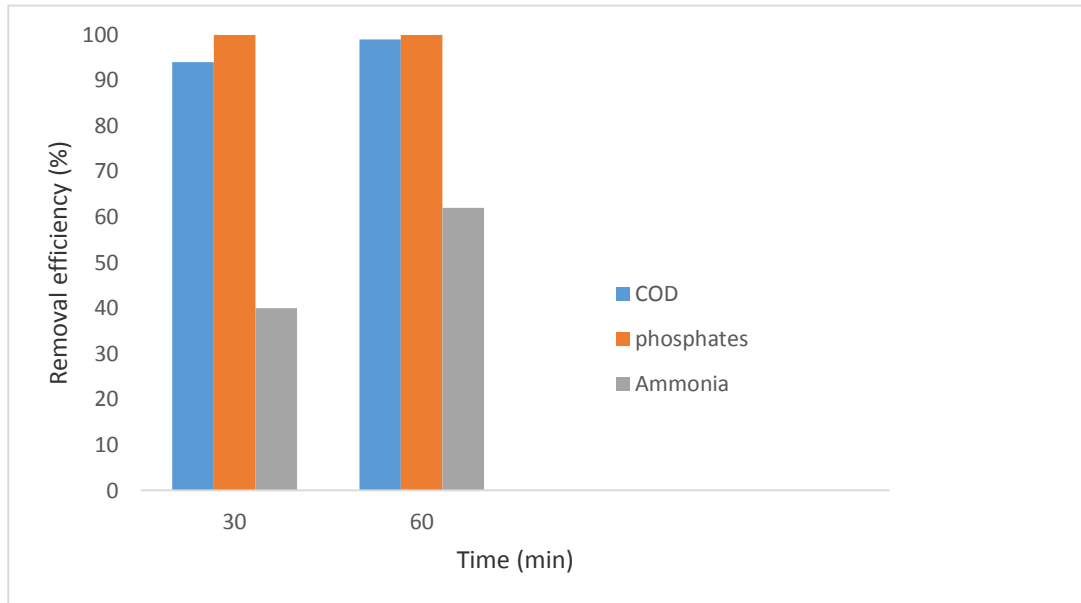


Figure 10: Effect of treatment time on removal efficiency at 15 volts

Figures 8-10 show pollutant reduction to be a function of time. An increase in treatment time results in a subsequent increase in removal efficiency. The best COD reduction was observed after 60 minutes. The same is true with ammonia. 100% phosphate removal efficiency just after 30 minutes at 15 volts, and at all voltages, excellent phosphate removal was observed after 30 minutes.

Effect of Applied Voltage

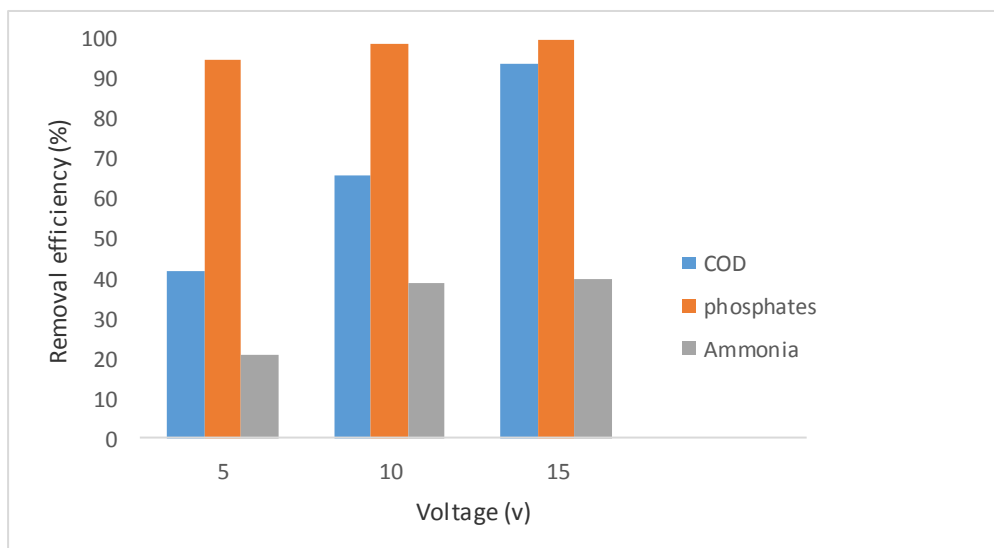


Figure 11: Effect of applied voltage after on removal efficiency 30 minutes treatment

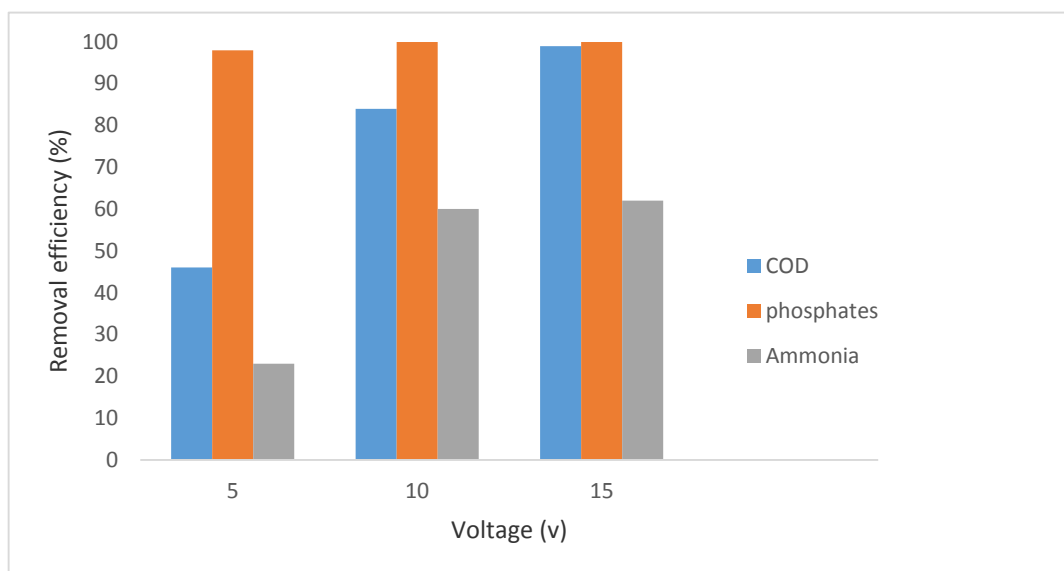


Figure 12: Effect of applied voltage on removal efficiency after 60 minutes treatment

Pollutant removal is observed to also be in accordance with Faraday's law in terms of increase in voltage. Removal efficiencies reached 46%, 84%, 99% for COD at 5, 10 and 15 Volts in 60 minutes respectively. High removal efficiency for phosphate was obtained at 5 volts reaching 98% in 60 minutes and 100% at 10 and 15 volts respectively. 23%, 60% and 63% removal efficiencies were obtained for ammonia at 5, 10 and 15 volts.

Effect of passivation

The effects of electrode passivation started developing after the electrodes were used for several different treatments. The effect of the formation of a passive layer was not initially considered but was only noted as after repeating the experiments three or more times.

Table 5: Characteristics of wastewater before and after treatment using passivized aluminium electrodes

5 VOLTS	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	631.7	554.9	534.9
Phosphates(mg/L)	5.72	0.34	0.10
Ammonia (mg/L)	40.5	39.3	36.2
10 VOLTS	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	691	550.9	500.1
Phosphates(mg/L)	5.53	0.13	0.00

Ammonia (mg/L)	39.2	36.5	34.5
15 VOLTS	Pre-Treatment	30-Minutes	60-Minutes
COD (mg/L)	722.7	543.5	466.7
Phosphates(mg/L)	6.82	0.06	0.00
Ammonia (mg/L)	41.3	32.2	31.4

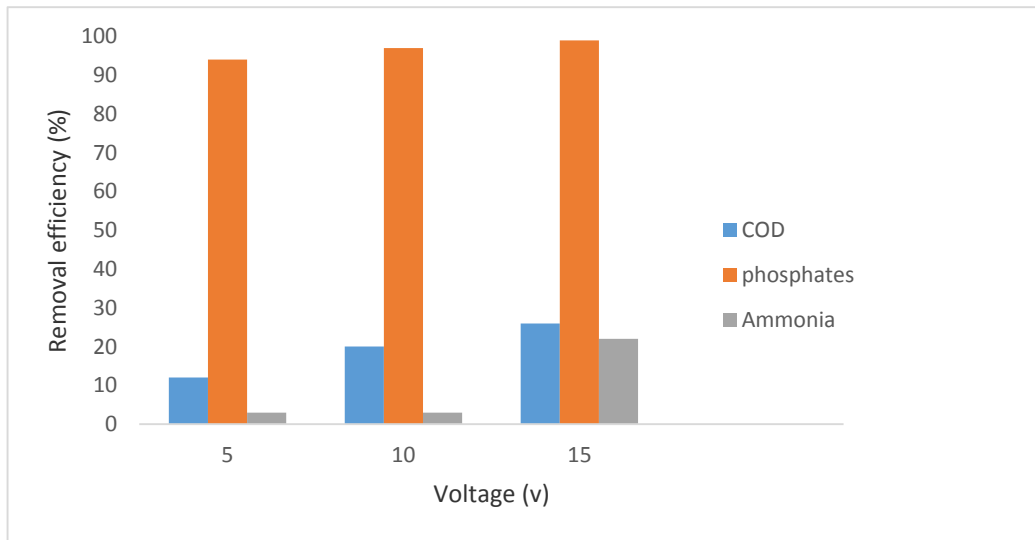


Figure 13: Effect of passivation on removal efficiency after 30 minutes with varying voltage

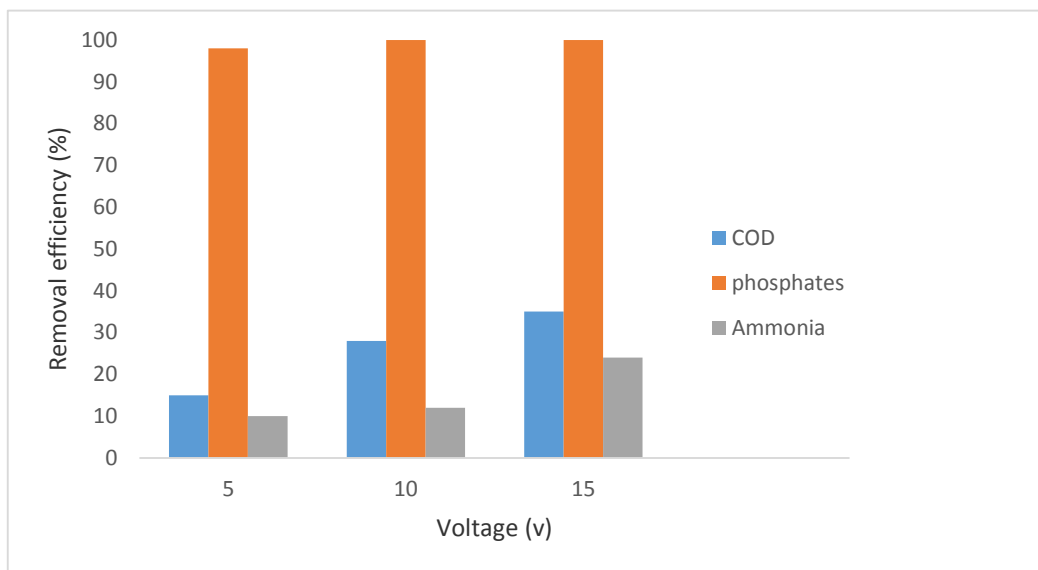


Figure 14: Effect of passivation on removal efficiency after 60 minutes with varying voltage

A decrease in removal efficiency was observed over time as seen in Table 5 and represents the final results using the passivized electrodes. Figures 13 and 14 show that the lowest removal for COD was 12% at 5 volts after 30 minutes treatment and the highest was 24% after 60 minutes treatment for COD. Ammonia removal reduction was also significantly affected by passivation recording such low removal efficiencies as 22% at 5 volts after 30 minutes and 24% was the highest at 15 volts after 60 minutes. Phosphate removal was unaffected by passivation and high removal of 100% was still maintained.

This passivation phenomenon occurred during the process and impeded the oxidation/reduction reactions. The oxide layer reduced the ionic transfer between the anode and the cathode directly, hindering the metal dissolution and indirectly preventing metal hydroxide formation [8].

Application of alternating pulse current

Note should be taken that this method of analyzing the effects of passivation is a novel process. Conductivity of the electrodes is decreased by the formation of the oxide layer, which increases the resistance to the flow of current in the cell.

Table 6: Analysis of conductivity of aluminium before and after treatment using an APC system

Before Treatment		After Treatment	
VOLTAGE	CURRENT	VOLTAGE	CURRENT
2	0.01	2	0.1
3	0.03	3	0.3
4	0.04	4	0.4
5	0.05	5	0.5

The notion of application of alternating pulsed current was brought about to reverse the effects of passivation. At first, manual changing of polarity of electrodes was done after 30 minutes of treatment. From literature passivation must decrease the electrodes' current conductivity, and this is observed in Table 6, the electrodes used had lower conductivity before APC was applied to them. They had a little passivation owing to the treatments they had performed. However, after electrocoagulation with APC their conductivity was observed to increase.

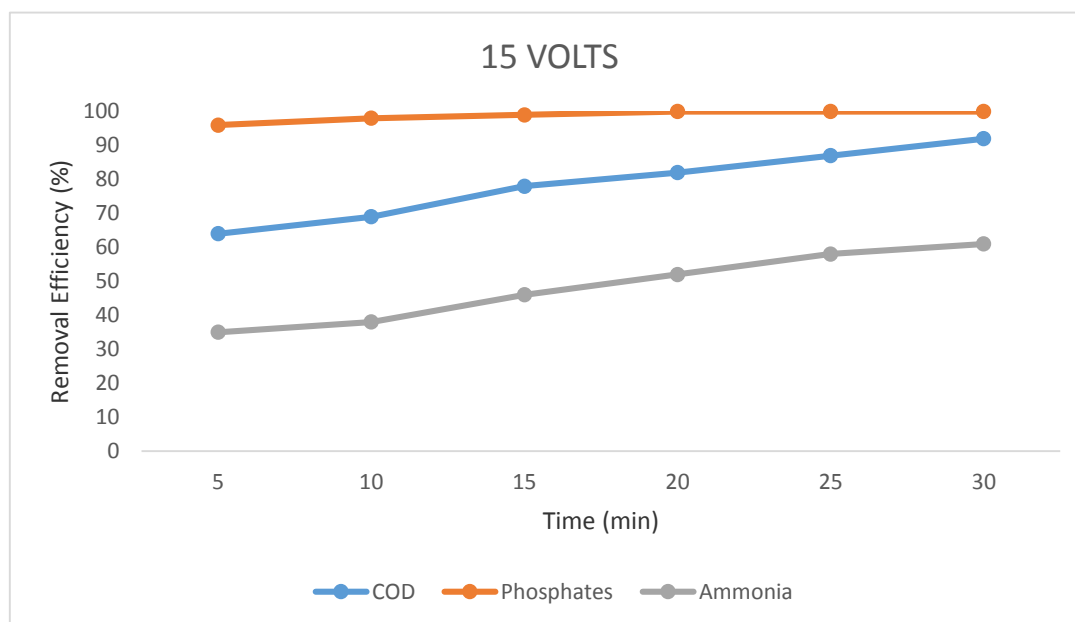


Figure 15: Effect of electrocoagulation on wastewater at 15 volts for 30 minutes using alternating pulse current

According to Figure 15 the rate of pollutant removal is high in the first 5 minutes and the rate decreases as time progresses. As time approaches 30 minutes, rate of pollutant removal decreases and reaches a monotonic state. This may be due to existence of excess colloids for adsorption

CONCLUSION

Electro coagulation was successfully applied for the treatment of municipal wastewater. The study was performed to evaluate the influence of different operational parameters on the reduction of COD, phosphates and ammonia in wastewater. Effects of type of electrode material, treatment time and applied voltage were investigated and the following observations were made:

- Aluminium and Iron were compared and Aluminium gave better results. Aluminium gave 99%, 100% and 62% removal efficiencies for COD, ammonia and phosphates respectively while Iron gave 80%, 100% and 54% removal efficiencies for the same parameters after 60 minutes treatment at 15 volts.
- Applied voltage was varied between 5, 10, 15 Volts. Pollutant removal increased with increasing voltage because of the increased coagulant generation per unit time. 15 Volts gave the best results
- Application of alternating pulsed current was effective in reducing the effects

passivation, with the conductivity of the already passivised electrodes increasing after applying alternated pulsed current. This also had the effect of increasing ammonia removal. At 15 volts, 30 minutes without the automated alternating pulsed gave 40% removal while after alternating pulsed current system gave 62% removal at the same time

- Phosphate was the most efficiently reduced pollutant, with 100% reduction being recorded at all voltages, then COD 99% and ammonia 63% at 15 volts.

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APPENDIX

Removal Efficiency Tables:

A1: Removal efficiencies of COD, phosphates and ammonia using Iron at 5, 10, 15 volts

IRON		5 VOLTS	10 VOLTS	15 VOLTS
30 Minutes	COD	30	53	68
	Phosphates	88	98	100
	Ammonia	11	36	44
60 Minutes	COD	53	67	80
	Phosphates	99	100	100
	Ammonia	13	47	54

A2: Removal efficiencies of COD, phosphates and ammonia at 5 volts with varying treatment time

5 VOLTS		Experiment 1	Experiment 2	Experiment 3	Average
30 Minutes	COD	43	41	43	42
	Phosphates	94	95	96	95
	Ammonia	22	20	21	21
60 Minutes	COD	46	46	46	46
	Phosphates	99	95	100	98
	Ammonia	23	23	24	23

A3: Removal efficiencies of COD, phosphates and ammonia at 10 volts with varying treatment time

10 VOLTS		Experiment 1	Experiment 2	Experiment 3	Average
30 Minutes	COD	69	63	65	66
	Phosphates	98	100	100	99
	Ammonia	40	38	40	39
60 Minutes	COD	83	82	87	84
	Phosphates	100	100	100	100
	Ammonia	63	60	56	60

A4: Removal efficiencies of COD, phosphates and ammonia at 15 volts with varying treatment time

15 VOLTS		Experiment 1	Experiment 2	Experiment 3	Average
30 Minutes	COD	94	94	94	94
	Phosphates	100	100	100	100
	Ammonia	38	41	42	40
60 Minutes	COD	99	97	100	99
	Phosphates	100	100	100	100
	Ammonia	63	60	63	62

A5: Removal efficiencies of COD, phosphates and ammonia after treatment using passivized electrodes

		5 VOLTS	10 VOLTS	15 VOLTS
30 Minutes	COD	12	20	26
	Phosphates	94	97	99
	Ammonia	3	3	22
60 Minutes	COD	15	28	35
	Phosphates	98	100	100
	Ammonia	10	12	24

A6: Removal efficiencies of COD, phosphates and ammonia with varying time during time optimization experiment

	5Minutes	10Minutes	15Minutes	20Minutes	25Minutes	30Minutes
COD	64	69	78	82	87	92
Phosphates	96	98	99	100	100	100
Ammonia	35	38	46	52	58	61

