Novateur Publications
International Journal of Innovations in Engineering Research and Technology [IJIERT]
ISSN: 2394-3696 Website: ijiert.org
Volume 11, Issue 7, July - 2024

ASSESSMENT OF THE PERFORMANCE OF ELECTRO-COAGULATION AND ELECTROLYTIC PROCESS IN THE TREATMENT OF PETROCHEMICAL EFFLUENT

Osuji, Charles Felix[1],
Ify Nwaogazie [2],
Ejikeme Ugwoha [3]
Center For Occupational Health, Safety and Environment, University 0f Port Harcourt, Rivers State, Nigeria Department of Civil and Environmental Engineering, University of Port Harcourt, Choba, Nigeria
osujicharlesfelix@gmail.com

Article History: Received on: 09/05/2024
Accepted on: 17/07/2024

DOI: https://doi.org/10.26662/ijiert.v11i7.pp1-13

Abstract

This study was conducted to assess the performance of the electro-coagulation and electrolytic plant currently used in treatment of petrochemical effluents produced in petrochemical plant in the Niger-delta Nigeria. Data used in this study is the daily data of the petrochemical effluent at the inlet and outlet of the electro-coagulation and electrolytic treatment plant collected within the duration of six month (February to July 2023) and contain information on eight physicochemical properties of the effluents, namely: pH, Chemical Oxygen Demand (COD), Oil & Gas content (O&G), Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Benzene-toluene-xylene content (BTX), turbidity and conductivity. The data of these physicochemical properties of the raw and treated effluent were evaluated on monthly averages and compared with National Environmental Regulation (NER) and World Health Organization (WHO) standards. The monthly-based performance of the treatment plant was also evaluated based on its ability to improve the physicochemical properties of the effluent. Descriptive statistics and T-test were used for the data analysis. The results showed that the physicochemical properties of the raw effluent were not within recommended standard while that of the treated effluent were within recommended standard except for pH (pH = 6.22, NER = 6.0 – 9.0, WHO= 6.5-8.5). The results showed that there is a significance difference between the physicochemical properties of the raw and treated effluents except for pH at 0.05 significance level, the results also revealed that the performance of the electro-coagulation and electrolytic treatment system is substantially high with respect to the treatment of the individual physicochemical properties of the effluents as follows: COD is 71.07%, Oil & Grease =79.38%, BTX =96.01%, TSS=75.08%, TDS=636%, Turbidity=76.3%, Conductivity =1200%. It was therefore concluded, among others, that electro-coagulation and electrolytic treatment system is suitable for treatment of petrochemical effluent. It was also recommended that designers of the petrochemical plant should improve its operations in a way that reduce the number of pollutants in their effluent,

Keywords; Electro-coagulation and electrolytic plant, Petrochemical Effluents, Performance

1.0 Introduction

Wastewater or effluent generated by chemical plants including petroleum refinery and petrochemical plants is often characterized by high concentrations of pollutants which usually comprise of organic and inorganic compounds. The organic compounds contained in this wastewater are mainly aliphatic and aromatic petroleum hydrocarbons, while the inorganic compounds are mostly heavy metals like mercury, lead, manganese, Nickel and other substances like Sulphur and phosphorus. These compounds and substances usually have detrimental effects on plant and aquatic life as well as surface and ground water sources. Therefore, treatment of the petrochemical effluents becomes very necessary in view of the high daily volume of the effluents produced from the petrochemical plants and the quantity of hazardous substances contained in the effluents (Khemis, *et al.,* 2015)

The effective treatment of effluent generated by the petrochemical plant represents a significant environmental pollution challenge, because of its large quantity and the diversity of pollutants present. Hence, effluents treatment facilities in most petrochemical and petroleum refinery plants usually rely on integration of expensive treatment methods to reduce the concentration of these contaminants before any final biological purification step and disposal. Therefore, efficient, cost effective and feasible methods for treatment of the effluents are needed. These treatment methods include biodegradation, ultrafiltration, adsorption, chemical coagulation, and electrochemical processes such as, electro-flotation (EF), electrodecantation (ED), electro-coagulation (EC), and electrokinetic remediation. Biological processes are rarely used since these effluents usually contain biocides which could hinder the activities of active bios needed for the treatment process (Canizares *et al.,* 2018)

Recently, several studies have focused on electro-coagulation (EC) because it is an effective process that can be used in treatment of effluents with diversity of pollutant and in industrial scale (Mollar *et al.,* 2014). EC technique is robust and compact, and hence has the potential to replace sophisticated processes that require large volumes and different chemicals (Canizares *et al.,* 2018). EC is a primary technique for treatment of various effluent generated by industries, agricultural activities and urban areas. The technique relies upon the electrochemical dissolution of sacrificial Aluminum or Iron electrodes. The generated cations contribute to the reduction of the stability of suspended entities contained in the effluent by reducing their zeta potential (Zongo *et al.,* 2019). In addition, upon formation of hydroxides ions at the cathode, metal ions form complexes with iron or aluminum hydroxides, which are known to be efficient coagulants. Furthermore, the hydrogen bubbles formed at the cathode adsorbed the flocs formed by the process, and ensure their flotation, which simplifies their separation from the treated water (Zongo *et al*., 2019).

The electro-coagulation and electrolytic technique has been considered for the treatment of effluents in a very wide range in terms of nature and composition, such as: wastewater from textile industry (Zodi *et al.,* 2019; Zongo *et al.,* 2019,), oil suspension (Khemis *et al.,* 2015), petrochemical industry wastewater (El-Naas *et al.,* 2019), wastewater containing arsenic (Balasubramanian et al, 2019), phenolic, compounds (Awad & Abuzaid 2010; Ugurlu *et al.,* 2018), heavy metals (Heidmann & Calmano.2018) and Fluorides (Ghosh *et al.,* 2018). It is this flexibility and effectiveness of the electro-coagulation electrolytic technique in terms of treatment of effluents that contain diverse number of different contaminants in industrial scale that encouraged and motivated the petrochemical plant in this study to adopt the process. However, since installation of the EC treatment plant, no empirical study has been carried out to assess the performance of the plant. Thus, this becomes the focus of this study targeted at assessing the performance of the petrochemical effluent treatment used in Petrochemical plant operating in River state.

The treatment of wastewater or effluents, generated by the industrial sector, represents a significant environmental pollution challenge, because of the large quantity and the diversity of pollutants present. One of these industries is the petrochemical industry, which produces considerable amounts of wastewater with high concentrations of organic and inorganic substances that usually have detrimental and harmful effects on plant and aquatic life, as well as the surface water and groundwater sources. Therefore, effective and feasible methods for treating petrochemical effluents are needed.

A petrochemical company operating in Eleme LGA has experienced complex expansion leading to increase in the volume of the effluent produced per day. This has resulted to overstretching of the conventional effluent treatment plant with the implication of release of poorly treated effluents into the environment particularly, the Okolu River in Eleme LGA, River state as well as detrimental pungent odor usually perceived within and around the plant premises.

In order to solve this problem, the management of the petrochemical company adopted and installed an electro-coagulation and electrolytic effluent treatment plant with the aim of treating the effluents in order to maintain the effluent at environmentally standard and acceptable level before disposal. Since the installation of the electro-coagulation and electrolytic treatment plant, no empirical study has been carried out to assess the performance of the plant as regard the effect of the physical properties and chemical composition of the effluent. Therefore, this current study is carried out to assess the performance of the electro-coagulation and electrolytic plant currently used in treatment of petrochemical effluents produced in petrochemical plants in order to ascertain its effect on the physical and chemical properties of the effluents. Hence, the objectives of the study are: Firstly, to determine the physicochemical properties of the raw effluent. Secondly, to determine the physicochemical properties of the treated effluent and finally, to ascertain the performance of the electro-coagulation and electrolytic treatment plant with respect to the physicochemical properties of the raw and treated effluent.

Some empirical studies have been carried out on effectiveness of electro-coagulation and electrolytic treatment process in treating different kinds of effluents. For instance, Kobya *et al.* (2015) studied Remazol Red 3B decolorization using electro-coagulation and electrolytic treatment process (iron electrodes) and found that 99% decolorization was possible under optimum conditions. The authors found that energy consumption could achieve 3.3 kWh/kg dye at a cost of 0.6 euro/m^3. in another study they concluded that aluminums electrodes are capable of treating fluorescent penetrant liquid for non-destructing testing part of aircraft industry. Having used electro-coagulation, the treatment present found 95% of chemical oxygen demand (COD), 99% colour, and 99% turbidity. Chou *et al.* (2010), in another study, electro-coagulation was used for removal of COD in wastewater, where it was determined that COD could be reduced by 90%. Also, the authors determined that this process followed pseudo-second order under the Freundlich adsorption isotherm model at various densities and temperatures. They also concluded that arsenic was removed by 98% when using NaCl, and was removed by 75% when using sodium sulfate and nitrate during a 5-minute appearance and an initial concentration of wastewater of 10 mg/L within the electro-coagulator. Adsorption was affected by several factors, including magnetic, particle size, and surface properties of the precipitate; solid waste from the treatment was non-hazardous.

Desphande *et al.* (2010), in their study, concluded that using a combined electro-coagulation and anaerobic fixed film reactor, COD, BOD, and color could be removed at 24%, 35%, and 70%, respectively, with conditions of pH at 7.2, current density of 80 A/m2, and electrolysis time of 25 minutes for mere electro-coagulation. However, when combined with the anaerobic fixed film reaction, removals increased to 80–90% COD, 86–94% BOD, at 0.6 to 4.0 kg COD/m3s organic loading rate. They also concluded that treatment of

Reactive Blue 140 and Direct Red 23 required electrical energy of 1.42 and 0.69 kWh/m3, respectively, with color (99%), COD (93%), and TS (89%) removal, when using a continuous electro-coagulation. In addition, the authors were able to harvest hydrogen. They also removed color (94%), turbidity (92%), COD (80%) for industrial wastewater at a flow rate of 50 mL/min. While Carlos *et al.* (2012) reported that combination of electro-coagulation and ozonation processes resulted in a synergy that enhanced the removal of all three contaminants (COD, color, and turbidity). A COD removal of 79% (170 mg/L) was attained after only 12.5 min and at relatively low current density. Thus, the combination of the electrochemical and ozonation processes is able to noticeably improve wastewater quality.

Dermentzis *et al*. (2012) evaluated the Electro-coagulation and Electrooxidation process in terms of its capability to simultaneously produce an oxidant and coagulant agents by using either iron or aluminum electrodes arranged in a bipolar configuration or graphite electrodes arranged in a monopolar configuration in the same electrolytic cell. Relatively high concentrations of active chlorine (9.6 mg/ min) and aluminum (20–40 mg Al/L) or iron (40–60 mg Fe/L) were produced in situ. The best performance for RWW treatment was obtained by using aluminum and graphite plates alternated in the electrode pack and operated at current of 0.4 A during 90 min of treatment with pH adjusted to approximately 7.0. Under these conditions, more than 98% of oil and greases (O&G) were removed, whereas chemical oxygen demand (COD) and biological oxygen demand (BOD) removal reached 90% and 86%, respectively. Likewise, more than 88% of soluble phosphate was removed, and the process was effective in removing turbidity (98%) and suspended solids (98%). Tchamango *et al.* (2016) conducted another empirical study on Treatment of dairy effluents by electro-coagulation using aluminums electrodes in which they studied the effects of using electro-coagulation for artificial wastewater with milk powder to simulate dairy effluents, COD was reduced by 61%, phosphorous by 89%, nitrogen 81%, and 100% turbidity. In addition, with low conductivity and neutral pH, treated water would be possibly reused, as reagent required was lowered for the aluminum anode for treatment. They also derived a statistic analysis using a Box Beh key design for surface response analysis using electrochemical sedimentation. Having considered current density, pH, and electrolysis design, the authors were capable of studying the effects of COD, turbidity, TS removal, and sludge settling with aluminum electrodes

2.0 Materials and Methods

2.1 Research Design

This study adopted experimental design. This design was suitable because it involves carrying out study or research based on data obtained from experiment which could be an experimental set-up or using a real operational machine or plant already being used in the field. In this study, the experiment was based on real electro-coagulation and electrolytic effluent treatment plant that is currently being used in a petrochemical plant in Eleme LGA, River State Nigeria.

2.2 Study Area

The study area was a petrochemical company located in Eleme Local Government Area of Rivers State. The Petrochemical company considered in this study is the largest producer of olefins and polyolefin plastics in West Africa. Furthermore, it is the only producer of polyolefins in Nigeria and plays a vital role in sustaining the domestic downstream plastics industry. The petrochemical complex sits on a large industrial estate of over 300 hectares that also consists of a captive power plant, utilities, warehouses, and storage tanks. The complex consists of a mixed feed ethylene cracker plant, polyethylene plant producing High-density Polyethylene and Low-density Polyethylene, and a polypropylene plant. The main feedstock is Natural Gas Liquids (NGL) which is supplied through pipeline from a gas separation plant and is supplemented by Propylene Rich Feed (PRF) from a nearby refinery, Port Harcourt Refinery, also located in Eleme, Rivers State. They produce over 300,000 tons of PE and PP resins annually, majority of which are sold in the domestic market. The company started in 1996, with staff capacity of over seven hundred (700), with other subsidiaries such as Indorama Eleme and Fertilizer Chemicals Ltd Nigeria. Figure 1 shows the location of the study area

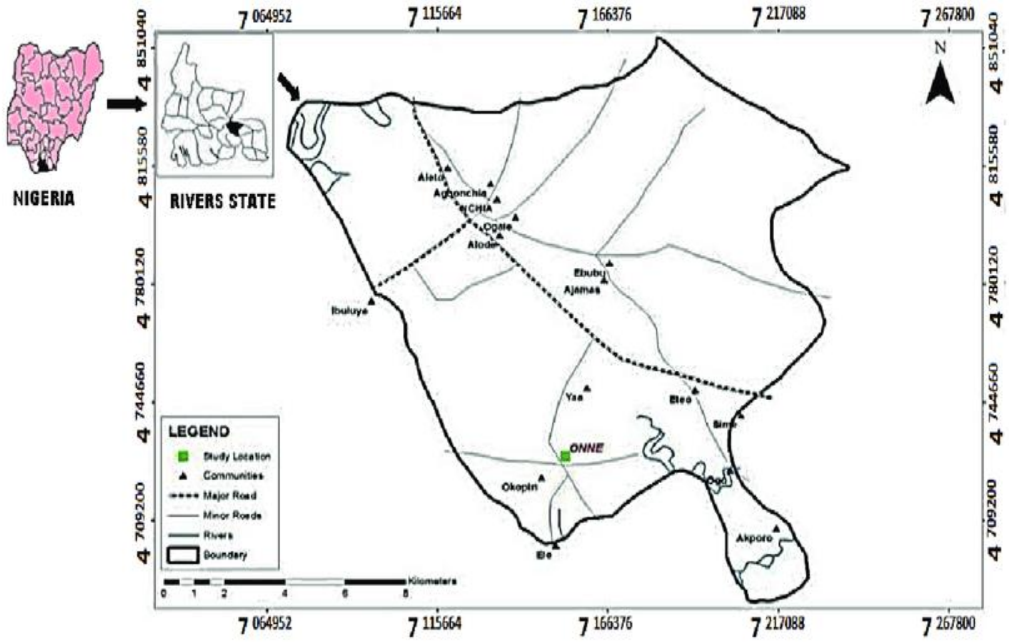

Figure 1 Map of Study Area; Eleme Local Government Area

2.3 Mechanism of Electro-coagulation and Electrolytic Processes in Effluent Treatment Plant

2.3.1 The plant set-up.

The plant is comprising of an electrolytic set-up in which the two electrodes are, aluminum serving as the Anode (negatively charged electrode) and iron as the cathode (positively charged electrode). The electrolyte is the effluents which is mixed with brine (sodium chloride solution) to improve the conductivity of the effluents and also increase the rate of the electrolytic process and a direct current source see Figure 2

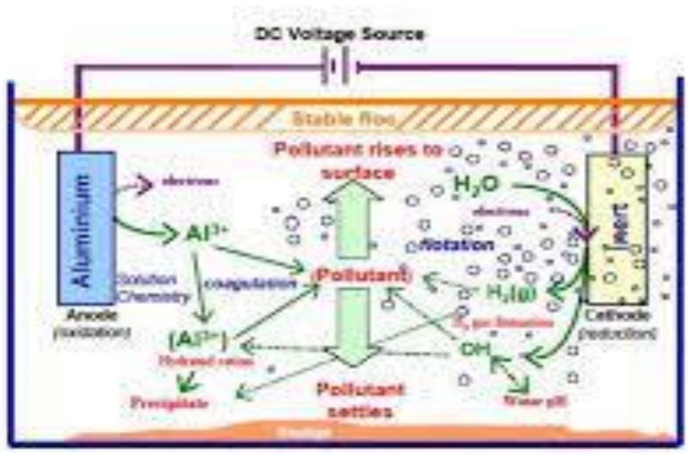

Figure 2 Electrolytic and Electro-coagulation Process Set-up (Source; Abhijit et al 2017)

Novateur Publications
International Journal of Innovations in Engineering Research and Technology [IJIERT]
ISSN: 2394-3696 Website: ijiert.org
Volume 11, Issue 7, July - 2024

2.3.2 The Electrolytic and Electro-coagulation Treatment Process

During the process, as current is passed through the electrode into the electrolyte, the aluminum (Al) electrode gradually and continually ionize into the electrolyte to form the coagulant through electrolytic oxidation process. The released Al ions neutralize the charges of the contaminant particles, thereby initiate coagulation. The Al ions and some hydroxyl ions remove the undesirable contaminants by chemical reaction or precipitation or by causing the colloidal materials to coalesce and are then removed as floating layers or sedimented or settled layers see Figure 3. Thus, the main processes occurring during the electrolysis and electro-coagulation are electrolytic reactions at the surface of electrodes, formation of coagulants in effluents, adsorption of soluble or colloidal contaminant on coagulants, and removal by sedimentation and floatation. The treated effluent is then filtered to remove the sediments and flocs. Finally, the treated effluent is tested to ensure that it is safe for disposal See Figure 3.

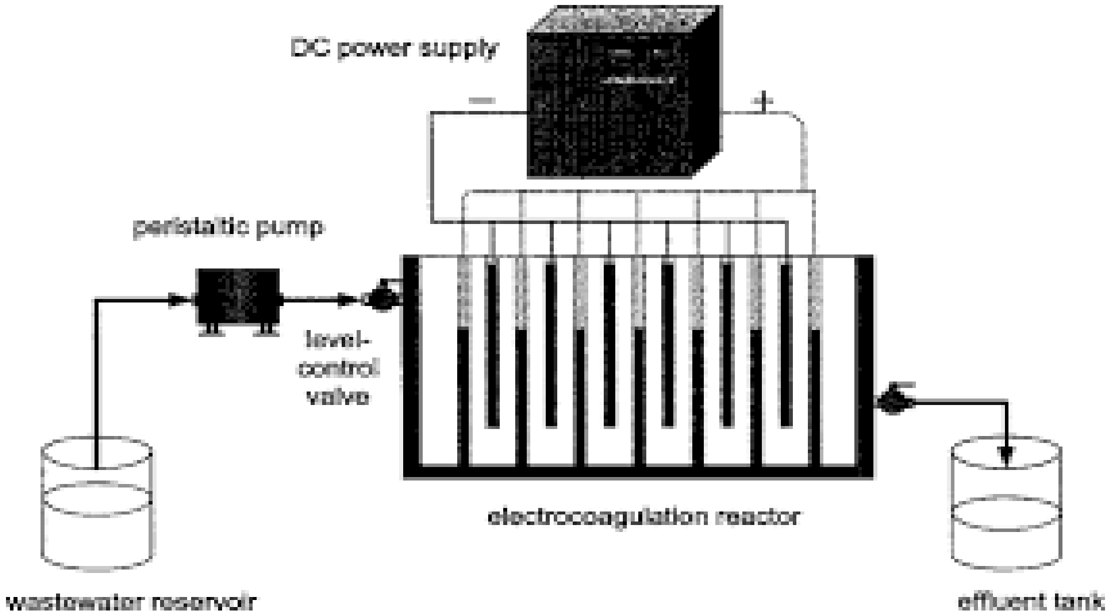

Figure 3 The Electro-coagulation and Electrolytic Treatment Plant (Source; Abhijit et al 2017)

2.4 Type of Data

The data used in this study was secondary data obtained from the Electro-coagulation and Electrolytic Treatment Plant operating in the Niger-delta**.** The data are daily physicochemical properties of the petrochemical effluents at the inlet and outlet of the treatment plant which represents data of the raw and treated effluents respectively. The data includes Chemical Oxygen Demand (COD), pH value, turbidity and conductivity as well as the data of the composition of the effluents which includes oil/grease content, Total Aromatic hydrocarbon, Total Suspended Solid (TSS) and Total Dissolved Solid (TDS)). The data were evaluated to monthly average of the properties of the effluents and compared to the national and international recommended limits such as National Environmental Regulation (NER) (2009) and WHO (2020) standards for effluent and sewage water disposal into body of flowing water. Table 1 shows the standards

Table 1 Standards for Effluent and Sewage water Disposal Into water body

PARAMETER	NER Standard	WHO Standard range
pH	6-9	6.5-8.5
COD	Less than 250 ppm	Less than 250 (ppm)
TDS	-------	500-1000 (ppm)
TSS	Less than 25 ppm	Less than 25 (ppm)
Turbidity	--------	Less than 25 NTU
Polycyclic Aromatic Hydrocarbon (PAHs) (BTX)	Less than 10 ppm	Less than 5.0 ppm
Oil and Grease	Less than 10 ppm	Less than 5.0 ppm
Electric conductivity	------	800-2500 µS/cm

2.5 Performance of Treatment Plant

The performance of treatment plant was calculated using the equation expressed as

$$PP = MOV-MIV/MIV \times 100/1$$

where; PP is Performance of the plant, MOV is Mean Outlet Value and MIV is Mean Inlet Value of the properties and composition of the effluent

2.6 Statistical Analysis

Descriptive statistic of mean, standard error and percentages were used to analyse data to achieve objective one and two. T-test was used to ascertain whether there is significant difference between physicochemical properties of the effluent samples before and after treatment. The performance of the treatment plant was expressed in percentage, and XL-Stat-6.0 version was used for the data analysis.

3.0 Results and Discussions

3.1 Physicochemical properties of the raw effluent

In this study eight physicochemical properties of the petrochemical effluent were considered and they include, pH, Chemical oxygen Demand (COD), Oil and grease amount (O&G), Total Polycyclic Aromatic Hydrocarbon (Benzene, Toluene, Xylene BTX), Total Suspended Solid, Total Dissolves Solid, Turbidity and Conductivity. Table 2 show the results of the eight physicochemical properties of the raw effluent at the inlet into the electro-coagulation and electrolytic effluent treatment plant obtained within six months of operation. The results were tabulated on monthly basis.

Considering the pH value of the raw effluent with respect to the NER and WHO standards, it was observed that the mean pH value of the raw effluent was within the NER and WHO recommended standard in February and March, while the mean pH value from April to July were all below WHO recommended standard but still within NER standards. On the average, the pH value of the effluent was 6.37 which is slightly below WHO recommended standard range of 6.5-8.5 but still within NER standard range of 6-9. This show that the raw effluent was slightly acidic within the six months treatment period considered. Considering the chemical oxygen demand (COD) of the raw effluent in comparison with the recommended standards, it was observed that the raw effluent has very high level of COD in each of the six months considered because their mean COD value was higher than 250ppm recommended for effluents, before disposal into water body. The results revealed that the highest COD level (912ppm) was observed in February while the lowest level (661ppm) was observed in July. On the average, the COD of the raw effluent was higher than the recommended range for effluent before disposal into water body.

The results in Table 2 also revealed that the amount of oil and grease in the raw effluent was higher than the recommended standard. In this case, oil and grease content was considered as part of hydrocarbon whose recommended and accepted standard in effluent for disposal is less than 5ppm. From the results, it was observed that the amount of oil and grease in the raw effluent was highest in May, and lowest in March. On the average, it was observed that the oil and grease content in the raw effluent is higher than acceptable standard. Table 4.1 also showed that BTX content of the raw effluent was higher than acceptable NER and WHO standards. The results revealed that BTX content was highest in the raw effluent treated in June and lowest in the raw effluent treated in March. On the average, the effluents treated in the plant within the six months period have higher BTX content than the recommended and acceptable range.

Table 2 also revealed that total suspended solid (TSS) in the raw effluent was higher than acceptable recommended range in all, except the second months considered in the study. The results revealed that TSS was highest in raw effluents treated in July and lowest in the raw effluents treated in March. On the average, the TSS content of the raw effluent (64.33ppm) was higher than the recommended range for effluent disposal into water body which is less than 25pmm. It was observed that the Total Dissolved Solid (TDS) in the raw effluent was lower than the acceptable recommended range of 500-1000 ppm. The result revealed that the lowest TDS content of the raw effluent was recorded in March while the highest TDS value was recorded in February.

For the turbidity of the raw effluent, the result revealed that the turbidity of the effluent is higher than the recommended standard in the six months effluent results considered, and it is highest in February and lowest in July. On the average, the turbidity of the raw effluent (55.69 NTU) was higher than the recommended standard for disposal (less than 25NTU). Considering the Conductivity of the raw effluent, Table 2 show that the average conductivity of the raw effluent in each of the six months considered is lower than recommended standard. And it was lowest in April and highest in June. From the raw effluent results, it was observed that the average conductivity of the raw effluent treated within the six months (122.62 µS/cm) is lower than the recommended range for effluent disposal (800-2500 µS/cm).

Table 2 Physicochemical Properties of the Raw Effluent

Parameters	pH	COD (ppm)	O&G (mg)	BTX (ppm)	TSS (ppm)	TDS (ppm)	Turbidity (Ntu)	Electrical Conductivity (µs/Cm)
February	7.28±0.18	912.29±31	20.00±1.22	140.50±6.4	27.92±3.4	157.25±33	109.00±28	124.30±17
March	6.57±0.17	836.25±24	17.29. ±1.1	61.77±4.5	23.28±1.9	89.75±6.2	63.00±21	121.15±16
April	6.43±0.19	777.58±27	20.87±0.89	103.02±7.9	30.71±2.4	109.86±16	48.30±12	111.96±8.5
May	5.98±0.10	823.52±23	21.47±±1.3	106.99±6.8	96.82±5.9	108.58±13	30.25±5.7	125.57±13
June	6.10±0.10	760.00±16	20.20±0.86	113.01±6.9	94.50±4.5	107.89±8.6	46.89±8.9	122.63 ±12
July	5.89±0.25	661.07±25	21.13±1.3	82.30±7.9	96.69±6.9	93.76±7.7	38.64±13	129.50±13
Mean	**6.37±0.13**	**795.14±22**	**20.17±1.4**	**101.25±5.9**	**64.33±3.9**	**111.03±7.6**	**55.69±9.8**	**122.52±12**

3.2 Physicochemical properties of the treated effluent

Table 3 show the physicochemical properties of the treated effluent at the outlet of the electro-coagulation and electrolytic effluent treatment plant. In comparison with the NER and WHO recommended standards for physicochemical properties of effluents before disposal into water body. In Table 3, it was observed that pH value of the treated effluent was within the NER recommended range in all the months. The pH value of February, May and Jume were within WHO range while the pH value in March, April and July were lower than the recommended. However, from the overall average, the pH value of the treated effluent (6,22) was slightly below WHO standard range of 6.5-8.5 but within the NER standard range of 6-9. For the Chemical oxygen demand (COD), the results in Table 3 showed that the average COD of the treated effluent in each of the six months considered was within the recommended standard of less than 250ppm. From the result, it was also observed that COD was lowest in July and highest in May. On the overall average, it was observed that the average COD level of the treated effluent (230.78ppm) was within the recommended standard (less than 250ppm).

Table 3 showed that the average amount of oil and grease in the treated effluents in each of the six months considered is within the recommended standard for effluent before disposal (less than 5.0ppm). It was also observed that the oil and grease content in the treated effluent was highest in the March and lowest in February. On the overall average, it was noticed that the mean amount of oil and grease in the treated effluent (4.16ppm) was within recommended standard (less than 5.0ppm). For the Total Polycyclic Aromatic hydrocarbon content of the treated effluent, the results in Table 3 also showed that average Polycyclic Aromatic hydrocarbon (BTX) content in the treated effluent in each of the six months considered is within recommended standard of less than 5.0ppm in the six months considered, specifically in March, April, May and July, but slightly higher than recommended standard in February and Jume. On the overall, it was observed that the average BTX amount in the treated effluent (4.03ppm) was within the recommended standard (less than 5.0ppm).

For the Total Suspended Solid, the results in Table 3 revealed that the average amount of the total suspended solid (TSS) in the treated effluent in each of the six months considered was within recommended standard (less than 25ppm). It was also observed that the TSS value was lowest in February and highest in May. From the result, it was observed that average TSS content of the treated effluent (15.75ppm) was within recommended standard (less than 25ppm). It was also observed that average TDS of the treated effluent in each of the six months considered was within the recommended standard (500-100ppm). The result also revealed that the TDS was highest in July and lowest May. Considering the result, it was ascertained that the overall average of the TDS of the treated effluent (8.6.95ppm) was within the recommended standard for effluent before disposal into water body (500-1000ppm).

Table 3 also showed that the average Turbidity value of the treated effluent in each of the six months considered was within the recommended standard for effluent before disposal (less than 25 NTU) and it was lowest in April and highest in March. Generally, the overall average turbidity of the treated effluent (in six month of operation was within (12.59 NTU) was within the recommended standard for effluent disposal (less than 25 NTU). Finally, considering the electrical conductivity of the treated effluent, the results revealed that electrical conductivity of the treated effluent in each of the six months considered was within recommended standard for effluent disposal (800-2500 µS/cm). it was ascertained that the conductivity was highest in February and lowest in July. From the result, the average conductivity value of the treated effluent within the six-month period was 1508.60 µS/cm which is within the recommended standard of effluents before disposal These results also agreed with studies conducted by Tchamango *et al,* (2016), 2016), Chou *et al.* (2010), Desphande *et al.* (2010), Dermentzis *et al*. (2012), Kobya *et al.* (2015) and Carlos *et al.* (2012) who, in their separate studies on electro-coagulation and electrolytic treatment processes, confirmed that there is substantial improvement in the pH, COD, O/G, TSS, TDS, BTX, turbidity and conductivity of raw effluent after undergoing the electro-coagulation and electrolytic treatment processes.

Table 3 Physicochemical Properties of the Treated Effluent

Parameters	pH	COD (ppm)	O/G (mg)	BTX (ppm)	TSS (ppm)	TDS (ppm)	Turbidity (NTU)	Conductivity (µS/cm)
February	7.03±0.47	215.28±30	3.92±0.14	6.62±2.5	7.80±2.3	726.83±150	10.92±2.8	1919.0±194
March	5.93±0.39	219.25±7.7	4.43±0.12	2.47±0.29	8.94±3.4	953.80±57	17.25±3.2	1676.80±97
April	5.52±0.37	242.50±10	4.06±0.11	2.07±0.28	11.31±2.4	882.16±19	9.20±0.99	1508.6±39
May	6.61±0.21	248.27±7.9	4.13±0.07	4.20±0.31	17.11±0.55	662.32±21	10.31±3.9	1620.58±30
June	6.61±0.32	257.73±10	4.16±0.10	5.47±0.71	13.15±0.76	681.11±48	9.69±2.7	1172.40±19
July	5.61±0.31	201.66±21	4.25±0.17	3.37±0.39	12.88±0.48	995.44±127	11.22±4.3	1156.11±24
Mean	**6.22±0,33**	**230.78±14**	**4.16±0.13**	**4.03±032**	**15.75±1.9**	**816.95±68**	**12.59±2.8**	**1508.60±47**

3.3. Comparison of the physicochemical properties of the treated effluent with discharge standards

Table 4 show the comparison of the physicochemical properties of the raw effluent, treated effluent with discharge standards. Based on these results, it was observed that raw effluent was highly polluted because all the physicochemical properties were not within the recommended standard for effluent before disposal. The results also showed that the treated effluent was safe for disposal because all the physicochemical properties of the treated effluent were within the recommended standard except for pH value which is slightly below the WHO recommended standard range.

Also, Table 5 showed that T-test analysis carried out to ascertain whether there is a significant difference between the physicochemical properties of the effluent before and after treated. And the results showed that there is statistically significant difference between the physicochemical properties of the effluent before and after treatment except for pH value at significance level of 0,05. This is because the p-values of the T-test for all the parameters considered were lower than 0.05 except for pH value whose p-value is higher than 0.05 showing, showing that there is no statistically significance difference between the pH value of the before and after treatment.

This finding is a clear indication of two main facts. Firstly, the raw effluents from the petrochemical production processes are highly polluted and should be properly treated to recommended discharge standard before disposal into any waterbody. Secondly, electro-coagulation and electrolytic treatment process is a suitable treatment process for effluent produced in petrochemical production processes. This finding aligns with the findings of Dermentzis *et al*. (2012), Kobya *et al.* (2015) and Carlos *et al.* (2012) who, in their separate studies on electro-coagulation and electrolytic treatment processes, confirmed that effluent from petrochemical production processes are highly polluted and must be properly treated to recommended standard before disposal and also maintained that electro-coagulation and electrolytic treatment processes is a suitable treatment process for petrochemical effluents in terms of improving the COD, O & G, TSS, TDS, BTX, turbidity and conductivity of raw effluent to recommended standard before disposal.

Table 4 Physicochemical Properties of the Raw Effluent, Treated Effluent and Discharge Standards

S/N	Physicochemical properties	Average Physicochemical value of the raw effluent	Average Physicochemical value of the treated effluent	NER 2009) Standard range for Effluent before Discharge	WHO (2020) Standard range for Effluent before Discharge
1	pH	6.37	6.22	6-9	6.5-8.5
2	COD (ppm)	795.14	239,76	Less than 250	Less than 250
3	Oil and Grease (ppm)	20.17	4.16	Less than 10	Less than 5.0
4	BTX (ppm)	101.25	4.03	Less than 10	Less than 5.0
5	TSS (ppm)	64.33	15.75	Less than 25	Less than 25
6	TDS (ppm)	111.03	816.95	----	500-100
7	Turbidity (NTU)	55.69	12.59	----	Less than 25
8	Conductivity (µS/cm)	122.52	1508.60	----	800-2500

Table 5 T-Test results to compare the properties of the effluent before and after treatment

		Paired Differences					t	Df	p-value
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	PH1 - pH2	.15667	.61455	.25089	-.48826	.80159	.624	5	**0.560**
Pair 2	COD1 - COD2	564.29667	85.07370	34.73119	475.01729	653.57604	16.248	5	**0.000**
Pair 3	OG1 - OG2	16.00167	1.61825	.66065	14.30342	17.69992	24.221	5	**0.000**
Pair 4	BTX1 - BTX2	97.22833	25.56786	10.43804	70.39651	124.06016	9.315	5	**0.000**
Pair 5	TSS1 - TSS2	49.78833	34.95472	14.27021	13.10560	86.47107	3.489	5	**0.017**
Pair 6	TDS2 - TDS1	705.76167	159.43015	65.08709	538.44998	873.07335	10.843	5	**0.000**
Pair 7	Turbidity1 - Turbidity2	44.57500	27.75278	11.33002	15.45025	73.69975	3.934	5	**0.011**
Pair 8	Conductivity1 - Conductivity2	-1386.39500	300.01041	122.47874	-1701.23662	-1071.55338	-11.319	5	**0.000**

3.4 Assessment of the monthly performance of the electro-coagulation and electrolytic plant.

Table 6 showed the monthly performance of the electro-coagulation and electrolytic effluent treatment plant with respect to physicochemical properties of the effluent. The pH was not considered because it has been established that there is no significant difference between the pH value of the effluent before and after the treatment therefore, it is expected that the performance of re treatment plant will be insignificant with respect to pH value. The monthly performance of the treatment plant was substantially high because all the monthly performance values for all the physicochemical parameters considered were above average. Note, the negative subscript in the performance value of some of the parameter signified a decrease in the value of the parameters after the effluent has passed through the treatment process, while a positive value signifies an increase in value of the parameter after effluent has passed through the treatment processes.

It was also observed that the performance of the treatment plant was substantially high in terms of improving the physicochemical properties of the effluent within the six-months period considered in the study. However, there was a substantial variation in the monthly performance of the plant in terms of all the physicochemical properties considered (COD, O&G, TSS, TDS, BTX, turbidity and conductivity) except for BTX. This finding revealed that there is an alteration in the monthly performance of the treatment plant and this alteration in performance is not merely by change but as a result of either technical or administrative issues.

These finding agreed with outcome of several studies such as the study by Tchamango *et al,* (2016) who conducted another empirical study on Treatment of dairy effluents using electro-coagulation with aluminum electrodes in which they studied the effects of using electro-coagulation for artificial wastewater with milk powder to simulate dairy effluents, COD was reduced by 61%, TSS by 89%, and 100% turbidity. The finding also agreed with work of Chou *et al.* (2010) who used electro-coagulation for removal of COD in wastewater, where it was determined that COD was reduced by 90%. Study by Desphande *et al.* (2010) also aligned with this finding as they used electro-coagulation process to treat industrial wastewater and their results revealed that turbidity was 92% improved, COD was 93%) and TSS was 89% removed and color was 99%. This finding also concurred with study by Dermentzis *et al*. (2012) who evaluated the Electro-coagulation and Electrooxidation process in terms of its capability to simultaneously produce an oxidant and coagulant agents by using either iron or aluminum electrodes arranged, which is similar to the treatment plant used in this study and their findings revealed that more than 98% of oil and greases (O&G) were removed, whereas chemical oxygen demand (COD) and biological oxygen demand (BOD) removal reached 90% and 86%, respectively. Also more than 88% of TDS was removed, and the process effectively removed turbidity by 98% and TSS was improved by 98%. Finally, the finding of this study equally aligned with works of Kobya *et al.* (2015), who also studied Remazol Red 3B decolorization using iron electrodes and found that 99% decolorization was possible under optimum conditions and their results revealed electro-coagulation removed 95% of chemical oxygen demand (COD), 99% color content and 99% turbidity.

Table 6 The monthly performance of the electro-coagulation and electrolytic effluent treatment plant with respect to physicochemical properties of the effluent

Performance (%)	COD	O/G	BTX	TSS	TDS	Turbidity	Conductivity
February	-76.43	-80.40	-95.30	-72.00	362.00	-89.89	1800
March	-74.17	-75.38	-96.00	-61.60	970.00	-72.62	1500
April	-68.81	-80.56	-97.99	-63.17	709.00	-80.95	1400
May	-69,85	-80.76	-96.07	82.33	512.00	-65.90	1420
June	-66.09	-79.41	-95.16	-86.08	513.00	-76.10	900
July	-69.50	-79.99	-95.90	-86.68	961.00	-70.96	1030
Mean	**-71,07**	**-79.38**	**-96.01**	**-75.08**	**636.00**	**-76.37**	**1230**

4.0 Conclusions

Based on the finding of this study, it was concluded that the effluent from the petrochemical plant considered in this study is highly polluted because their physicochemical properties were not within the recommended standards for disposal into water bodies. Therefore, the effluents must not be discharged into water bodies without proper treatment using systems like the electro-coagulation and electrolytic treatment plant. Secondly, petrochemical effluents treated using the electro-coagulation and electrolytic treatment plant is safe to be discharged into any form of water body because their physicochemical properties are within the recommended standards for disposal into water bodies and thirdly, the performance of the electro-coagulation and electrolytic treatment plant is substantially high as regard to improving the individual physicochemical properties of effluent.

5.0 Recommendations

Based on the conclusions of this study, it was recommended that:

1. The technical and engineering management section of the petrochemical company should ensure that they improve on the operations of the plant in a way that would reduce the amount of pollutant that infiltrate the effluent to reduce the pollution level of effluent and in turn reduce the costs usually incurred during the treatment and disposal processes.
2. Rivers state government under the ministry of environment and other environmental protection agencies, having confirmed the pollution level of effluents from petrochemical plants, should ensure that strict and enforceable policies are rolled out for the industries in order to prevent unlawful disposal of effluent into water bodies in the state

References

1. Awad, Y.M. & N.S. Abuzaid (2010) The influence of residence time on the anodic oxidation of Phenol. Separation and Purification Technology 18 (4) 227–236.
2. Balasubramanian, N., T. Kojima & C. Srinivasakannan (2019). Arsenic removal through electro-coagulation: Kinetic and statistical modeling. Chemical Engineering Journal 155(7) 76-82

3. Canizares, P., F. Martínez, M.A. Rodrigo, C. Jiménez, C. Sáez & J. Lobato (2018). Modeling of wastewater electro-coagulation processes Part II: Application to dye-polluted wastewaters and oil-in-water emulsions. Separation and Purification Technology 60(147–154).
4. Carlos Barrera-Díaz, Lina. A. Bernal-Martínez, Reyna Natividad, and Juan M. Peralta-Hernández (2012), Synergy of Electrochemical/O3 Process with Aluminum Electrodes in Industrial Wastewater treatment. Industrial. Engineering. Chemistry. Research, 51(23), 9335−9342.
5. Chou, W., Wang, C., Chang, W. & Chang, S. (2010), Adsorption treatment of oxide chemical mechanical polishing wastewater from a semiconductor manufacturing plant by electro-coagulation. Journal of. Hazard. Mater., 180(27) 217-224.
6. Dermentzis, K., Christoforidis, A. Valsamidou, E. Lazaridou, A. Kokkinos, N. (2011), Removal of Hexavaent Chromium from Electroplating Wastewater by Electro-coagulation with Iron Electrodes. Global NEST Journal, 13(4), 412-418.
7. Deshpande, A.M. Satyanarayan, S. & Ramakant, S. (2010). Treatment of high-strength pharmaceutical wastewater by electro-coagulation combined with anaerobic process. Water Science Technology., 61(7) 463-472.
8. El-Naas, M. H., S. Al-Zuhair & A. Al-Lobaney (2019). Assessment of electro-coagulation for the treatment of petroleum refinery wastewater. Journal of Environmental Management 91(3) 180-185
9. Ghosh, D., C.R. Medhi & M.K. Purkait. (2018) Treatment of fluoride containing drinking water by electro-coagulation using monopolar and bipolar electrode connections. Chemosphere 73(5) 1393– 1400.
10. Heidmann I. & W. Calmano. (2018) Removal of Zn (II), Cu (II), Ni (II), Ag(I) and Cr (VI) present in aqueous solutions by aluminum electro-coagulation. Journal of Hazardous Materials 152 (6) 934–941.
11. Khemis, M., G. Tanguy, J. P. Leclerc, G. Valentin & F. Lapicque (2015) Electro-coagulation for the treatment of oil suspension: Relation between the rates of electrode reactions and the efficiency of waste removal. Process Safety and Environmental Protection 83(1) 50–57.
12. Kobya, M., Demirbas, E. Sozbir, M. (2015), Industrial wastewaters treated by electro-coagulation. Color Technology., 5(3) 282-288.
13. Mollah, M.Y.A., P. Morkovsky, J.A.G. Gomes, M. Kesmez, J. Parga & D.L. Cocke (2014). Fundamentals, present and future perspectives of electro-coagulation. Journal of Hazardous Materials 114 (199–210).
14. Tchamango, S. Nanseu-Njiki, C.P. Ngameni, E. Hadjiev, D & Darchen, A.(2016), Treatment of dairy effluents by electro-coagulation using aluminum electrodes. Science. Total Environment, 408, 947-952.
15. Ugurlu, M., A. Gurses, C. Dogar & M. Yalc-ın. (2018) The removal of lignin and phenol from paper mill effluents by Electro-coagulation. Journal of Environmental Management 87 (8) 420–428.
16. WHO (2020) Revision of guidelines for water quality 4th ed world health organization Geneva, Switzerland
17. Zodi, S., O. Potier, F. Lapicque & J. Leclerc (2019). Treatment of the textile wastewaters by electro-coagulation: Effect of operating parameters on the sludge settling characteristics. Separation and Purification Technology 69 (5) 29–36
18. Zongo, I., A.H. Maiga, J. Wéthé, G. Valentin, J. Leclerc, G. Paternotte & F. Lapicque (2019). Electro-coagulation for the treatment of textile wastewaters with Al or Fe electrodes, Compared variations of COD levels, turbidity and absorbance". Journal of Hazardous Materials 169 (70–76).