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Treatment of Automobile Service Station Waste Water using ECC

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ABSTRACT
The present study was conducted to investigate the treatment of service station wastewater using electrochemical coagulation techniques. The performance of ECC treatment on wastewater was examined for operating conditions like cell voltage of 10, 20 and 30V at electrode spacing of 1cm, 2cm and 3cm using aluminum and stainless steel for removal of COD, TDS, Turbidity and pH. The pH , COD, TDS, Turbidity were measured in 180 minutes of electrolysis time, and 30-minute intervals from the sample withdrawal. For the treatment of waste water from car service stations employing SS electrodes, the ideal electrolysis period to achieve maximal COD removal was 180 minutes. Remarkable removal efficiency were obtained for 3cm electrode distance employing SS electrodes, demonstrating 80% of COD removal, 70% of TDS removal, and 71% of Turbidity removal. When treating vehicle wastewater with aluminum Al electrode more removal rate were observed, with 91% of COD removal, 85% of TDS removal, and 75% of Turbidity removal. The sludge obtained at optimum condition was characterized using EDS, XRD and SEM to know the elemental composition, structure and morphology and the results indicated that the sludge has reuse capabilities.

Keywords: **Electrochemical Coagulation; Scanning Electron Microscopy; Electron Dispersive Spectroscopy; X-ray Diffraction Analysis.**

1 INTRODUCTION

Growth of urban population has increased the demand of fresh water source and its rapid depletion has been a concern to ecologists. Rapid urbanization has led to hasty growth of service station in urban areas and this has necessitated the need to have automobile service centers at regular intervals. Service stations ranges from authorized service stations to small scale service centers, which undertake repair, washing and servicing of vehicles. According to report provided by International Car wash Association, a home car wash can go through 120 to 170 liters of water, some water will also be used to wash floor and washing equipment' s. this wash water contains oil and grease, detergents, phosphate, sulphate, nitrate and heavy metals. Diphare et al., (2013) have given an overview of physical, chemical, biological wastewater treatment. ECC is an innovative and environmentally friendly wastewater treatment method that uses electricity to remove various types of contaminants. Unlike conventional coagulation, which relies on the addition of chemical agents such as alum or ferric chloride, ECC generates coagulants directly in the treatment system through the dissolution of metal electrodes. This method is gaining attention due to its simplicity, effectiveness, and reduced reliance on external chemical inputs.

The objectives of the study are Service station wastewater typically contains a complex mixture of pollutants such as oils, grease, suspended solids, heavy metals, and various organic compounds, making its treatment a critical environmental concern. ECC has gained attention as an effective and environmentally friendly method for treating such industrial wastewater due to its ability to remove a wide range of contaminants without the need for chemical additives. This study aims to assess the suitability of ECC for treating service station wastewater by first determining its initial physico-chemical characteristics. It further investigates the treatment efficiency under varying operational parameters such as cell voltage, electrolysis time, and electrode spacing in a batch setup. sludge generated under optimal conditions is characterized to evaluate its properties and potential environmental impact, providing insights into the overall efficiency and feasibility of ECC as a treatment method.

The outcomes of this study are expected to contribute positively to environmental protection by demonstrating the effectiveness of electrochemical coagulation in significantly reducing harmful pollutants from service station wastewater. By identifying optimal treatment conditions, the process can minimize the discharge of contaminants such as oil, grease, heavy metals, and suspended solids into natural water bodies, thereby reducing the risk of soil and water pollution. Additionally, since electrochemical coagulation generates less chemical sludge compared to conventional methods, it

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offers a more environmentally sustainable waste management solution. The characterization of the sludge will also help determine its environmental safety and potential for reuse or safe disposal. Overall, the study supports cleaner industrial practices and promotes a low-impact, energy-efficient approach to wastewater treatment that aligns with environmental sustainability goals.

2. MATERIALS AND METHODOLOGY

2.1 Experimental Setup

A laboratory-scale batch electrochemical coagulation (ECC) process was conducted to treat wastewater samples from service stations. The ECC system consisted of stainless steel (SS) and aluminum (Al) plate electrodes, an electrochemical reactor (ECR) with a 2.5 L working capacity, a magnetic stirrer, and a DC power supply. Two Al and SS electrodes were used in each experiment, arranged in parallel and submerged in the wastewater sample within the reactor. The electrodes were connected in a bipolar configuration to the DC power supply, with cell voltages ranging from 10V to 30V and electrode spacing of 1cm, 2cm, and 3cm. The magnetic stirrer agitated the reactor at 250 rpm during the 180-minute electrolysis period.

Fig 1: Experimental set up for treating automobile wastewater and collection of wastewater

2.2. Methodology for Different Electrode Spacing, Electrolysis time, Current and Voltage

Bipolar configuration of aluminum and stainless steel plate electrodes was used for electro coagulation. The electrodes are placed at inter electrode gap of 1cm up to 3cm at an interval of 1cm, on the fiber electrode holding stand fixed to the mouth of the reactor and connected to the 30V dual DC power supply. The batch experiment was conducted at varying voltage of 10V, 20V and 30V with selected time intervals of 30, 60, 90, 120 and 180 minutes and current vary from 2A – 4A at room temperature. In each run, approximately 2.5 liters of service station wastewater sample was placed in reactor.

2.3. Sludge Analysis

The EDS, SEM, and XRD analyses were performed on the sludge produced during the experiment with the highest pollutant removal effectiveness for treated wastewater from Al and SS electrode materials.
Scanning Electron Microscopy (SEM) is an analytical technique that employs a focused beam of high-energy electrons to examine a sample's surface, producing highly magnified images for in-depth analysis. It is especially useful for micro structural analysis and diagnosing the underlying causes of material failures in solid inorganic substances. By capturing different signals emitted from the sample's surface, SEM creates detailed two-dimensional images that highlight variations in features such as surface orientation.
Energy Dispersive Spectroscopy (EDS) is a powerful technique used to determine the elemental composition of a material's surface. By directing an electron beam onto the sample, EDS excites the atoms present, allowing for the identification of individual elements and even creating detailed elemental maps. This method is especially useful for both localized analysis and broader surface composition studies. While EDS is effective at detecting a wide range of elements including many

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lighter ones — it does have some limitations. Specifically, it cannot detect elements like lithium, helium, or hydrogen. However, it can accurately identify most other stable elements, making it a valuable tool for qualitative and semi-quantitative material analysis across various scientific and industrial applications

X-ray Diffraction (XRD) analysis is a non-destructive technique that provides comprehensive insights into a material's crystallographic structure, physical properties, and chemical composition. Based on the principle of constructive interference, XRD involves directing monochromatic X-rays onto a crystalline sample, resulting in diffracted photons. The diffracted rays are then detected, analyzed, and measured, generating a diffraction pattern that graphically represents the intensity of scattered rays a various angle. This pattern reveals the material's structural information, enabling the determination of its physical and chemical characteristics.

3 RESULTS AND DISCUSSION

Performance evaluation of electro chemical coagulation process with the aluminum and stainless steel electrodes as carried out for different voltages of 10V, 20V and 30V with selected time of 30 to 180 minutes at time intervals 30 minutes. Different electrode spacing of 1cm up to 3cm at an interval of 1cm was discussed. Removal efficiency for operating parameters was discussed and presented.

3.1 Initial Characteristics of Automobile service station Wastewater

SL NO	PARAMETERS	OBTAINED VALUE	INLAND DISCHARGE STANDANDARDS
1	pH	8.9	5.5-9
2	TURBIDITY (NTU)	470	10
3	CONDUCTIVITY (us/cm)	821	--
4	TDS (mg/l)	2104	1500
5	COD (mg/l)	3200	250
6	BOD (mg/l)	60	50
7	HARDNESS (mg/l)	504	300
8	CHLORIDE (mg/l)	60	100
9	TSS (mg/l)	850	100
10	OIL AND GREASE (mg/l)	20	10
11	PHOSPHATE (mg/l)	27.5	---
12	SULPHATE (mg/l)	5.2	10
13	NITRATE (mg/l)	5.71	10
14	TOTAL SOLIDS (PPM)	856.4	100

Table 1: Characteristics of service station wastewater

(Source: CPCB standards)

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In the present study wastewater collected from automobile service stations was analyzed as per standard methods and presented in Table 1.
All the parameters were determined in laboratory scale, As per the characterization, the pH Range from more basic. The COD, TDS, Turbidity, Oil and Grease, Hardness of the wastewater is higher. Resulting in discharge of more organic pollutants. The major consequences are it affects the aquatic eco system.

3.2. Effect of Potential and Electrolysis Time
The result and percentage removal efficiency for varying voltage of 10V, 20V and 30V, electrolysis time of 30, 60 up to 180 minutes electrode spacing of 3cm aluminum and stainless steel electrode

pH variation for different cell voltage and electrode spacing

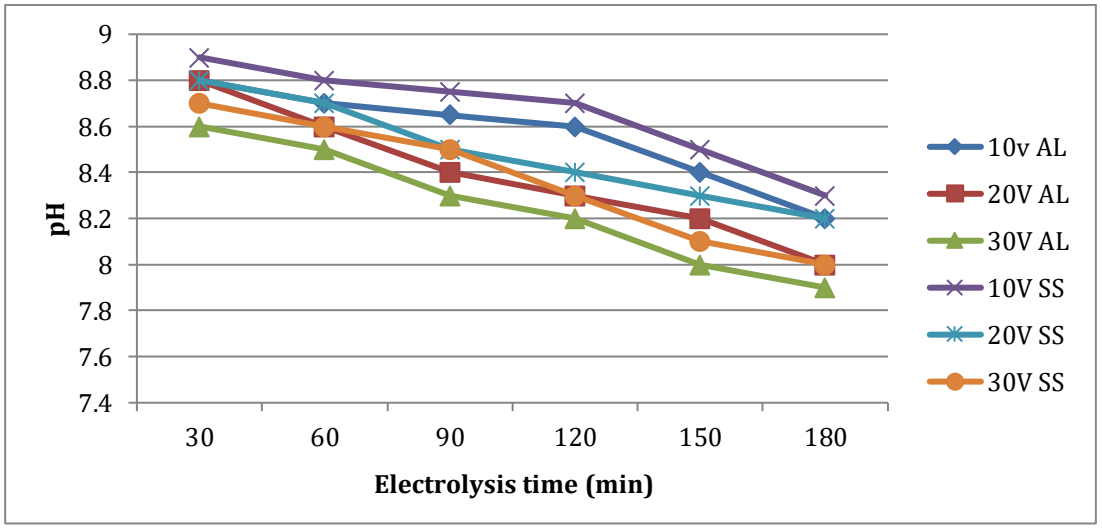

Fig 2 pH variation in different cell voltage, electrode spacing of 1cm with 2A @ 250 rpm

Fig 2 Represents the changes in pH over the time during electrolysis using two types of electrodes are Al and SS with three voltage levels each: 10V, 20V and 30V. For all electrode types and voltage levels, the pH consistently basic towards neutral as electrolysis time increases from the 30 to 180 minutes. This accelerated decrease is attributed to intensified electrochemical activity at higher voltages, which speeds up the dissolution of the Al anode. As a result, more acidic by-products such as hydrogen ions and compounds like aluminum hydroxide are released into the solution, causing a greater reduction in pH. In stainless steel electrodes, pH change over time is also evident, though the rate of decline is more gradual compared to Al. This slower rate of acidification is due to the lower reactivity of stainless steel, which undergoes less corrosion during electrolysis. As a result, fewer hydrogen ions and acidic by-products are introduced into the solution, leading to a more stable pH profile over time.

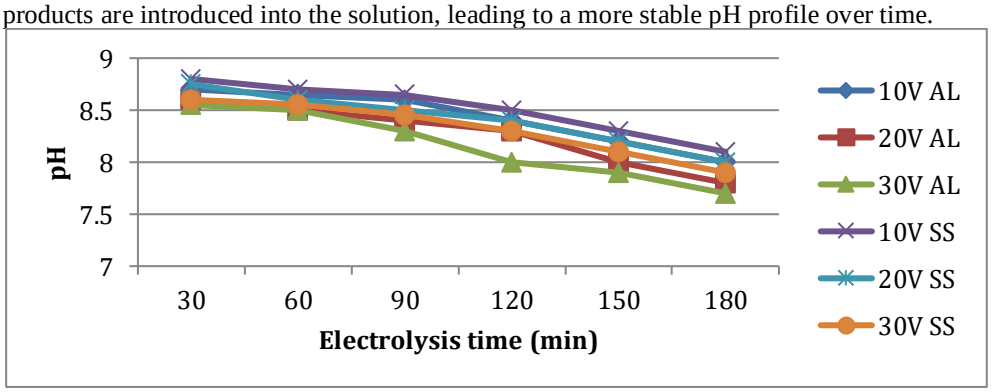

Fig 3 pH variation in different cell voltage, electrode spacing of 2cm with 2A @ 250 rpm

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Fig 3 shows the variation of pH for aluminum electrodes becomes more as the applied voltage increased. This intensified decrease at higher voltages is due to the fastest electrochemical reactions that happened in the Al electrode. With increased the voltage, Al dissolves at an accelerated rate, releasing more Al and hydrogen ions into the solution. These ions contribute to the faster acidification; resulting pH is neutrality in 180 minutes. In stainless steel electrodes, the pH also declines over time and with increased voltage, but the change occurs more gradually and steadily compared to Al. Stainless steel is less reactive than Al electrode.

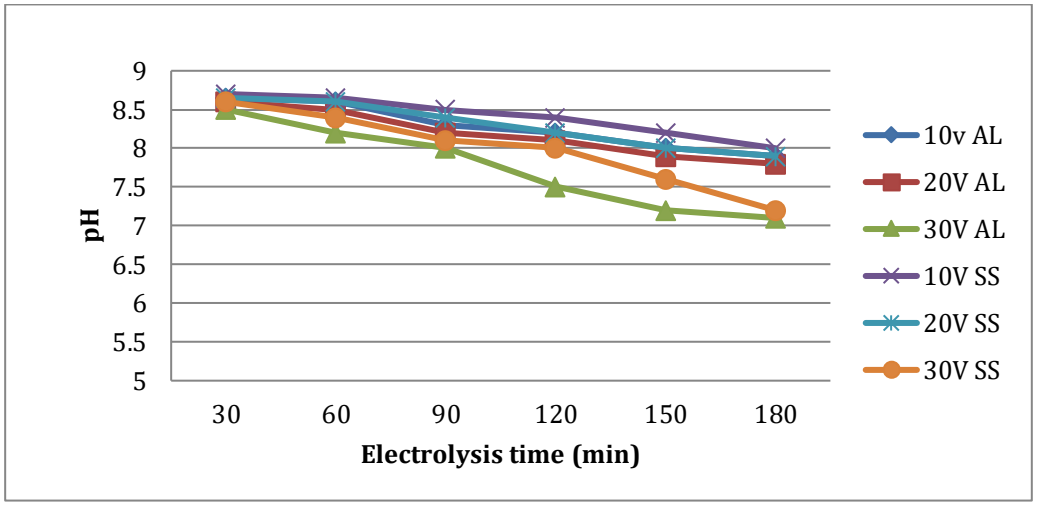

Fig 4 pH variation in different cell voltage, electrode spacing of 3cm with 3A @ 250 rpm

Fig 4 shows the pH at aluminum electrodes, the pH basic to neutral more as the voltage is increased. The steepest reduction is observed at 30V**,** where the pH basic to neutral from approximately 8.6 to 7.9**.** This greater neutral at higher voltages is due to more aluminum dissolution and intensified electrochemical reactions, which release a higher concentration of aluminum and hydrogen ions into the solution. These ions accelerate the acidification process, causing the pH to neutral more rapidly. In stainless steel electrodes show a similar alkalinity in pH over time, but the decline is more gradual and less pronounced than with aluminum. The slower reduction in pH with stainless steel is attributed to its lower chemical reactivity compared to aluminum. Because stainless steel corrodes at a slower rate during electrolysis, fewer metal ions and acidic compounds are released into the solution, which leads to a slower acidification process.

Turbidity variation for different cell voltage and electrode spacing.

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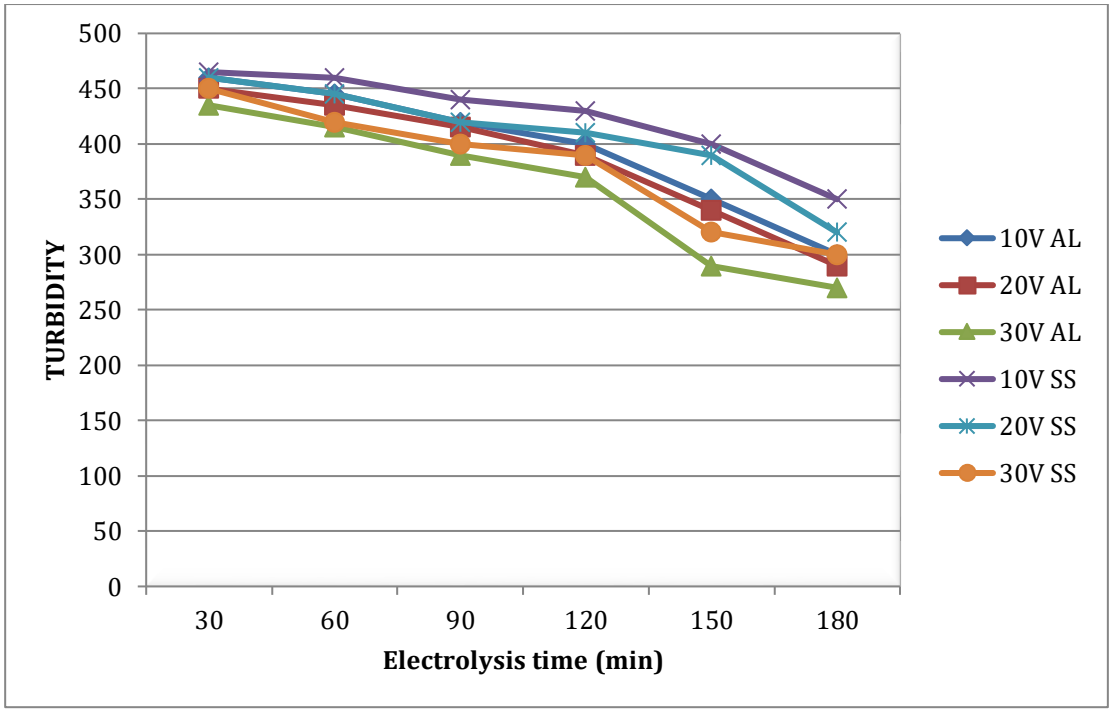

Fig 5 Turbidity variation in different cell voltage, electrode spacing of 1cm with 2A @ 250 rpm

Fig 5 shows the aluminum electrodes; turbidity decreases more quickly with increase in voltage. The accelerated reduction at higher voltages is due to electrochemical reactions that promote the formation of Al hydroxide flocs. These flocs efficiently capture and bind suspended particles, causing them to settle at the solution and thereby lowering turbidity.
In stainless steel electrodes, a similar reduction trend in turbidity the slower turbidity reduction is due to the lower reactivity of stainless steel, which leads to a decrease the rate of metal hydroxide flocs formation.

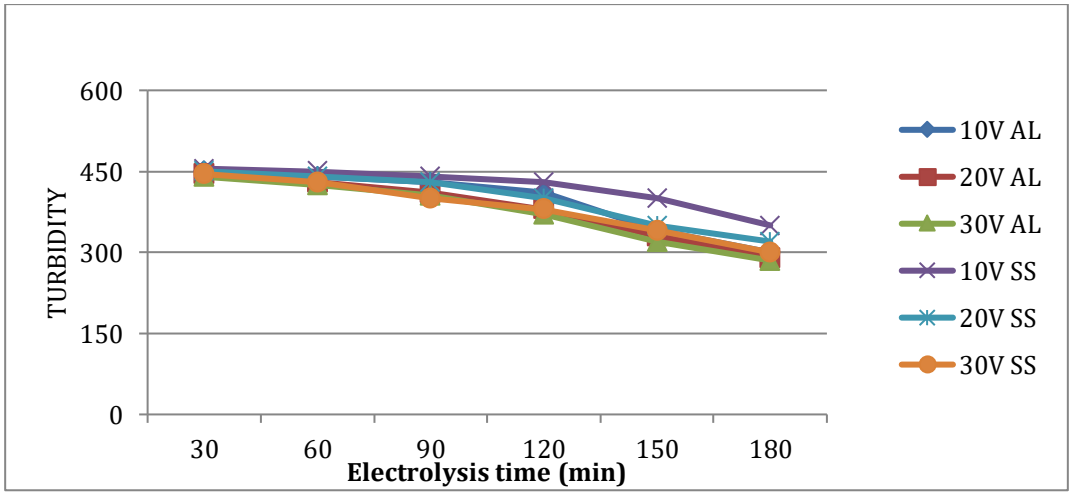

Fig 6 Turbidity variation in different cell voltage, electrode spacing of 2cm with 3A @ 250 rpm

Fig 6 shows the aluminum electrodes; Turbidity consistently reduces with electrolysis duration and higher voltage. This trend says that applying higher voltage enhances the electro coagulation process by generating a greater amount of aluminum hydroxide flocs, which help to capture and remove the suspended particles from the solution more efficiently.
In stainless steel electrodes, the reduction in turbidity is generally less effective compared to Al electrode. At 30V, stainless steel shows a more improvement, with turbidity levels nearing those achieved by 30V Al by the end of the process. This indicates that while stainless steel can perform well, it needs a higher voltage to match the turbidity removal efficiency with Al electrodes.

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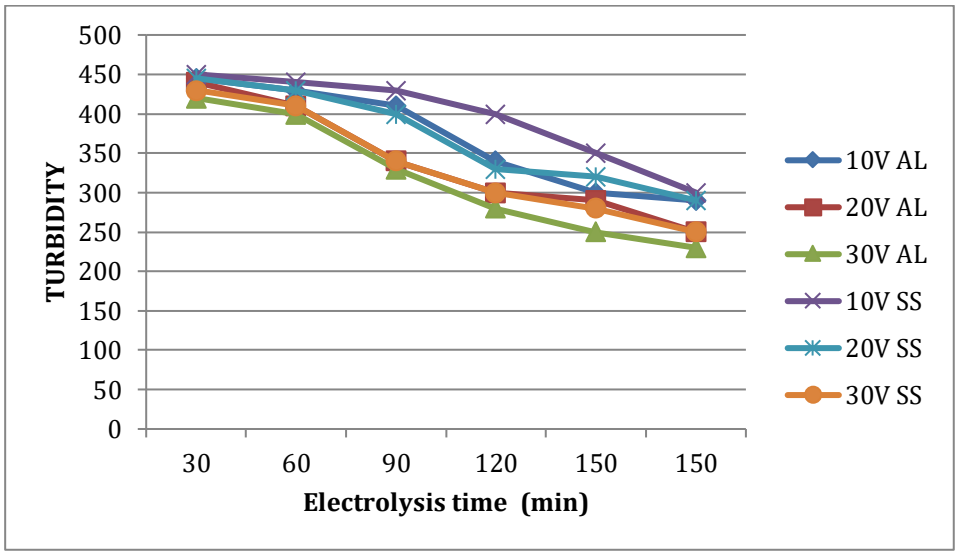

Fig 7 Turbidity variation in different cell voltage, electrode spacing of 3cm with 3A @ 250 rpm

Fig 7 shows the aluminum electrodes there is a clear and steady reduction in turbidity as both time and voltage increase. This pattern suggests that increasing the voltage boosts the production of aluminum-based coagulant compounds, such as aluminum hydroxide, which play a key role in capturing suspended particles and improving clarity. In stainless steel electrodes, turbidity also decreases over time, but the overall efficiency is lower compared to aluminum. These results suggest that stainless steel can aid in turbidity reduction, but higher voltage levels are necessary for it to perform as effectively as aluminum.

TDS variation in different cell voltage and electrode spacing

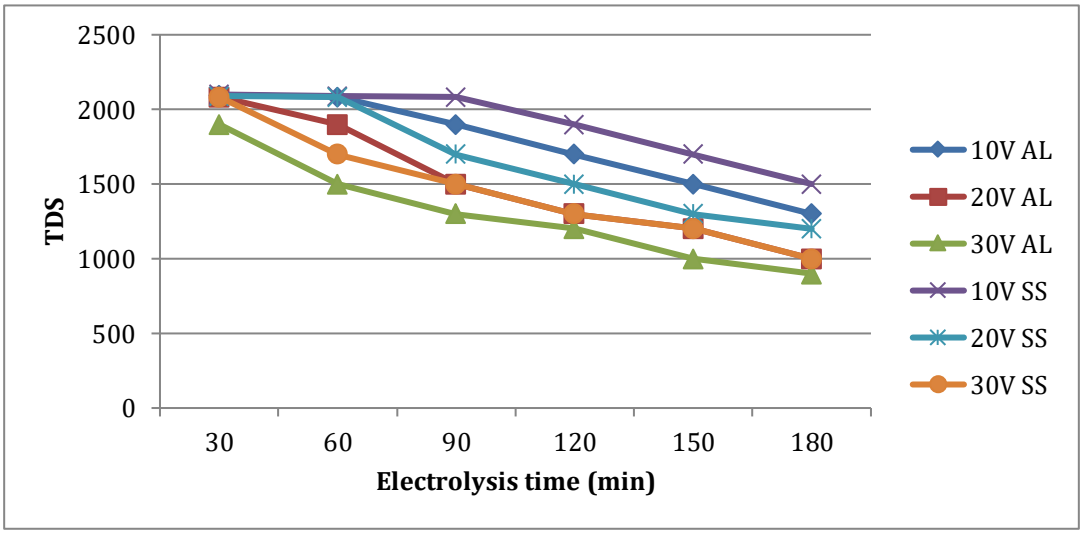

Fig 8 TDS variation in different cell voltage, electrode spacing of 1cm with 2A @ 250 rpm

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Fig 8 shows the aluminum electrodes, decrease in TDS is observed were increase in voltage. This suggests that applying higher voltage enhances the efficiency of the electrochemical process by increasing the production of hydroxide ions. These ions play a critical role in reacting with dissolved substances.In stainless steel electrodes, the reduction in TDS follows a similar trend to Al but is generally less removal efficiency compared to Al. This indicates that while stainless steel is capable of reducing TDS, it requires higher voltage to reach comparable effectiveness.

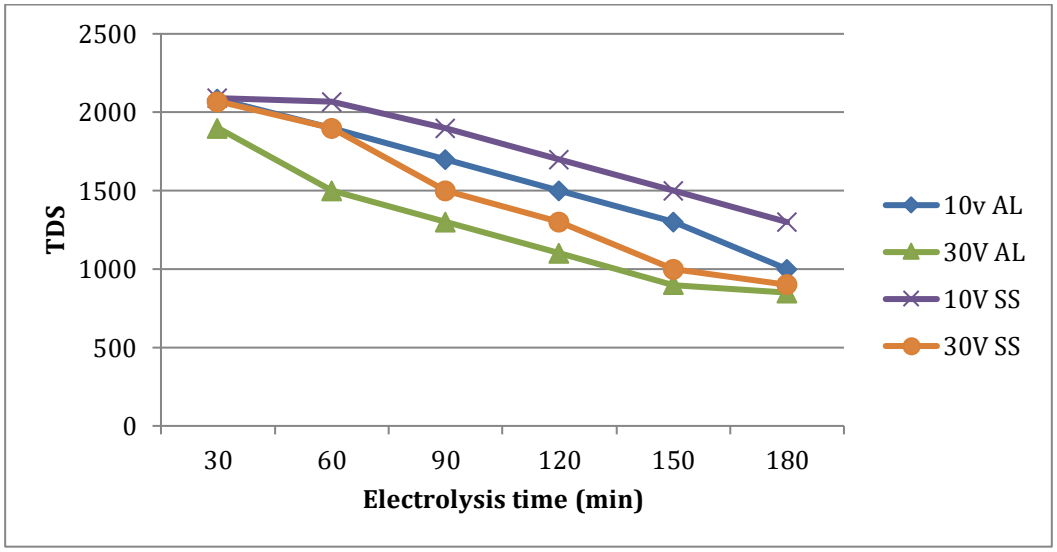

Fig 9 TDS variation in different cell voltage, electrode spacing of 2cm with 3A @ 250 rpm

Fig 9 shows reduction in TDS becomes more efficient as voltage increases in Al electrodes. This enhanced removal at higher voltages is attributed to the increase in the production of aluminum hydroxide and other coagulant species, which bind with dissolved ions to create insoluble compounds that settle out of the wastewater, effectively lowering the TDS levels. In stainless steel electrodes, a similar pattern of decreasing TDS, though their removal efficiency is less compared to Al electrode. This indicates that higher voltages enhance the electrochemical reactions on stainless steel electrodes, increasing release of ions and accelerating the processes that transform dissolved solids into precipitates for removal.

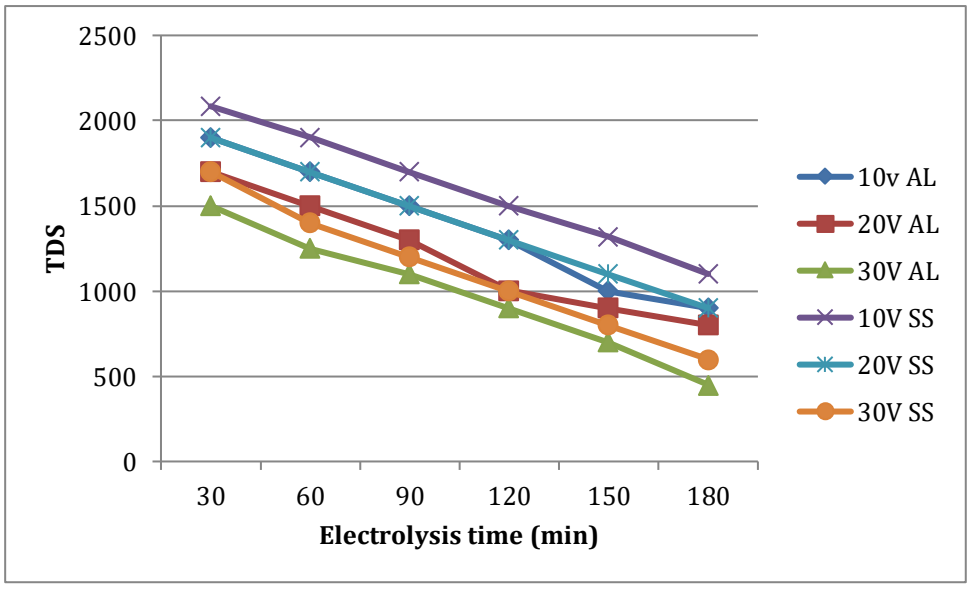

Fig 10 TDS variation in different cell voltage, electrode spacing of 3cm with 4A @ 250 rpm

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Fig 10 shows that aluminum electrodes, the reduction in TDS becomes more significant as the voltage increases. This improvement at higher voltages is due to the increased production of aluminum hydroxide coagulants, which bind with dissolved contaminants to form insoluble substances that either settle or can be removed more effectively. In stainless steel electrodes, a similar downward trend in TDS, although the decrease is generally less significant compared to aluminum. These findings suggest that stainless steel electrodes can also aid in removing dissolved solids, but they require higher voltage levels to achieve removal efficiency comparable to aluminum. The improved performance at elevated voltages is attributed to enhanced redox reactions and increased release of ions, which help convert dissolved materials into solid precipitates.

COD variation for different cell voltage and electrode spacing.

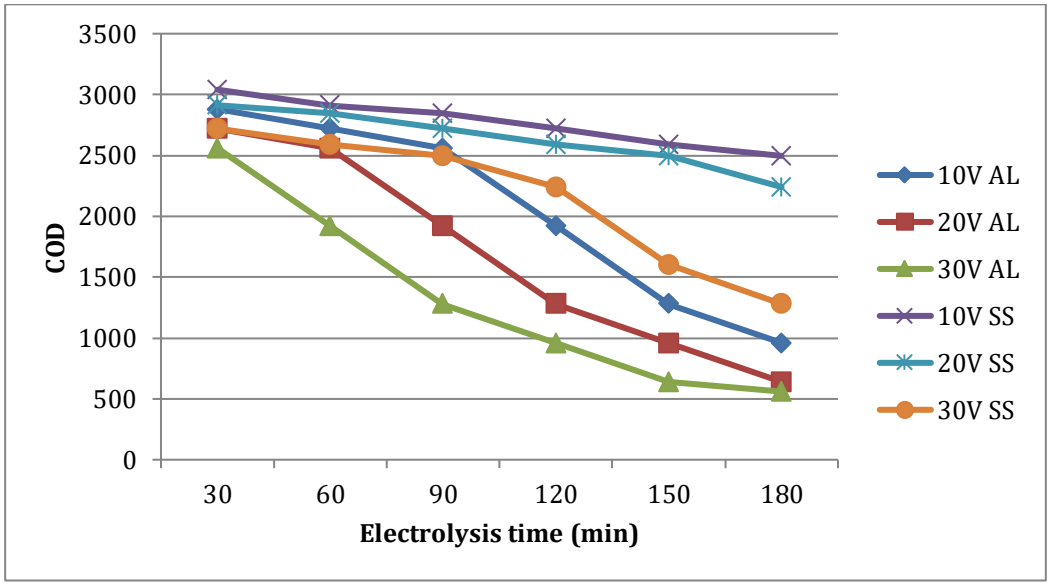

Fig 11 COD variation in different cell voltage, electrode spacing of 1cm with 2A @ 250 rpm

Fig 11 shows the aluminum electrodes, a significant decrease in the COD becoming more as the voltage increases. This improved efficiency at higher voltages is due to the enhanced production of aluminum hydroxide and other reactive compounds generated during electrolysis, which facilitate the breakdown of complex organic pollutants into smaller organic pollutants. In stainless steel electrodes, the COD reduction trend is evident but generally less removal efficiency compared to Al electrode, especially at lower voltages. While stainless steel electrodes are not as efficient as Al electrode, the improvement at higher voltages is linked to enhanced redox activity and the increased formation of reactive oxygen species, which help break down organic contaminants during electrolysis.

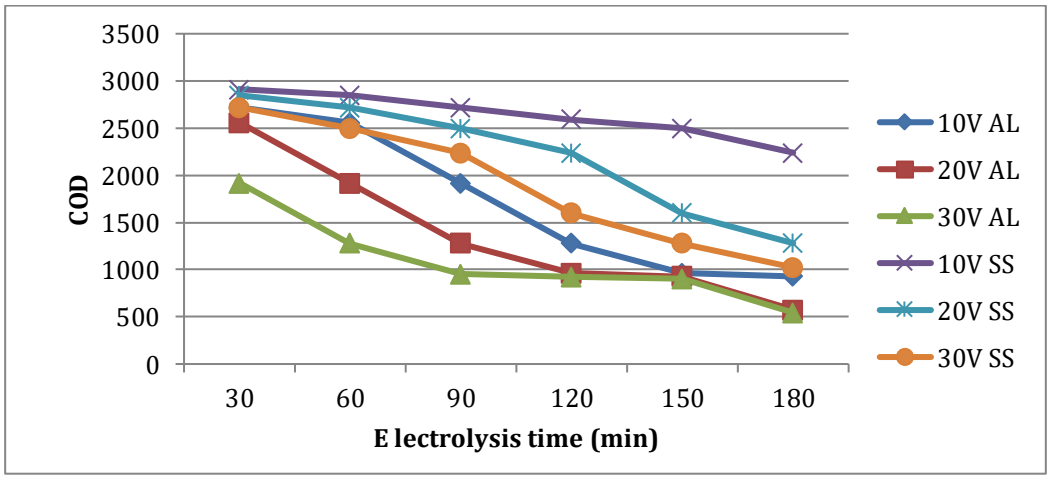

Fig 12 COD variation in different cell voltage, electrode spacing of 2cm with 3A @ 250 rpm

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Fig 12 shows the aluminum electrodes, the COD levels decreased throughout the process, with more reductions observed at higher voltages. This enhanced efficiency at elevated voltages is due to the increased production of aluminum hydroxide flocs and reactive compounds that help to break down complex organic pollutants to simple organic pollutants. In stainless steel electrodes, COD reduction is evident but not as effective as with Al electrodes. This improvement at higher voltages is primarily due to enhanced electrochemical activity at the stainless-steel electrode surface, leading to the formation of reactive oxygen species and intermediate compounds that assist in the breakdown of organic matter. However, the overall removal efficiency remains lower than that of aluminum electrodes due to slower pollutant degradation mechanisms.

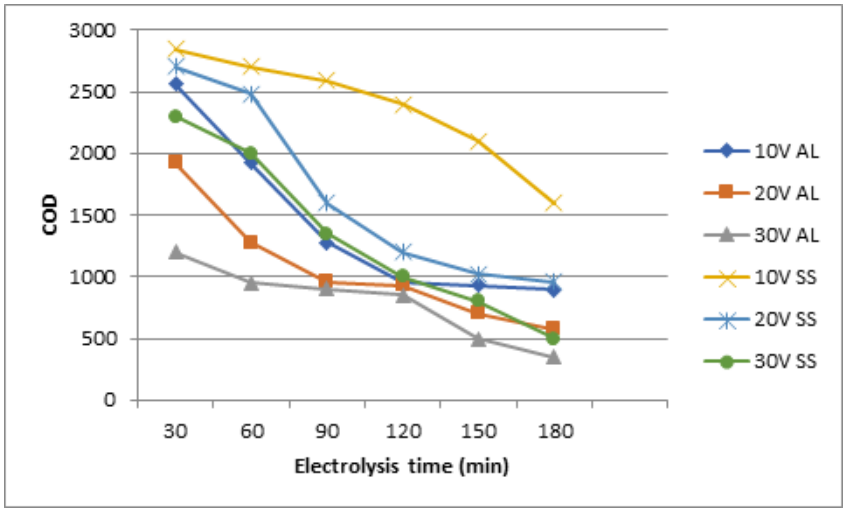

Fig 13 COD variation in different cell voltage, electrode spacing of 3cm with 4A @ 250 rpm

Fig 13 shows the effectiveness of COD removal using aluminum electrodes improves as the voltage increases. This enhanced performance at elevated voltages is primarily due to the increased generation of aluminum hydroxide flocs and other reactive species during electrolysis. These substances assist in destabilizing, adsorbing, and oxidizing organic pollutants, thereby improving the breakdown and removal of contaminants from the solution.
In Stainless steel electrodes also show a decline in COD levels over the treatment period, though their performance is generally less effective compared to aluminum. This enhanced removal at elevated voltages can be attributed to intensified electrochemical reactions, which produce a greater amount of oxidizing agents like hydroxyl radicals and reactive oxygen species.

3.3 Sludge analysis Scanning Electron Microscopy (SEM) :

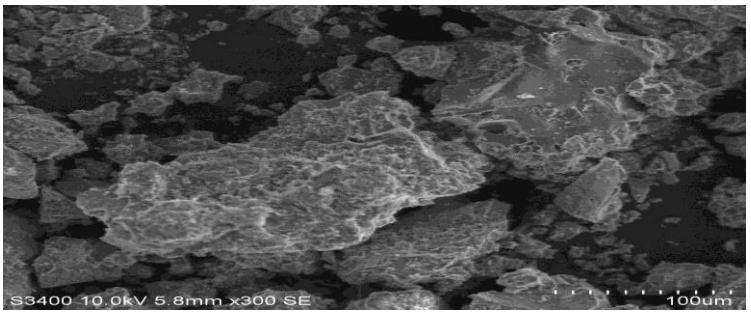

Fig 14: SEM image of ECC sludge of 30V-3cm for Al electrodes

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Fig 14 Represents the SEM image of TWW for Al electrode. The magnification of x300 resolution at the scale length of 10um – 100um and acceleration voltage of 10kV. The magnification of SEM image shows the specific area and structure. The aggregates observed showed a different geometrical appearance, spherical and prismatic (Drouiche et al., 2018) and the smaller particles are attached to larger one.

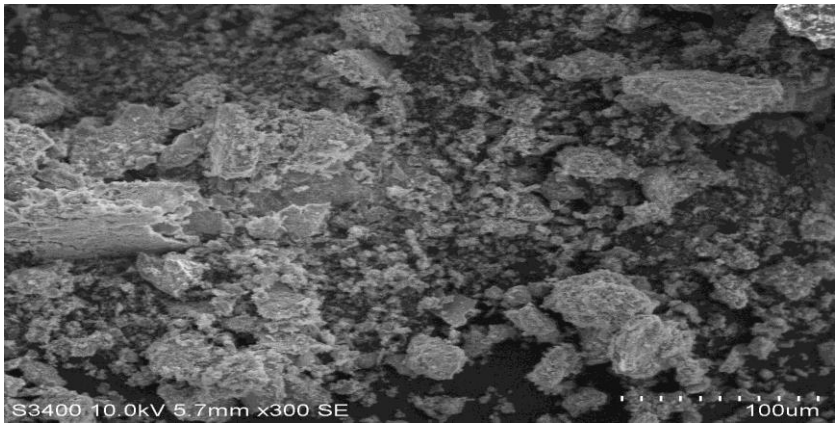
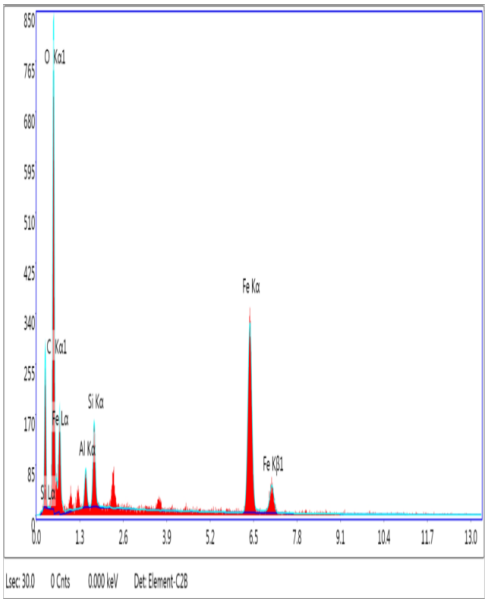


Fig 15: SEM image of ECC sludge of 30V – 3cm for SS electrodes

Fig 15 Represents the SEM image of TWW for SS electrode. The magnification was of x300 resolution at the scale length of 100um and acceleration voltage of 10Kv. The magnification of SEM image shows the specific area of distribution of the sludge and surface structure of the sludge. It can be observed that here the aggregates exhibit similar structure and they are binded together and appear to be crystallinity

Electron Dispersive X-ray Spectroscopy (EDS) :



Element Line	Weight %	Weight % Error	Atom %
C K	4.74	± 1.66	6.52
O K	14.22	± 1.61	17.02
Mg K	2.49	± 0.54	1.70
Al K	70.01	± 0.58	70.05
Si K	6.02	± 0.84	3.54
Si L	---	---	---
S K	1.20	± 0.27	0.62
S L	---	---	---
Ca K	1.32	± 0.33	0.55
Ca L	---	---	---
Total	100.00		100.00

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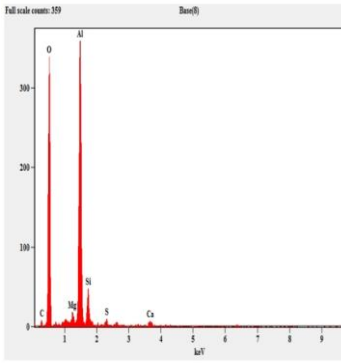

Element Line	Weight %	Weight % Error	Atom %
C K	5.09	± 0.83	8.97
O K	52.10	± 0.98	68.90
Mg K	1.56	± 0.26	1.36
Al K	3.09	± 0.22	4.10
Si K	5.10	± 0.27	3.84
Si L	---	---	---
Ca K	0.96	± 0.21	0.51
Ca L	---	---	---
Cr K	5.05	± 0.77	2.06
Cr L	---	---	---
Mn K	2.68	± 0.64	1.02
Mn L	---	---	---
Fe K	24.37	± 1.74	9.24
Fe L	---	---	---
Total	100.00		100.00

Fig 17: EDS image of ECC sludge of 30V-3cm of TWW for SS electrodes.

Fig 17 Represent the elemental composition in terms of weight and atomic weight present in the ECC sludge of TWW. Elements such as C (5.09 Wt. %), O (52.01 Wt. %), Mg (1.56 Wt. %), Al (3.09 Wt. %), Si (5.10 Wt.%), Ca (0.96 Wt. %), Cr (5.05 Wt. %), Mn (2.68 Wt. %) and Fe (24.37 Wt. %). It can be noted that elements such as O, C and Fe are present in a large amount in the sludge. The elemental analysis of the sludge sample indicates a diverse composition with oxygen (O) as the dominant element, constituting about 52.10% by weight and nearly 69% by atomic percentage. This suggests a significant presence of oxides or oxygen-rich compounds within the material. Iron (Fe) is the next major component, making up approximately 24.37% by weight and 9.24% atomically, highlighting its crucial role in the sample's structure or function.

X-ray Diffraction Analysis (XRD) :

This study utilized X-ray diffraction (XRD) analysis to investigate the crystallographic structure, chemical composition, and physical properties of the sludge sample produced from WW treatment at 30V cell voltage and 3cm electrode spacing.

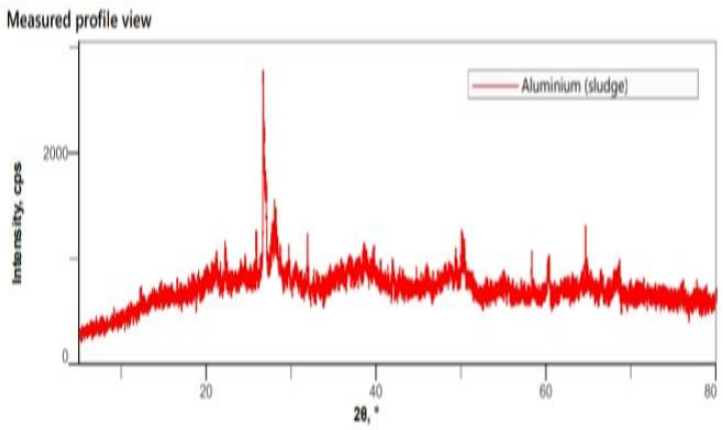

Fig 18: XRD analysis of ECC sludge of TWW for Al electrodes.

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The X-ray diffraction (XRD) pattern of the aluminum sludge sample reveals key information about its crystalline structure and phase composition. The graph plots intensity (in counts per second, cps) against the diffraction angle 2θ, covering a range from approximately 5° to 80°.
The most prominent feature in the pattern is the intense peak observed near 20°, indicating a highly crystalline phase corresponding to aluminum or its compounds in the sludge. This peak suggests a strong and well-ordered atomic arrangement typical of crystalline aluminum hydroxides or oxides, which are commonly formed during electro coagulation sludge generation.

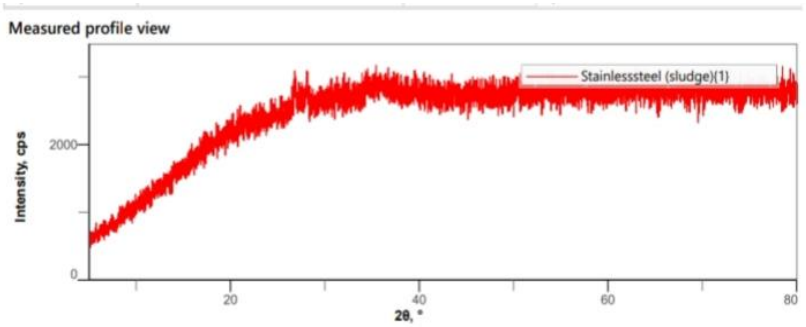

Fig 19: XRD analysis of ECC sludge of TWW for SS electrodes

Fig 19 shows The X-ray diffraction (XRD) pattern of the stainless steel sludge reveals important information about its structural and phase characteristics. The graph plots the intensity of diffracted X-rays (in counts per second, cps) against the diffraction angle 2θ, spanning from about 5° to 80°.

4. ONCLUSIONS

Based on the experimental results obtained from batch studies fallowing conclusions have been drawn.

- The increase in voltage and electrolysis time increases the removal efficiency.
- The wastewater quality parameters such as total solids, turbidity, TDS, suspended solids, hardness, COD, BOD and conductivity exceed the allowable discharge limits for inland water bodies as per CPCB.
- pH remains within acceptable standards, the high levels of these indicate that the service station wastewater is significantly contaminated and requires treatment prior to disposal.
- When WW was treated with Al electrodes, 91% of the maximum COD removal, 85% of the TDS removal, 75% of the Turbidity removal were achieved, whereas during treatment using SS electrodes, 80% of the COD removal, 70% of the TDS removal, and 71% of the Turbidity removal were achieved.
- EDS shows the elemental composition and detected the high levels of carbon, oxygen, aluminum, iron, and silica.
- SEM showed diverse mineral shapes, including irregular, elongated, and spherical forms, with some exhibiting agglomerate properties.
- XRD indicated a predominantly crystalline structure, featuring prismatic minerals. The sludge has potential uses in soil fertilization, providing micronutrients, and energy generation, such as biogas production. Additionally, its silica content makes it suitable for construction material applications.

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