ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VIII, August 2025

Evaluating Electrocoagulation Techniques for Landfill Leachate Treatment in Urban Storm Water Systems

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DOI: https://doi.org/10.51583/IJLTEMAS.2025.1408000138

Abstract: This work examines the efficiency of electrocoagulation (EC) as an eco-friendly and energy-efficient method for treating landfill leachate in the context of urban storm water management. EC was employed using three electrode configurations punched aluminium-steel, plain aluminium-steel, and plain aluminium - aluminium to evaluate their performance in removing key pollutants such as COD, BOD_5, and TSS. The tests were conducted on leachate samples from a landfill in Bangalore, India, by means of a lab-scale electrochemical reactor under constant voltage and varying electrode arrangements. Findings revealed that the punched aluminium - steel combination attained the highest pollutant removal efficiencies (up to 93.3% BOD, 91.8% COD, and 82.9% TSS) while consuming the least energy. The outcomes highlight that optimizing electrode design and spacing significantly enhances EC performance. The study supports integrating electrocoagulation into sustainable urban drainage strategies, emphasizing its role in mitigating leachate contamination and improving water quality in developing cities.

Keywords: Electrocoagulation, landfill leachate, storm water management, BOD, COD, TSS, wastewater treatment, punched electrodes, urban planning, environmental engineering.

I. Introduction

Urban areas are increasingly facing critical challenges in managing wastewater due to rapid industrialization, population growth, and inadequate infrastructure [1]. Conventional wastewater treatment methods, often reliant on chemical processes, are not only expensive but also raise environmental concerns due to secondary pollution and chemical residues [2]. Urban wastewater frequently contains a complex mix of contaminants including heavy metals, suspended solids, and organic pollutants, which are difficult to treat effectively using traditional methods [3]. Moreover, as cities expand, the demand for clean water grows, putting additional pressure on already strained treatment systems [4]. In this context, innovative solutions such as electrocoagulation have emerged as promising alternatives that offer environmentally sustainable treatment by reducing chemical usage and improving removal efficiencies of key pollutants [5].

Electrocoagulation or is a physicochemical method utilized to purify wastewater [6]. The idea behind this procedure is that when wastewater is fed through an electrocoagulation cell, which is an assembly of conducting electrodes immersed in a chemical solution and used to generate chemical reactions with an electrical current, numerous reactions occur concurrently [1]. At first, a metal ion is introduced into the wastewater [2]. Freshwater is hydrolysed on the cathode's surface, yielding hydrogen gas and hydroxyl groups [3].

In the meantime, protons move freely, destabilizing surface charges on impurities [5]. As the reaction progresses, a huge floating form, trapping suspended particles, heavy metals, and other chemical contaminants [7]. As air entrainment continues, the development of flocs expands, and they can be removed by splitting them [8]. The productivity of the method is examined by varying several factors, including the choice of electrode materials based on their redox potentials, the quantities of catalysts used, the pH level of the wastewater, the sources of electrical supply, and the reaction time [6].

Electrocoagulation in urban planning filed the design of cities faces several issues, especially in terms of managing water resources sustainably [1]. As cities grow, so does the demand for clean water and effective treatment of wastewater [2]. Conventional approaches frequently use chemical modifications and can be expensive and detrimental to the environment [8]. Electrocoagulation (EC) emerges as a viable alternative, providing an innovative and environmentally beneficial method of purifying water [1].

Electrocoagulation is a procedure that utilizes electricity to remove substances from the water [3] [9]. It involves running an electric current through water, which causes metal electrodes (typically made of metal or iron) to release ions [10] [11]. These ions eliminate the electrons of contaminants, causing them to begin to stick together into bigger pieces that can be simply eliminated through dissolution or filtering [7]. Electrocoagulation, also called EC, is a physicochemical method for treating wastewater that employs electrical energy to filter water and remove contaminants, including pollutants like heavy metals, inorganic and organic chemicals, suspended particles, and microorganisms [12]. The approach is simple yet highly effective, and it provides enormous benefits in tackling city water supply concerns [5].

Electrocoagulation provides an environmentally friendly means to manage urban water resources [13] [14]. It promotes cleaner industrial production, increases water from urban redevelopment, and helps with the safeguarding of natural water bodies [15]. Cities that incorporate EC into their urban planning plans may fulfill the growing need for clean water while minimizing their ecological effects and paving the road for environmentally conscious and sustainable urban expansion [3]. Several industries in urban areas generate toxic sewage [16]. EC may efficiently treat this effluent, eliminating contaminants and assisting industry in

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meeting environmental laws [17]. This also preserves surrounding water bodies and encourages environmentally friendly manufacturing processes [7] [18].

Leachate, the liquid that percolates through landfill waste, poses a significant environmental threat due to its complex and variable composition [2]. It often contains high concentrations of chemical oxygen demand (COD), total suspended solids (TSS), heavy metals, and various organic and inorganic pollutants [4]. If not adequately treated, leachate can infiltrate groundwater and surface water systems, leading to contamination and long-term ecological damage [19]. The treatment of leachate is particularly challenging due to its fluctuating nature, which varies with landfill age, waste composition, and climatic conditions [16]. Traditional treatment methods often fall short in achieving regulatory discharge standards [20]. Recent studies have shown that electrocoagulation, especially when combined with flotation and sedimentation, can effectively reduce leachate pollutants while offering energy efficiency and operational simplicity [13] [15]. Addressing leachate treatment is thus critical for sustainable waste management and the protection of natural water resources [21].

Leachate is a contaminated liquid emanating from the bottom of the solid waste such as landfills and contains soluble organic and inorganic compounds as well as suspended particles [4]. Depending on weather leachate flow can increase (during rainy season) or decrease (during dry/summer season) [20]. The landfill leachate discharge may lead to serious environmental problems [19]. Leachate may percolate through landfill liners and subsoil causing pollution of ground water and surface waters resources [16]. Moreover, can causes eutrophication in the water bodies ends up to [2]. A landfill is designed to protect the environment from harmful contamination by minimizing the migration of contaminants in leachates by providing appropriate liner [1].

This work deals with the efficiency of successive electrocoagulation, or EC, Electro flotation and sediment technique for treating landfill leachate. The electrocoagulation technique used to treat the city of Gachsaran landfill leachate, and coagulant separation accomplished using EF and precipitation procedures in succession. Appropriate variables for the EC process explored, including electrode kind, electrode distance, voltage, procedure duration, and pH influence. Because landfill leachate contains a variety of contaminants, water purification variables including chemical demand for oxygen (COD), total solids in suspension (TSS), grease and oils (O&G), and viscosity employed to assess the efficiency of the process [21].

To assess the efficiency by the process (by comparing allowable parameters as per standard)

II. Materials and Methodology

Sampling Site of study area:

The Landfill is situated at survey no.108, at Mavallipura village, Hesaragatta zone, Bangalore North, Karnataka state. This site has been used as processing site for the municipal solid waste generated from the Bangalore city. Fig.1. shows the leachate locations point in the Mavallipura, leachate accumulated in the surface water pond in the landfill area.



Figure 1 Leachate source point in study area

Parameters Investigated for the Research

Analysis was carried out according to IS 3025 2003 to meet BIS standards

The study is thus a comparison of efficiency of 22Electrocoagulation-flotation in treatment of leachate between plain Aluminium-iron electrodes and punched Aluminium.

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Table 1. Parameters of the experiments

Parameters	Unit of Measurement
BOD	*Mg/l*
TSS	*Mg/l*
COD	*Mg/l*
VOLTAGE	*Volts*
TIME	*Minutes*

Design of the Tank

The electrodes were coupled in a monopolar configuration of two anode electrodes and two cathodes. In the electrocoagulation reactor for the Al-Steel combination, aluminium was used as the anode. The figure below depicts the reactor in detail.

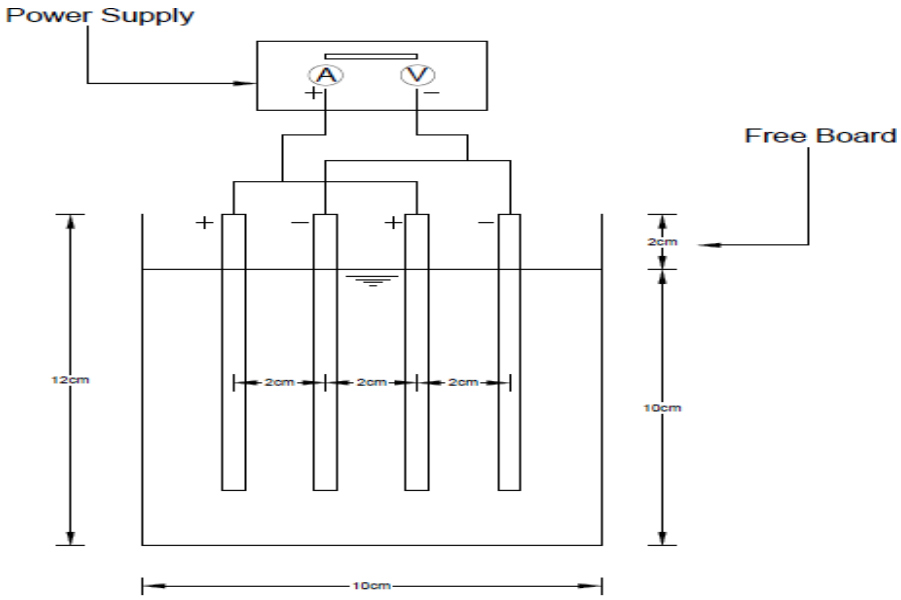


Figure 2. Design Tank of the experiment

Parameter for the design of tank

- Total capacity = 1.2L.
- Working volume = 1L.
- Free board = 2 cm.
- Working depth = 10cm.
- DC power Supply 30-40V.
- Distance between electrodes=2 cm.
- Sampling of leachate will be done in accordance with IS 3025 to meet the BIS standards.
- Fresh sample will be tested for the mentioned parameters and will be recorded.
- Samples will be kept in a fridge at 4 degrees Celsius. then will be transferred into the working tank.
- Specific amount of SDS will be weighed and then added to the working tank to bring about flotations.
- DC power supply will be switched on.
- The experiment will be conducted for 90 minutes.
- Sample will test for the mentioned parameters.

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Experimental Procedure

The leachate from this area collected and stored in a dry and cool environment to use without any pre-treatment. The leachate exhibits a strong odor and is dark brown/ black in color, with average pH of 8.9, and COD concentration of 10400mg/l. In this investigation, 1 L of leachate injected into an electrochemical cell, and electrocoagulation tests carried out for 45 minutes on each run. At 15-minutes intervals, samples were taken from electrocoagulation, and filtered, delivered to containers of BOD, COD, and TSS for the analysis. All samples were examined at a licensed laboratory in Bangalore.

The equation used to compute removal effectiveness (RE %) following EC was

$$RE\ (\%) = [(Co\text{-}C)\ /Co] \times 100$$

Where Co and C are the percentages of the mentioned above variables prior to and following EC, in mg/L.

The energy usage (Ec; kWh/m3) was determined utilizing this formula is as follows:

$$Ec = (V \times I \times T) / Vw$$

Where V is voltage (V), I is current (A), T is operation time, and Vw is sewage volume (m3).



Figure 3. Laboratory experiments

The Research Work Setup

The experimental setting comprised of Regulated DC electrical power source. (Dual), and Electrochemical Reactor. In the electrochemical cell, four cylindrical electrodes were used (dimension: length (h) = 10cm, diameter (d) = 0.5cm) with two anodes and two cathodes. Three different electrodes, combinations were used: Punched Aluminium-Steel, Plain Aluminium-Steel and Plain Aluminium-Plain Aluminium. The voltage (V) was kept constant at a value of 5V. The punched Al electrodes consist of three holes of 3mm diameter. A depth of approximately 8cm was fully immersed in the leachate solution with the electrodes' average surface area calculated as:

Surface Area

For Plain Electrodes Combination

Surface Area= $[(\pi d) \times h + \pi d^2/4] \times 4$

= $[(\pi \times 0.5) \times 8 + (\pi \times 0.5^2)/4] \times 4$

= $12.76\ cm^2 \times 4$

= **$51.04\ cm^2$**

For Punched Electrodes Combination

Surface Area = **(The** Area of all four Plain Electrodes – 2 x Area of the Circle of Punched holes**)** + Additional Surface Area due to punching

= $(51.04 - 2 \times \pi \times 0.3^2) + \{[(\pi d) \times h] \times 3\} \times 2$

= $(51.04 - 0.57) + \{[(\pi \times 0.3) \times 0.5] \times 3\} \times 2$

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= 50.47 +2.83

= **53.30 cm^2**

2.4.3 Current Density

Current Density for each electrode combination was calculated as:

- Punched Al-Steel:

  Current Density = 1.96 / 53.30 = **36.77 Ma/cm^2**

- Plain Al-Steel:

  Current Density = 2.18 / 51.04 = **42.71 Ma/cm^2**

- Plain Al-Plain Al:

  Current Density = 4.6 / 51.04 = **90.13 Ma/cm^2**



Figure 4. Samples of the analysis

III. Results and Dscussion

COD v/s TIME

Voltage = 5V, Time = 45min, Electrode Distance = 2 cm

Table 2. Results of COD v/s Time

Time (min)	**COD (mg/l)**		
	Punched Al-Steel	**Plain Al-Steel**	**Plain Al-Plain Al**
0	10400	10400	10400
15	1800	3050	4020
30	962	1900	3810
45	847	1089	3700
Current (A)	1.96	2.18	4.6
Current Density (Ma/cm2)	**36.77**	**42.51**	**90.13**

The influence of electrode type on COD elimination was examined using a three-combination electrode. The results are presented in the image below.

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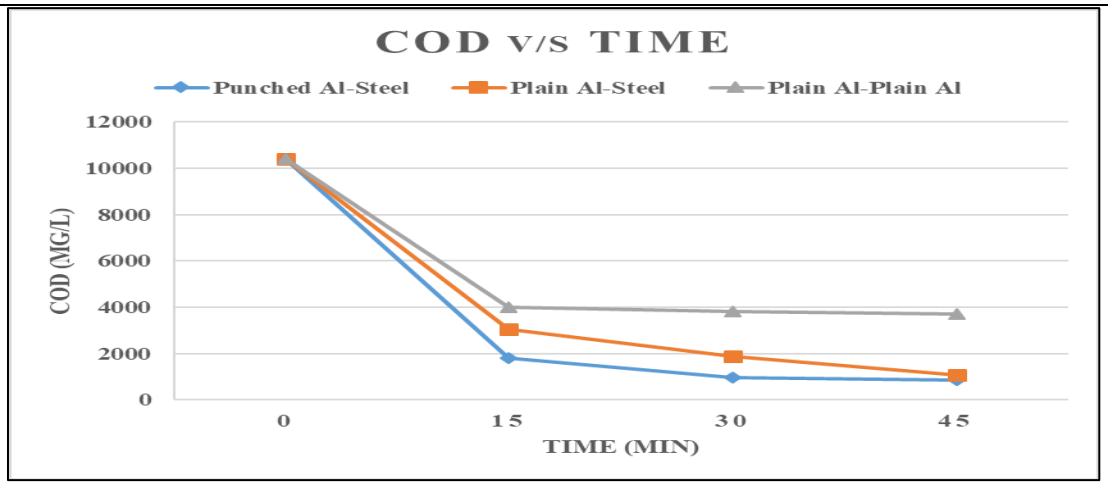


Figure 5. Results of COD v/s Time

From the figure, it can be seen that the COD removal of the Punched Al-steel combination is greater and the Plain Al-steel combination is greater than the Plain Al-plain Al combination. This is because steel is a better conductor than aluminium, and punched Al electrodes provide a greater surface area for the electrocoagulation process. Even though a greater current density is produced by the plain Al-plain Al combination, it does not result in greater removal.

TSS v/s TIME

Voltage = 5V, Time = 45min, Electrode Distance = 2cm

Table 3. Results of TSS v/s Time

Time (min)	**TSS (mg/l)**		
	Punched Al-Steel	**Plain Al-Steel**	**Plain Al-Plain Al**
0	2050	2050	2050
15	520	710	1210
30	320	550	1090
45	350	560	1070
Current (A)	1.96	2.18	4.6
Current Density (Ma/cm2)	36.77	42.51	90.13

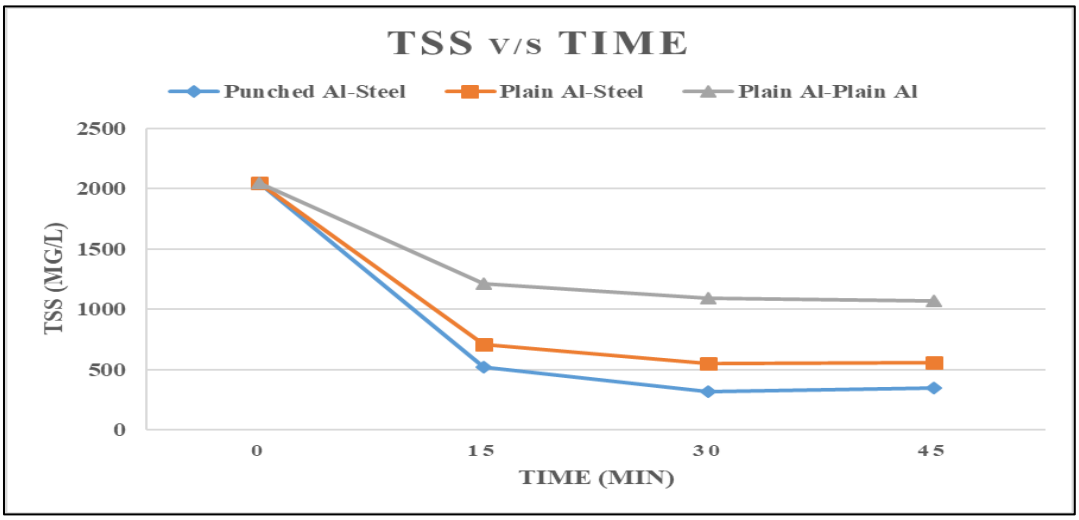


Figure 6. Results of TSS v/s Time

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From the figure, again, it can be seen that the TSS removal of the Punched Al-steel combination is greater and the Plain Al-steel combination is greater than the Plain Al-plain Al combination. This is because steel is a better conductor than aluminium. Punched aluminium electrodes provide a greater surface area for the electrocoagulation process. The plain Al-plain Al combination produces a higher current density but does not result in a higher removal.

BOD5 v/s TIME

Voltage = 5V, Time = 45min, Electrode Distance = 2cm

Table 4. Results of BOD**5** v/s Time

Time (min)	**BOD5 (mg/l)**		
	Punched Al-Steel	**Plain Al-Steel**	**Plain Al-Plain Al**
0	1500	1500	1500
15	700	920	1090
30	370	515	650
45	100	230	470
Current (A)	1.96	2.18	4.6
Current Density (Ma/cm2)	36. 77	42.51	90.13

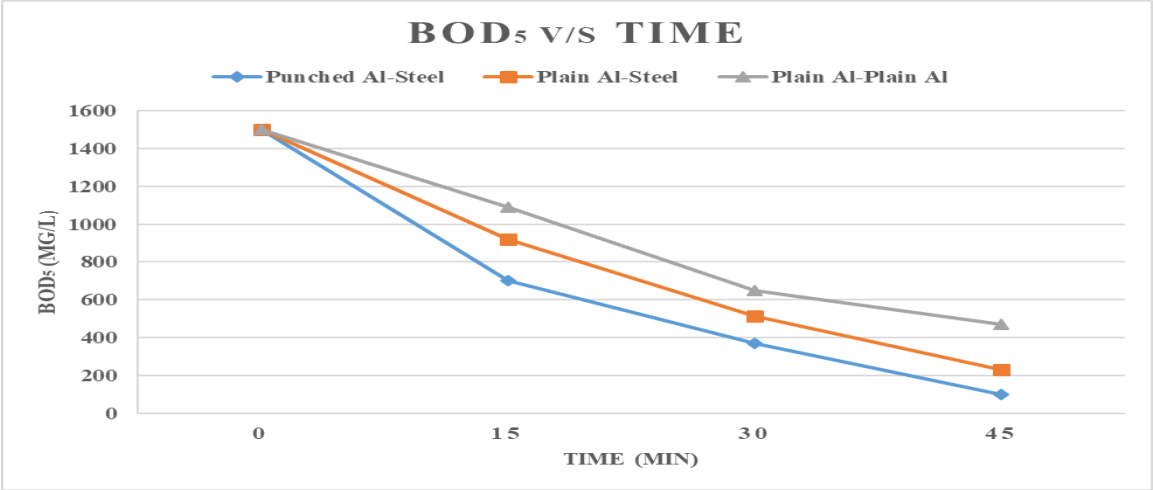


Figure 7. Results of BOD**5** v/s Time

From the figure, again, it can be seen that the BOD**5** removal of Punched Al-Steel combination is greater and Plain Al-Steel combination is greater than Plain Al-Plain Al combination. This is because Steel is a better conductor than Aluminium Punched Al the electrodes supply a greater surface area for the Electrocoagulation process, this Plain Al-Plain Al combine produces a higher density of current, but it fails to end up in increased elimination.

Removal Efficiency (RE)

$$RE\ (\%) = [(Co-C)/Co] \times 100$$

COD:

Punched Al-Steel:

RE (%) = (10400 – 847) / 10400 = **91.85 %**

Plain Al-Steel:

RE (%) = (10400 – 1089) / 10400 = **89.52 %**

Plain Al-Plain Al:

RE (%) = (10400 – 3700) / 10400 = **64.42 %**

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TSS:

Punched Al-Steel:

RE (%) = (2050 – 350) / 2050 = 82.92 %

Plain Al-Steel:

RE (%) = (2050 – 560) / 2050 = 72.68 %

Plain Al-Plain Al:

RE (%) = (2050 – 1070) / 2050 = 47.80 %

BOD:

Punched Al-Steel:

RE (%) = (1500 – 100) / 1500 = 93.33 %

Plain Al-Steel:

RE (%) = (1500 – 230) / 1500 = 84.67 %

Plain Al-Plain Al:

RE (%) = (1500 – 470) / 1500 = 68.67 %

Table 5. Removal Efficiency of the COD, TSS, & BOD**5**

Parameters	**Punched Al-Steel**	**Plain Al-Steel**	**Plain Al-Plain Al**
COD	91.85%	89.52%	64.42%
TSS	82.92%	72.68%	47.80%
BOD5	93.33%	84.67%	68.67%

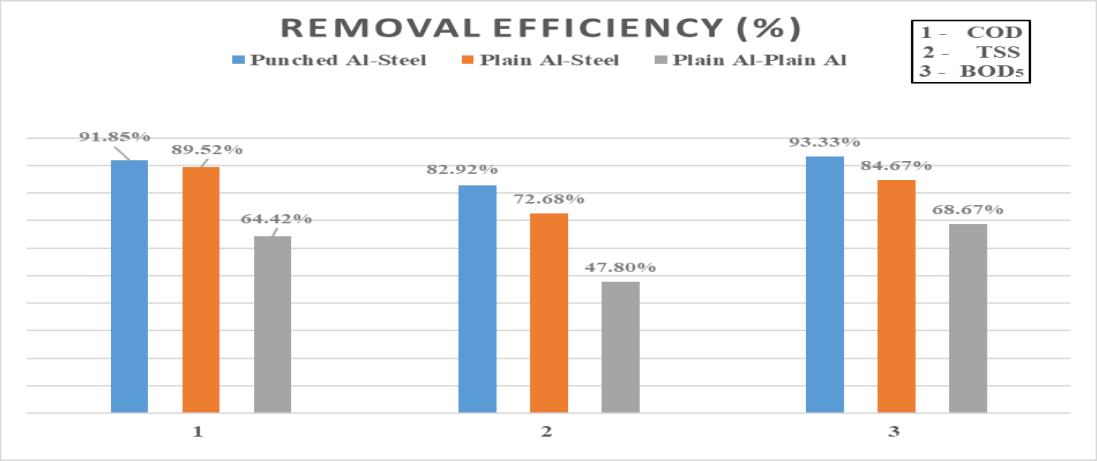


Figure 8. Removal Efficiency of the COD, TSS, & BOD**5**

As The diagram shows, the purification performance of Punched Al-Steel combination is greater for all three parameters (BOD_5, COD, TSS). This is attributed to its greater surface area and superior conductibility of steel, despite drawing a lesser current density.

Energy Consumption (EC)

The equation for calculating energy consumption (Ec kWh/m3) as follows:

$$Ec = (V \times I \times T) / Vw$$

Punched Al-Steel:

Ec = (V × I × T) / Vw = [5 x 1.96 x 45/60] / (1 / 1000) = 7350 kWh/m^3

Plain Al-Steel:

Ec = (V × I × T) / Vw = [5 x 2.18 x 45/60] / (1 / 1000) = 8175 kWh/m^3

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Plain Al-Plain Al:

$Ec = (V \times I \times T) / Vw = [5 \times 1.96 \times 45/60] / (1 / 1000) = 17250\ kWh/m^3$

As it can be seen from the results, the energy consumption increased with increasing current. Which Punched Al-Steel combination consumes less energy than Plain Al-Steel and Plain Al- Plain Al combination.

IV. Conclusion and Future Scope

This study highlights the effectiveness of electrocoagulation-flotation (ECF) using aluminium-steel electrodes, particularly Punched Al-Steel, in treating landfill leachate. The process significantly reduces key pollutants like COD, BOD_5, and TSS, making it a viable solution for leachate management. Punched Al-Steel electrodes demonstrated the highest efficiency with lower energy consumption, positioning them as a sustainable option. The research also emphasizes the need to optimize operational variables such as current density, electrode spacing, and reaction time to balance treatment efficiency and energy use.

The environmental benefits of electrocoagulation are substantial, as it mitigates leachate pollution at the source, reducing its impact on urban drainage systems and natural water bodies. By integrating this technology into urban water management, cities can enhance storm water infrastructure resilience and align with sustainable development goals. The study advocates for policy measures promoting advanced treatment methods like ECF, underscoring its role in sustainable urban planning and pollution control.

Future research should focus on optimizing process parameters, such as voltage, electrode distance, and current density, to improve efficiency. Investigating alternative electrode materials, like punched aluminium paired with chromium, could enhance contaminant removal for specific wastewater types. Additionally, developing modular or multi-stage reactor designs could improve scalability and energy efficiency for diverse wastewater applications. Pilot studies in urban settings would help validate the technology's feasibility in real-world storm water management systems.

Further exploration of the underlying mechanisms floc formation, particle interactions, and electrode reactions could transition the process from empirical optimization to predictive modelling. A comprehensive sustainability assessment, including sludge management and life cycle analysis, is also needed to evaluate environmental impacts. With growing global water treatment demands, advancing electrocoagulation through innovative engineering and interdisciplinary research could solidify its role in sustainable urban water management and global water security.

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