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**Research Article**

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# Optimization of electrocoagulation process using aluminum electrodes for effective treatment of household wastewater: A kinetic and economic analysis of time and electrode distance effects

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**Abstract**

This study aimed to optimize a batch electrocoagulation (EC) process with aluminum electrodes for treating real household wastewater, focusing on the synergistic effects of electrolysis time and inter-electrode distance (IED) on treatment efficacy, kinetics, and economics.

Wastewater was treated with a neutral pH and a constant current density of 0.8 A $dm^{-2}$. Samples were collected during a 90-minute period while the inter-electrode spacing was changed between 0.2 and 0.5 cm. Turbidity, Biological oxygen demand ($BOD_5$), Chemical oxygen demand (COD), and Total dissolved solids (TDS) removal efficiencies were calculated. Operating expenses were computed based on energy and electrode usage using kinetic models.

Compared to 0.5 cm, a lower inter-electrode spacing of 0.2 cm performed far better. Remarkable removals were achieved with optimal performance at 90 minutes and 0.2 cm IED: 98.00% ($BOD_5$), 96.04% (COD), 97.78% (TDS), and 98.80% (turbidity), all of which met discharge standards. Rate constants at 0.2 cm were 1.5–2.3 times higher, confirming pseudo-first-order behavior according to kinetic analysis. Nevertheless, the corresponding energy consumption of 11.52 kWh $m^{-3}$ resulted in an operating cost of 4.37 US dollars $m^{-3}$.

For decentralized wastewater treatment, electrocoagulation is a very efficient method. A crucial, inexpensive design technique that improves kinetics and lowers energy consumption is minimizing inter-electrode spacing. Future research should investigate continuous-flow operation and include renewable energy to increase economic feasibility.

**Keywords:** Electrocoagulation; Wastewater treatment; Optimization; Aluminum electrode; Operating cost; Removal kinetics

## 1 Introduction

Household wastewater treatment is still a major global environmental problem, especially in developing nations where centralized treatment facilities are frequently insufficient or nonexistent [1].This high-strength effluent poses serious threats to aquatic ecosystems, contaminates water resources, and endangers public health when it is directly discharged. It is loaded with organic matter, nutrients, suspended particles, and pathogens [2]. Conventional biological techniques, including activated sludge operations, need a large amount of acreage, expert operation, and a steady supply of energy and can be unsuccessful for highly variable or resistant waste streams [3]. Despite its effectiveness, chemical coagulation produces a significant amount of chemical sludge and poses a danger of secondary pollution due to coagulant residues [4].

Over the past 20 years, electrocoagulation (EC) has become a reliable, portable, and adaptable electrochemical method for treating water and wastewater [5]. When a direct current is applied, sacrificial metal anodes—typically iron or aluminum—dissolve electrochemically, releasing multivalent cations ($Al^{3+}$ or $Fe^{2+}/Fe^{3+}$) into the solution [6]. These cations then hydrolyze to produce a variety of monomeric and polymeric hydroxo-metal species, which lead to the in situ creation of amorphous metal hydroxide flocs (such as $Al(OH)_3(s)$ or $Fe(OH)_3(s)$) [7]. Through processes including charge neutralization, adsorption, and enmeshment (sweep flocculation), the newly generated active flocs function as excellent coagulants, destabilizing and aggregating colloidal particles, emulsified oils, and dissolved organic matter [8]. A buoyant force is simultaneously produced at the cathode by hydrogen gas bubbles, which facilitate the effective flotation and separation of the aggregated flocs [9].

EC's main advantages over traditional techniques are its ease of use, low need for chemical additives (which lowers sludge volume and toxicity), high effectiveness in eliminating a wide range of contaminants, and suitability for automation and decentralized applications [10]. However, operational costs, which are mostly caused by electrical energy consumption and electrode material degradation, frequently limit its widespread implementation [11]. For

58 treatment to be economically and environmentally sustainable, process optimization to enhance
59 treatment efficacy while minimizing resource consumption is crucial [12].

60 A complex interaction of operational and design parameters, such as applied current density,
61 electrolysis time, initial pH, electrolyte composition, and reactor architecture, determines the EC
62 process's performance and cost-effectiveness [13]. Inter-electrode distance (IED) and electrolysis
63 time are two of the most important of these. The total charge transmitted, which regulates the
64 stoichiometric dosage of coagulant metal ions and the kinetics of pollutant-coagulant
65 interactions, is directly determined by the electrolysis time [14]. IED is an important reactor
66 design parameter that has a significant impact on the ohmic resistance of the system. Ohm's rule
67 states that the cell voltage (and consequently energy consumption, $E = I \cdot V \cdot t$) is directly
68 proportional to the IED for a given solution conductivity and electrode area [15]. While a smaller
69 IED may improve mass transfer and current efficiency and lower energy consumption, it also
70 raises the possibility of electrode passivation and short-circuiting, necessitating careful
71 engineering [16].

72 While EC has been thoroughly studied for a variety of industry effluents (textile, tannery,
73 olive mill, etc.) and synthetic wastewaters [17], there are less systematic investigations that
74 concentrate on treating actual, high-strength, non-industrial residential wastewater. Additionally,
75 IEDs between 1 and 3 cm are used in the majority of investigations [18]. For such difficult actual
76 matrices, there is a substantial research need regarding the quantitative evaluation and
77 optimization of ultra-small IEDs (< 0.5 cm), which could lead to significant process
78 intensification and energy savings.

79 By carrying out a thorough, process-oriented analysis of a batch EC system using aluminum
80 electrodes for the treatment of actual, high-strength household wastewater from Shambu,
81 Ethiopia, this study seeks to close this gap. This work is new since it explicitly and methodically
82 compares a minimal IED (0.2 cm) with a more traditional distance (0.5 cm), along with thorough
83 kinetic and economic evaluations for an actual wastewater matrix.

84 The specific objectives are to: (1) evaluate the removal kinetics of key pollutants ($BOD_5$,
85 COD, TDS, turbidity) as a function of electrolysis time; (2) quantify the individual and
86 synergistic effects of IED on treatment efficiency, energy consumption, and operating cost; and

(3) identify the optimal operating conditions that achieve maximum pollutant removal while minimizing resource use, providing practical insights for decentralized system design.

## 2. Materials and Methods

### 2.1. Wastewater Sampling and Characterization

Samples of composite raw residential wastewater were taken from Shambu Town's main drainage system in the Oromia region of Ethiopia. In accordance with established procedures, sampling was done over a 24-hour period to account for diurnal fluctuation [19]. In order to reduce biological deterioration before analysis, samples were promptly brought to the lab in previously cleaned polyethylene containers, homogenized, and stored at 4°C. The Standard Methods for the Examination of Water and Wastewater [19] were followed in the physicochemical characterization of the raw wastewater. Important factors were examined, such as pH, electrical conductivity (EC), chemical oxygen demand (COD), five-day biochemical oxygen demand ($BOD_5$), total dissolved solids (TDS), and turbidity.

The mean characteristics were presented in Table 1, highlighting the high organic and solids strength of the wastewater, which significantly exceeds the permissible discharge limits set by the Ethiopian Environmental Protection Authority [20].

### 2.2. Experimental EC Setup and Procedure

Using a 2 L cylindrical glass beaker as the electrochemical reactor and 1.5 L of wastewater each run, all electrocoagulation experiments were carried out in batch mode. Two rectangular slabs of 99.5% pure aluminum (Al 1050) measuring 8 cm in height by 6 cm in width by 0.6 cm in thickness comprised the electrode assembly. A total effective active surface area of 192 $cm^2$ (1.92 $dm^2$) was obtained by arranging the electrodes in a monopolar-parallel configuration with both sides exposed. Using calibrated non-conductive polypropylene spacers, the inter-electrode distance (IED), a crucial variable in this investigation, was accurately fixed to either 0.2 cm or 0.5 cm.

A digital DC power supply (Model APS-3005S, Array Inc., Taiwan) that could run in either constant current or constant voltage mode was connected to the electrodes.

All studies were conducted with a constant current density of 0.8 A $dm^{-2}$. Before every run, 0.1 M NaOH or 0.1 M HCl solutions were used to bring the wastewater's starting pH down to 7.0

± 0.1. A supporting electrolyte, sodium chloride (NaCl, analytical grade), was added at a concentration of 0.1 g $L^{-1}$ to improve solution conductivity and lower energy consumption [21]. To guarantee uniform distribution of ions, coagulants, and bubbles and to avoid excessive sedimentation on the reactor bottom, the solution was thoroughly stirred using a magnetic stirrer running at a steady speed of 500 rpm [22].

A total of ninety minutes were spent doing the experiments. At predefined intervals of 0 (starting), 5, 30, 60, and 90 minutes, aliquot samples (each around 50 mL) were taken out of the reactor. The samples were immediately analyzed for the target parameters after being filtered through Whatman No. 1 filter paper to remove the produced flocs. To ensure reproducibility, each experimental condition (IED and time combination) was carried out in triplicate, and the mean values was shown.

### 2.3. Analytical Methods and Calculations

In accordance with normal procedures, all analytical determinations were carried out in triplicate [33]. The closed reflux titrimetric method was used to measure COD. The 5-day incubation technique at 20°C was used to measure $BOD_{\circ}$. Following evaporation at 180°C, TDS was measured gravimetrically. A portable turbidimeter (HACH 2100Q) was used to measure turbidity. Calibrated multi-parameter probes were used to measure pH and EC.

The removal efficiency (R, %) for each pollutant at time *t* was calculated using Eq. (1) :

$$R\ (\%) = [(C_o - C_e) / C_o] \times 100 \quad (1)$$

where $C_o$ and $C_e$ are the initial and final concentrations (or values) of the pollutant, respectively.

The operational costs are a critical metric for practical feasibility. The total operating cost (OC, US $ $m^{-3}$ of treated wastewater) was estimated based on the consumption of electrical energy and the sacrificial electrode material, following established methodologies [11], as shown in Eq. (2):

$$OC = a \times C_{energy} + b \times C_{electrode} \quad (2)$$

where $a$ is the unit energy price, assumed as 0.0072 US$ $kWh^{-1}$ based on the electricity tariff in Ethiopia and $b$ is the unit cost of aluminum electrode material, taken as 33.25 US$ $kg^{-1}$ (commercial price for Al 1050 plates).

144 *C*energyis the specific energy consumption (kWh $m^{-3}$), calculated using Eq. (3) [23]:

145 $C_{Energy}$ (Energy consumption) = $\frac{U*I*t_{EC}}{V}$ (3)

146 *C*electrodeis the specific electrode consumption (kg Al/$m^3$), calculated using Faraday's law of
147 electrolysis, as per Eq. (4) [24]:

148 $C_{Electrode}$ (Cost for electrode) = $\frac{I*t_{EC}*M_W}{Z*F*V}$ (4)

149 Where, U - Cell voltage (V) $t_{EC}$ - Electrolysis time (s)

150 I - Current (A) $M_W$ - Molecular mass of aluminum (26.98 g $mol^{-1}$),

151 V- Volume of sample taken ($m^3$) Z - number of electrons transferred (z = 3 for Al)

152 F - Faraday's constant (96,487 C $mol^{-1}$).

153 The kinetics of pollutant removal were analyzed by fitting the experimental data to common
154 kinetic models. The pseudo-first-order (PFO) model, expressed in its integrated form in Eq. (5),
155 was found to provide the best fit for the majority of the data.

156 $\ln(C_0/C_t) = -k_1 t$ (5)

157 Where $k_1$ the PFO rate constant ($min^{-1}$). The model fit was evaluated based on the correlation
158 coefficient ($R^2$).

159 **3. Results and Discussion**

160 3.1. Wastewater Characteristics and Overall Treatment Performance

161 Table 1 provided a summary of the raw home wastewater's physicochemical properties. With
162 mean COD and $BOD_5$ contents of 4800 mg $L^{-1}$ and 2750 mg $L^{-1}$, respectively, the wastewater
163 showed remarkably high pollution strength, indicating a significant organic load mostly of home
164 origin. The $BOD_5$/COD ratio of roughly 0.57 indicates that the wastewater is both biodegradable
165 and probably contains a considerable amount of complex organics. The turbidity (430 NTU) and
166 high TDS (4500 mg $L^{-1}$) highlight how difficult this effluent is. Effective treatment was required
167 before any environmental release because all parameters significantly exceeded Ethiopian
168 discharge limits [20].

169 Additionally, Table 1 shows how well the EC procedure performed under the determined
170 ideal parameters (90 minutes, IED = 0.2 cm). Excellent removal efficiency of over 96% were

attained by the technique for all major contaminants. The ultimate effluent values of turbidity (5 NTU), COD (190 mg $L^{-1}$), and $BOD^2$ (55 mg $L^{-1}$) were all well within the strict national discharge guidelines. The TDS was significantly lowered to 100 mg $L^{-1}$, much below the limit, considering how challenging it is to remove dissolved particles through coagulation. As a result of cathodic processes that produce $OH^-$ ions, the final pH of Al-EC systems typically rises to about 8.1 [25].

### 3.2. Effect of Electrolysis Time and Removal Kinetics

One key factor influencing coagulant dosage and the development of coagulation-flocculation phenomena is electrolysis time. The evolution of removal efficiency for COD, $BOD_5$, TDS, and turbidity over time for both IEDs was shown in Fig. 2. All pollutants showed a similar two-phase kinetic profile: a fast initial removal phase (0–30 min) followed by a slower, asymptotic period (30–90 min) where removal efficiency reached a plateau. This pattern is consistent with documented EC mechanisms [14]. The first fast phase is explained by the large concentration of cationic Al-hydrolyzed species (e.g., $Al(OH)^{2+}$, $Al_2(OH)_2^+$), which instantly neutralizes the charge of negatively charged colloidal particles, causing rapid instability and aggregation [7].

In the slower phase that follows, the primary mechanism shifts to sweep flocculation, where contaminants become entangled in the expanding amorphous $Al(OH)_3$(am) floc network. This process necessitates longer contact durations for optimal agglomeration and growth [26].

To quantitatively compare the removal rates, the experimental data were fitted to the pseudo-first-order (PFO) kinetic model. The calculated rate constants ($k1$) and corresponding correlation coefficients ($R^2$) are summarized in Table 2.

The PFO model's applicability is confirmed by the strong $R^2$ values (>0.93), which imply that the removal rate is proportionate to the concentration of residual pollutants [27]. A key conclusion was shown in Table 2: with the lesser IED of 0.2 cm, the rate constants for all pollutants were consistently and significantly higher. A “Kinetic Enhancement Factor” that ranges from 1.5 for $BOD_5$ to 2.3 for turbidity measures this benefit. This shows that lowering the IED significantly speeds up the treatment process while simultaneously increasing the ultimate removal efficiency.

### 3.3. The Critical Impact of Inter-Electrode Distance (IED) on Process Efficiency and Energy

One design parameter that had a significant impact was the IED. The 0.2 cm IED arrangement performed better than the 0.5 cm setup at every sampling point for every measured parameter, as shown in Tables 1 and 2 and Figure 2. Basic electrochemical concepts are the foundation of this exceptional performance. One of the main elements of the total cell resistance (Rcell) in an electrochemical reactor is the inter-electrode gap [28]. Eq. (6) can be used to approximate Rcell for a basic parallel plate design.

$$Rcell \propto \kappa \cdot Ad \tag{6}$$

where $d$ is the IED, $\kappa$ is the solution conductivity, and $A$ is the electrode area. Reducing $d$ from 0.5 cm to 0.2 cm (a 60% reduction) directly decreases *Rcell*. For a constant applied current (I), the cell voltage (V = I·R_{cell}) is therefore lower, leading to a direct reduction in energy consumption (E ∝ V).

Table 3 quantifies these effects. Operating at 0.2 cm IED reduced the average cell voltage by 24.3%, which translated into a nearly equivalent 23.9% saving in specific energy consumption (from 15.14 to 11.52 kWh $m^{-3}$). Since solely Faraday's law (Eq. 4) for a given charge passed governs electrode consumption, it remained unchanged. The combined effect yielded a 20.8% reduction in total operating cost.

The decreased IED improves process efficiency in addition to conserving energy. At the electrode-solution interface, a smaller Rcell enhances charge transfer efficiency and current distribution [29]. As a result, the anode may dissolve uniformly and possibly more quickly, preserving a high, localized concentration of $Al^{3+}$ ions. Additionally, a greater population of smaller hydrogen bubbles is created at the cathode because of the improved current efficiency [30]. Because of their greater surface-area-to-volume ratio, these finer bubbles are more effective at bubble-floc attachment and flotation, which improves the separation of aggregated pollutants [9, 31]. IED minimization is a potent tactic for EC process intensification because of the combined effect of reduced energy consumption and improved treatment kinetics.

### 3.4. Process Economics, Cost Analysis, and Comparative Assessment

Any water treatment technology's practical acceptance depends critically on its economic viability. Fig. 3 shows the comprehensive cost breakdown under ideal circumstances (90

minutes, IED=0.2 cm). Electrical energy contributed roughly 3.11 US $ $m^{-3}$ (71.2% of the total) and electrode material contributed 1.26 US $ $m^{-3}$ (28.8%) to the overall operating cost of 4.37 US $ $m^{-3}$. This makes it evident that energy consumption is the main factor driving costs, which is a problem that electrochemical water treatment systems frequently face [11, 32].

Table 4 presents a comparison analysis with other EC studies treating municipal or high-strength organic wastewaters in order to put these results in context. Direct cost comparisons are difficult because of the wide variations in wastewater composition, scale, local energy/electrode costs, and treatment goals.

Despite attaining superior removal efficiency, the operating cost in this study is comparable to or lower than costs reported for treating other highly concentrated industrial effluents like landfill leachate [33] and olive mill wastewater [34], even though it is higher than for treating weaker municipal wastewater [35]. The cost is closely connected to the starting pollution load and the intended removal aim, as this research highlights. The great level of efficiency attained here justifies the related expense for adhering to stringent requirements.

The comparison also highlights the urgent need for methods to lower specific energy consumption, like increasing current density, using pulsed or periodic current reversal modes to reduce electrode passivation, enhancing reactor hydraulics in continuous systems, and, most promisingly, incorporating renewable energy sources like solar photovoltaic (PV) systems to power the EC unit [36].

### 3.5. Sludge Production and Management Considerations

Sludge made mostly of metal hydroxides, adsorbed organics, and the EC process unavoidably produces entrapped particles. The aluminum hydroxide sludge used in this investigation was large, light, and readily floatable. The volume of the sludge cake was greatly decreased after skimming and dewatering using a basic filter press. Sludge management must be sustainable.

Although disposing of waste in a landfill is the most straightforward method, there are worries about aluminum and other pollutants leaching over time [37]. Circular economy ideas are consistent with a more sustainable strategy. The stabilized sludge can be used as a coagulant assist in wastewater treatment [38], as an inexpensive adsorbent for pollutants following thermal activation [39].

## Conclusions

With an emphasis on the effects of electrolysis time and inter-electrode distance (IED), this study offers a thorough description of the electrocoagulation process employing aluminum electrodes for the treatment of actual, high-strength home wastewater.

Under ideal conditions (90 min electrolysis, IED of 0.2 cm, current density of 0.8 A $dm^{-2}$ pH 7), the Al-EC process showed remarkable performance, reaching removal efficiencies of 98.00% for $BOD_5$, 96.04% for COD, 97.78% for TDS, and 98.80% for turbidity. Ethiopian discharge regulations were regularly met by the treated wastewater.

The elimination of pollutants proceeded according to pseudo-first-order kinetics. Importantly, the removal rate constants rose by a factor of 1.5 to 2.3 when the IED was reduced from 0.5 cm to 0.2 cm, greatly speeding up the treatment procedure. In comparison to the 0.5 cm gap, the minimized IED (0.2 cm) decreased the system's ohmic resistance, resulting in a 23.9% reduction in specific energy consumption (from 15.14 to 11.52 kWh $m^{-3}$) and a 20.8% reduction in total operating cost (from 5.52 to 4.37 US \$ $m^{-3}$), all while improving treatment outcomes. The main financial obstacle to EC implementation was highlighted by the fact that energy costs accounted for the majority of operational costs (~71%). It emphasizes the need for energy optimization even while the expense is warranted in order to achieve high treatment standards for difficult wastewater.

To advance this technology towards sustainable, decentralized application, future work should prioritize: (i) Integration with renewable energy sources, particularly solar PV, to decouple operational cost from grid electricity tariffs and improve carbon footprint. (ii) Development and testing of a continuous-flow EC reactor based on the optimized parameters (especially the small IED) to assess hydraulic performance and long-term stability. (iii) A detailed techno-economic analysis (TEA) and life cycle assessment (LCA) comparing solar-powered EC with conventional treatment options in off-grid contexts. (iv) Investigation of sludge valorization pathways to transform a waste product into a resource, closing the material loop.

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**Table 1** Characteristics of raw wastewater and treated effluent under optimal conditions (90 min, IED=0.2 cm).

| Parameter | Unit | Raw Wastewater (Mean ± SD) | Treated Effluent (Optimal) | Removal Efficiency (%) | EEPA Discharge Limit [34] |
|---|---|---|---|---|---|
| pH | - | 7.8 ± 0.2 | 8.1 ± 0.1 | - | 6-9 |
| EC | μS $cm^{-1}$ | 6250 ± 150 | 1850 ± 80 | 70.4 | - |
| COD | mg $L^{-1}$ | 4800 ± 210 | 190 ± 15 | 96.04 | 250 |
| $BOD_5$ | mg $L^{-1}$ | 2750 ± 180 | 55 ± 8 | 98.00 | 80 |
| TDS | mg $L^{-1}$ | 4500 ± 200 | 100 ± 10 | 97.78 | 3000 |
| Turbidity | NTU | 430 ± 25 | 5 ± 1 | 98.80 | 30 |

**Table 2** Pseudo-first-order rate constants ($k1$, $min^{-1}$) for pollutant removal at different inter-electrode distances.

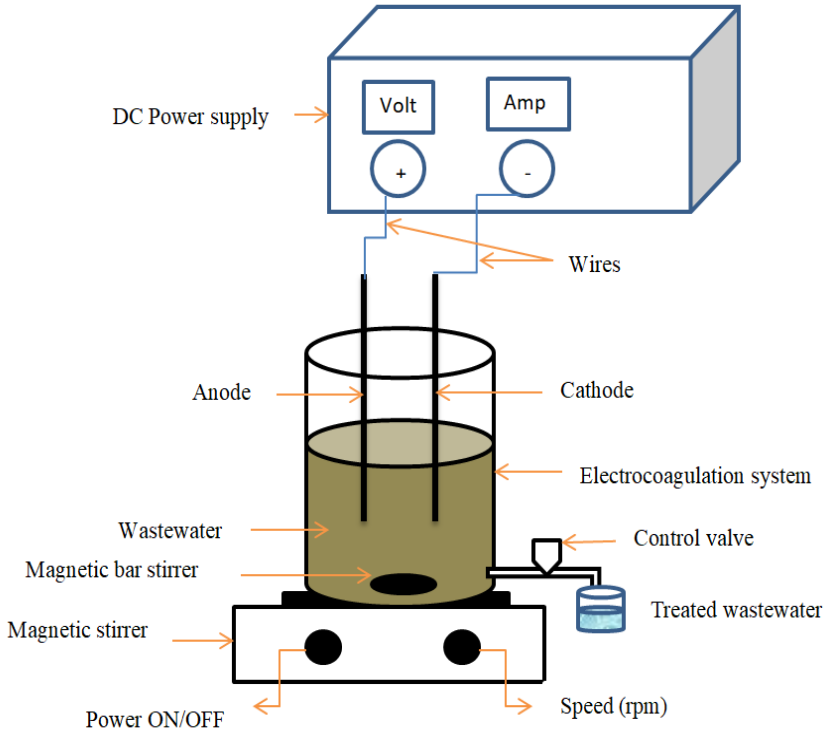
| Pollutant | IED = 0.2 cm | $R^2$ | IED = 0.5 cm | $R^2$ | Kinetic Enhancement Factor ($k_{10.2}$ / $k_{10.5}$) |
|---|---|---|---|---|---|
| $BOD_5$ | 0.0451 ± 0.002 | 0.983 | 0.0298 ± 0.003 | 0.961 | 1.51 |
| COD | 0.0389 ± 0.003 | 0.972 | 0.0241 ± 0.002 | 0.954 | 1.61 |
| TDS | 0.0422 ± 0.002 | 0.991 | 0.0195 ± 0.002 | 0.942 | 2.16 |
| Turbidity | 0.0487 ± 0.004 | 0.978 | 0.0212 ± 0.003 | 0.938 | 2.30 |

**Table 3** Comparison of energy and operational parameters at 90 min for the two IEDs.

| Parameter | Unit | IED = 0.2 cm | IED = 0.5 cm | % Change |
|---|---|---|---|---|
| Avg. Cell Voltage (U) | V | 8.4 ± 0.3 | 11.1 ± 0.4 | -24.3% |
| Energy Consumption (C_energy) | kWh $m^{-3}$ | 11.52 | 15.14 | -23.9% |
| Electrode Consumption (C_electrode) | kg Al $m^{-3}$ | 0.129 | 0.129 | 0% |
| Total Operating Cost (OC) | US \$ $m^{-3}$ | 4.37 | 5.52 | -20.8% |

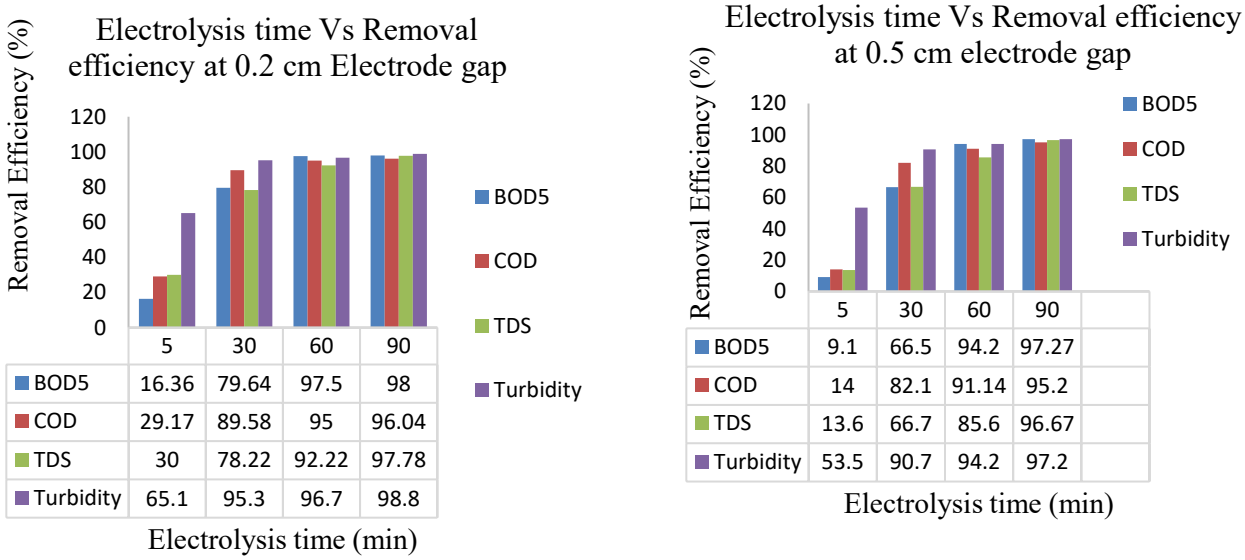
**Table 4** Comparative performance of EC processes for various wastewaters.

| Wastewater Type | Pollutant | Electrode / Conditions | Removal (%) | Energy (kWh $m^{-3}$) | Cost (US \$ $m^{-3}$) | Ref. |
|---|---|---|---|---|---|---|
| Household (This Study) | COD: 4800 mg $L^{-1}$ | Al, 0.8 A $dm^{-2}$, 0.2 cm IED, 90 min | COD: 96.0 | 11.52 | 4.37 | - |
| Municipal | COD: 650 mg $L^{-1}$ | Al, 6.67 mA $cm^{-2}$, 1 cm IED, 60 min | COD: 73.0 | 2.10 | 0.48 | [48] |
| Landfill Leachate | COD: 5200 mg $L^{-1}$ | Fe, 75 A $m^{-2}$, 1 cm IED, 120 min | COD: 66.0 | 45.00 | 5.90 | [49] |
| Poultry Slaughterhouse | COD: 3450 mg $L^{-1}$ | Al, 10 mA $cm^{-2}$, 2 cm IED, 45 min | COD: 85.0 | 5.87 | 1.15 | [50] |
| Olive Mill Wastewater | COD: 32,500 mg $L^{-1}$ | Al/Fe, 50 mA $cm^{-2}$, 1 cm IED, 180 min | COD: 78.5 | 31.50 | 4.80 | [51] |




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416 **Fig. 1.** Schematic diagram of the laboratory-scale batch EC experimental setup



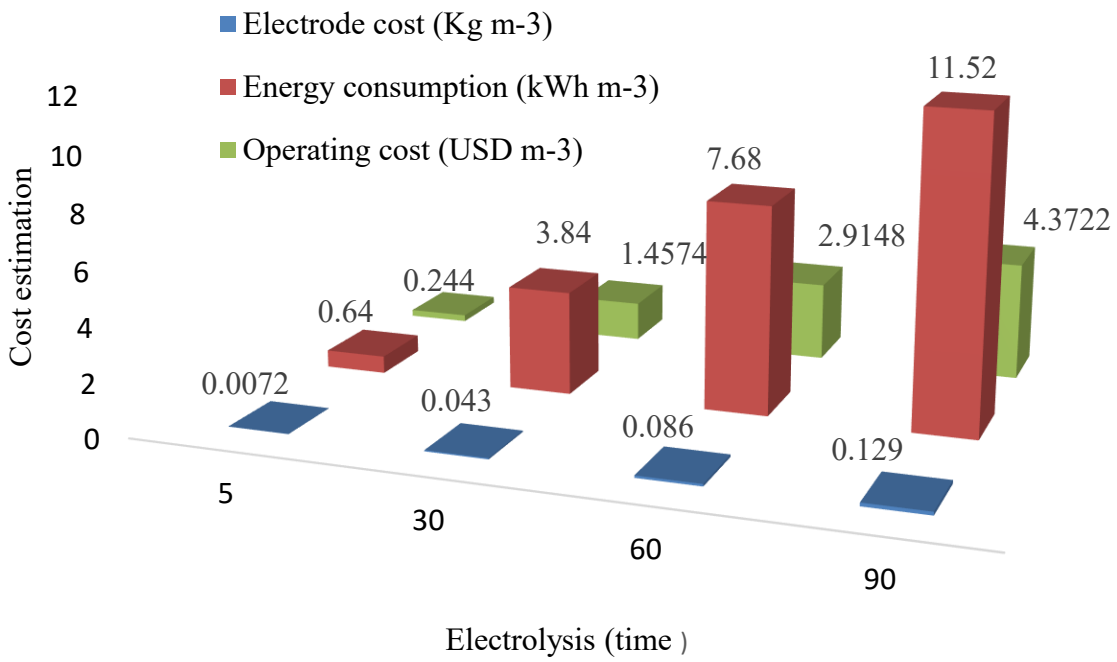

| | 5 | 30 | 60 | 90 |
|---|---|---|---|---|
| BOD5 | 16.36 | 79.64 | 97.5 | 98 |
| COD | 29.17 | 89.58 | 95 | 96.04 |
| TDS | 30 | 78.22 | 92.22 | 97.78 |
| Turbidity | 65.1 | 95.3 | 96.7 | 98.8 |

| | 5 | 30 | 60 | 90 |
|---|---|---|---|---|
| BOD5 | 9.1 | 66.5 | 94.2 | 97.27 |
| COD | 14 | 82.1 | 91.14 | 95.2 |
| TDS | 13.6 | 66.7 | 85.6 | 96.67 |
| Turbidity | 53.5 | 90.7 | 94.2 | 97.2 |

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419 **Fig. 2.** Variation of pollutant removal efficiency (%) with electrolysis time for (a) IED = 0.2 cm

420 and (b) IED = 0.5 cm.)




421
422 **Fig. 3.** Breakdown of operating cost (US $ $m^{-3}$) under optimal conditions (IED=0.2 cm, 90 min),
423 showing contributions from energy and electrode consumption.