Review

Treatment of oily wastewater by electrocoagulation technology: A general review (2018-2022)

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Abstract

A huge amount of oily wastewater is discharged annually from several industries like petroleum and petrochemical factories. Scientists and researchers are permanently concentrated on creating conventional technologies or identifying novel treatment options for oily wastewaters, since they need to be treated before being discharged into the soil and aquatic ecosystems. Electrocoagulation technology (ECT) is an electrochemical method employed to remove numerous pollutants from domestic and industrial wastewaters. This paper aims to review the recently published articles from 2018 to 2022 concerned with ECT for oily wastewater remediation. Based on the present review, it is obvious that ECT is strongly dependent on the value of electric current or voltage applied to provide the required amounts of electro-coagulants for efficient remediation, reaction time duration for the generation of electro-coagulants and pollutants elimination, and electrode configuration such as shape, type of metal, and distance between electrodes. Other operating parameters include solution pH (since some pollutants are removed based on their cationic or anionic nature), type of electrolyte which affects the electric conductivity and ohmic drop and stirring speed that may influence the contact among numerous ions throughout the EC reactor. The core findings show that the ECT is highly effective, eco-friendly, and cost-effective in eliminating organic and inorganic pollutants from oily wastewater.

Keywords

Wastewater treatment; electrochemical methods; electrocoagulation technology (ECT); hybrid systems; electrode configurations

Introduction

Oil is a vital economic resource for many nations since oil and its derivatives are used in many different sectors, including petrochemicals and oil refineries [1]. Large amounts of oily wastewater are released during the oil production [2]. Ecological degradation brought on by oily wastewater from various industrial operations, including oil drilling sites, petroleum refineries, and

petrochemical plants, represents a serious threat to the ecosystem [3]. Releasing untreated or incompletely treated petroleum refinery wastewaters into the climate causes amphibian biological system contamination, unattractive ecological issues, costly wastewater remediation, and the deficiency of cropland and fish [4]. The ecologically sustainable administration of oil production regions and the economic growth of the petrochemical industry depends heavily on the effective treatment and reuse of oily wastewaters [5].

Crude oil contains a wide range of constituents that can be classified as organic (hydrocarbons) or inorganic (biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD), total organic carbon (TOC), total dissolved solids (TDS), turbidity (TUR), ammonia, cyanide, and heavy metals) [6]. Wastewaters vary in oil concentrations depending on the depth and position of the crude oil wells, with annual discharges of billions of cubic meters ranging from 1 to 40,000 ppm. As a result, the primary cause of oceanic ecological pollution is related to evacuated oily wastewaters [3]. In the extracted petroleum, oily wastewater levels range from 0.4 to 0.6 % [7]. Figure 1 illustrates oily wastewater resources, forms, impacts and remediation benefits [8].
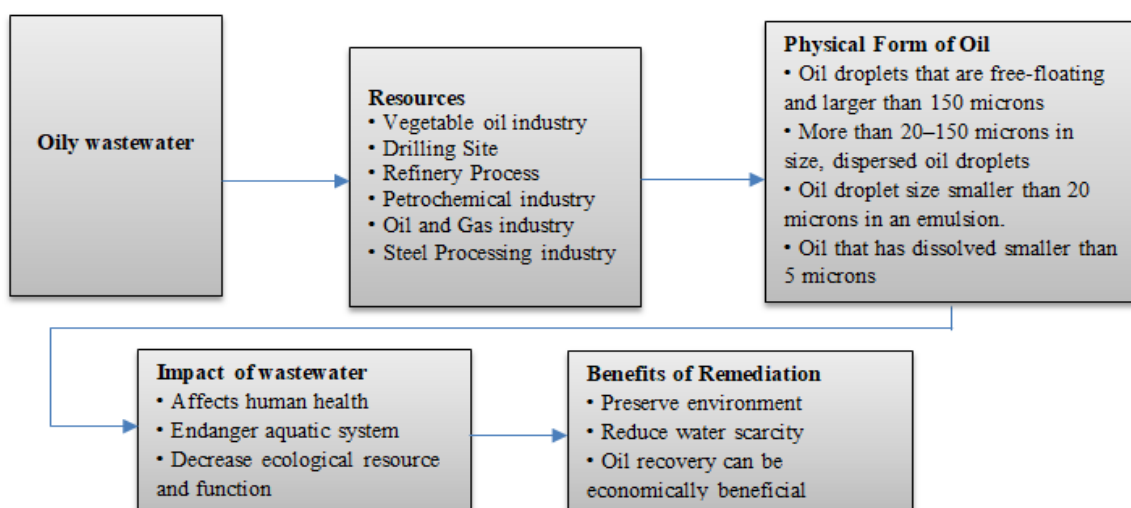

Figure 1. *General schematic for sources, impacts, physical forms and remediation benefits of oily wastewater*

Oily wastewaters have a negative impact on humankind because they are difficult to degrade. Consequently, the effluent sources should be treated utilizing distinct methodological techniques depending on the quantity and types of emulsified oily wastes [9]. Cyclone separation, sorption, chemical precipitation, and electrochemical techniques are part of the accessible treatment strategies used for this objective [10]. The effectiveness of the applied strategies relies upon removal capacity, time expected to achieve the treatment interaction, optional pollution created, the building cost, and running/maintaining of the unit. Subsequently, and because of the fast improvement of industries and human claims, some savvy treatment technique is necessary for oil removal from wastewater, and the reuse of freshwater [11].

Due to their simplicity of automation and ease of use, electrochemical techniques such as electrooxidation, electrofloatation, and electro-Fenton are frequently used to treat various wastewaters [12]. Electrocoagulation (EC) has been established as an effective electrochemical treatment approach for enhancing the deep cleaning of oily wastewater. EC utilizes redox reactions that happen by passing an electric current across electrodes made usually from aluminum or iron. The quantity of metal cations, like Al^{3+} or Fe^{2+}, is enhanced as a result of anode disintegration, whereas hydrogen gas (H_2) and hydroxyl ions (OH^-) are realized at the cathode [13,14]. Various ions

formed at both electrodes make electrocoagulants that eliminate contaminants through adsorption without using any chemical addition [15].

Still in 1904, Elmore recommended use of electrolysis for mineral extraction, while in 1906, Dietrich obtained a patent for electrocoagulation (EC) that would clean ship bilge water of contaminants. Up to now, the EC method has been established as an efficient, environmentally friendly, and cost-effective treatment for removing several poisons from wastewater. Over the past three decades, ECT has been successfully used as a water-treatment innovation to eliminate various pollutants. Technological advancements that consume less energy and cleaner output have increased the interest in EC as a generated water remediation technique [16].

The current work aims to review a number of particular papers appearing in the literature from 2018 to 2022 and assess the efficacy of ECT in treating actual oily wastewater. As a result, this study investigated EC mechanisms, operative factors that affect how well the EC process works, and its application to diverse petroleum effluents. This paper also provides an overview of the key findings from the publications investigated.

Electrochemical techniques

Electrochemical technology has been evolving in later years due to its highly efficient adaptability and ease of automation. Electrochemical processes have high oxidation capacity, do not require adding extra oxidative agents, and are modular. Due to these elements, electrochemical technology passed from theory to practice in practical engineering [17]. The unlimited evacuation of a few kinds of metal ions and organic and inorganic pollutants present in wastewater is regarded as effective and limited-cost when compared to ineffective modification techniques [18]. Electrochemical technologies are most efficient in wastewater treatment due to their eco-friendliness and ability to remove many contaminants through reduction reactions, oxidation, and energy consumption [19]. Electrochemical techniques are quite simple to use, have the characteristic of supplying electrons, which are immaculate, many-sided, and efficacious viable reagents for pollutant removal, and do not emit toxic byproducts. Electrochemical mechanisms such as electrooxidation, electro-reduction, electro-flotation, electro-dialysis, and electrocoagulation have demonstrated their adequacy in pollutant expulsion from wastewaters. Among these mechanisms, the electrochemical high-level oxidation processes have already received much interest. Pollutants are oxidized electrochemically through either immediate or vicarious electrolysis. The last method employs electroactive types of the membrane to degrade organic pollutants [20].

A multitude of anodes and cathodes, primarily consisting of aluminum, iron, magnesium, and stainless steel, are often used in electrochemical EC processes. When a DC electric current is run through the apparatus, the anodes produce positively charged ions that act as coagulants in the solution. These anodes can be found in various shapes, including plates, balls, rods, and tubes. Throughout the operation, cathodes should not corrode [21]. Electrochemical techniques have several features, including reduced chemical prescribed dose and multilateral operation, as well as a shorter maintenance cost, and only electrons can be used for treatment rather than micro-organisms and toxicants. Furthermore, the sludge produced by this technology is easily settled down and dewaterable [22].

Electrocoagulation technology (ECT)

Because of its wide variety of utilizations and low cost, electrocoagulation technology (ECT) is one of the most popular electrochemical technologies. The electrocoagulation operation can also

be used as a pre-processing unit to eliminate suspended solids as well as colloidal particles from water and work on improving wastewater biodegradability. In some research, electrocoagulation was designed to deal with highly concentrated organic wastewater [17].

EC is a powerful technique for better cleanup of oily wastewater *via* redox reactions caused by passing an electric current through electrodes. The anode is the electrode where oxidation occurs, while reduction occurs at the cathode. As schematically illustrated in Figure 2, metal cations (M^{n+}) that are launched because of the anode degeneracy are forming electro-coagulants ($M(OH)_n$), while the hydrogen gas (H_2) and hydroxyl ions (OH^-) are developed at the cathode of the EC cell.
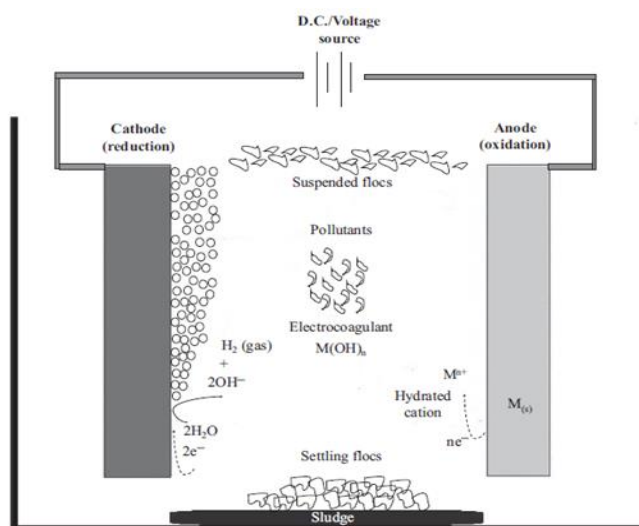

Figure 2. Schematic representation of a basic EC cell in batch mode

The EC process develops in 3 stages:
A. Oxidation reaction and development of electro-coagulants.
B. Portion emulsifiers and destabilization of contaminants.
C. Incorporating pollutants to shape loads that go with the flow or precipitate in line with the sort of pollution [1].

The EC utilizes electric current to break down metal electrodes and supply coagulants or destabilization flocs [23]. EC technique has many advantages, including simple device, shorter reaction time, neither chemical required, minimal energy usage and least electrode demand. Moreover, EC can be performed as a pretreatment process or in hybrid systems with different treatment techniques along with adsorption and alternate ionic processes. Regardless of the abundant benefits of the electrocoagulation process, the mechanism of oil elimination from oily wastewater is complex due to its physicochemical parameters. The electro-coagulants fashioned throughout the electrocoagulation process possess a bigger functionality than chemical coagulants for casting off contaminants from exceptional types of wastewaters. Additionally, they are bigger than chemical coagulants, which results in the lowest solubility of products in a certain pH range, and as a result, this will enable an easier separation [6]. The ultralight substances will float to the solution surface by the buoyancy process, whereas heavier substances will settle at the bottom of the reactor [16].

Main reactions of EC process

The material used for the electrodes influences the coagulant, which immediately influences the separating efficiency. Anode oxidation and cathode reduction occur when the electrode coagulation operation is initiated by the required voltage or current applied to a cell. The solution pH will

increase while hydrogen gas is launched for the duration of the reduction process. The major reactions at the electrodes during the EC process are as follows [1, 24-26]:

At the anode:

$$M_{(s)} \Rightarrow M^{+n} + ne^- \tag{1}$$

$$2H_2O \Rightarrow O_2 + 4H^+ + 4e^- \tag{2}$$

At the cathode:

$$2H_2O + 2e^- \Rightarrow H_{2(g)} + 2OH^-_{(aq)} \tag{3}$$

$$M^{+n}_{(aq)} + ne^- \Rightarrow M_{(s)} \tag{4}$$

For example, the anodic reactions at the aluminium anode are

$$Al_{(s)} \Rightarrow 2Al^{+3}_{(aq)} + 6\,e^- \tag{5}$$

$$Al^{3+}_{(aq)} + 3OH^- \Rightarrow Al(OH)_3 \tag{6}$$

while for the iron electrode, the following reactions occur [22,26,27]:

$$Fe_{(s)} \Rightarrow Fe^{2+}_{(aq)} + 2e^- \tag{7}$$

$$Fe_{(s)} \Rightarrow Fe^{3+}_{(aq)} + 3e^- \tag{8}$$

$$4Fe^{+2}_{(aq)} + O_2 + 4H^+ \Rightarrow 4Fe^{3+}_{(aq)} + 2H_2O \tag{9}$$

$$Fe^{3+}_{(aq)} + 3H_2O \Rightarrow Fe(OH)_{3(s)} + 3H^+_{(aq)} \tag{10}$$

Electrode arrangement

The electrode arrangement is an important factor in the EC process affecting the removal effectiveness. The electrodes in the EC cell may be placed in several configurations [28-32]. As shown in Figure 3, electrodes may be set up as a monopolar or bipolar system. By connecting all anodes and cathodes in series (MP-S), the same current can flow through each pole. Electrodes can also be connected to a parallel system (MP-P). In a bipolar system (BP-S), the external electrodes are connected in series to a source capable of producing both voltage and current. The negative side is obverse, and the other electrode side is polarized with a positive charge. According to research, the bipolar system is the most effective in removing various pollutants [33,34].
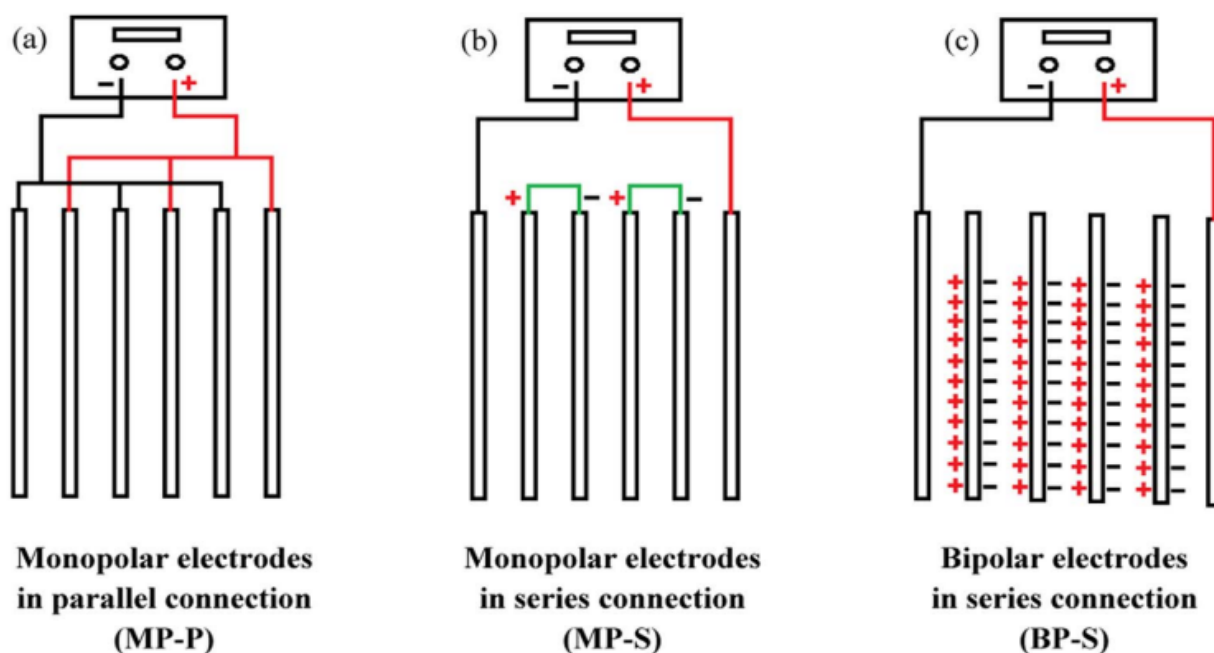

Monopolar electrodes in parallel connection (MP-P)　　**Monopolar electrodes in series connection (MP-S)**　　**Bipolar electrodes in series connection (BP-S)**

Figure 3. *Arrangements of electrodes in EC cells: (a) monopolar electrodes in parallel connection; (b) monopolar electrodes in series connection; (c) bipolar electrodes in series connection*

ECT for oily wastewater treatment

Numerous scientists have used the electrocoagulation technique to deal with real and/or synthetic oily wastewater. Several indicators of contaminated oily wastewater, such as COD, BOD, TOC, DOC, oil content, *etc*., have been followed and minimized in oily wastewater using ECT alone or in integrated systems.

ECT system

The most important indicator of water pollution is COD, which has been taken into consideration by several studies. Yang *et al*. [5] employed six parallel and sequential Al-sheets as electrodes in a batch electrocoagulation reactor to investigate EC demulsification and oil elimination performance at various electric fields and both connection modes (monopolar and bipolar). Bipolar EC, with an electric field intensity of 38 V/m, and monopolar EC of 180 V/m, were used at a solution pH of 7.0. COD and turbidity values were measured during the electrolysis process of 0 to 30 minutes. When the current density was 0.67 mA/cm^2, the COD and turbidity removal rates under monopolar and bipolar EC were 77.9, 98.0, 66.9 and 89.1 %. This study proved that the monopolar connection mode is more effective for minimizing COD compared to the bipolar mode. Moussavi *et al*. [21] used electrocoagulation to dispose of organics and suspended matter emanating from a petroleum refinery liquid waste using an Al-rectangular plate as the anode positioned parallel to and 5 cm aside from the stainless-steel cathode. The optimum conditions were 120 min of treatment, pH 6, and a current density of 35 mA/cm^2 to attain 94 % TSS removal and 90 % COD removal. The core results of this work revealed that the configuration of electrodes affects the performance of the EC reactor. The same proof was stated by Madhavan *et al*. [35] (2021), who developed a novel electrocoagulation device to treat the produced water using mild steel-parallel plates under switching electrode polarity applied to minimize electrode passivation. The experimental set-up for electrocoagulation research included filter-press cells for which the cell width can be changed using gaskets, frames, and a movable piston mechanism. The anode and cathode were made of flat, rectangular slabs of mild steel with 1 cm inter-electrode gap separating plates from one another. At the batch recirculation time (BRT) of 15 min, the current density (CD) was 1.6 A/dm^2, SC was 3 g/L, and switchover time (SOT) was 1 min. It was shown that the majority of 99 % COD and 98 % oil and grease from a sample of produced water could be removed. Oil removal of 88 % was reached using the BRT operating parameters of 3 min, 2.14 A/ dm^2 CD, 3 g/L SC, and 1.9 min SOT at the lowest operating cost of 0.65 US$/kg COD. Similar conclusions have been provided by [16,36-40], and other previous works are briefly listed in Table 1.

Bajpai *et al.* [41] performed monopolar-parallel Al/Fe electrodes to optimize the most influential parameters on the COD removal efficiency from the pharmaceutical wastewater. They attained 86.70 % COD elimination at 16 mA/cm^2, pH 8, and 40 min of the treatment time. This finding proved that the mode of connection of electrodes toward the electric power source has a high impact on the performance of the EC cell. The impact of the connection mode of the electrodes to the power supply has been investigated by [42-46], as shown in Table 1. These works proved that the type of connection mode to the power supply is extremely important, affecting the performance of the EC reactor for eliminating COD and associated pollutants.

AlJaberi *et al*. [1] investigated the capacity of an innovative batch electrocoagulation reactor with concentric aluminum tubes of the total active area of 285 cm^2 in a monopolar mode to remove 523.11 mg/L oil content and 168 NTU turbidity from real oily wastewater discharged from the moist oil unit. The electrolysis time ranged from 10 to 40 min.

The current density was 1.77 to 7.07 mA/cm^2, pH 6.5, 126 mS/cm conductivity, and 200 rpm stirring speed were studied as the operating variables. Optimal parameter values were obtained at the current density of 5.675 mA/cm^2, pH 6.5, and 40 min of electrolysis time. The maximum removal of oil content and turbidity were found as 85.982 and 84.439%, respectively. Other studies on oily wastewater treatment were done by the same author [6,9,16], with details summarized in Table 1.

Zhang *et al*. [36] used electrocoagulation as an effective technique for the pretreatment of shale gas extraction wastewater. A batch reactor with concentric iron slabs running in a monopolar mode was used, with Fe electrodes consisting of 5 parallel slabs, each measuring 10 cm in width, 17 cm in height, and 0.2 cm in thickness. Each plate having a surface area of 170 cm^2 was spaced 2.0 cm apart. For each run, 1.45 L of wastewater sample was maintained in the EC reactor. The optimal processing conditions for turbidity, TOC, and Ca^{2+} elimination, were obtained. The electrolysis period varied from 0 to 20 minutes, and the conductivity was 14.48 mS/cm. The power source was 0 to 40 volts and 0 to 5 A. Under the optimum conditions, the highest removal rates for turbidity, TOC, and Ca^{2+} were around 98.3, 78.5 and 56.5%, respectively. The following operating parameters were suggested for the efficient and cost-effective treatment of drilling wastewater by the EC process: 20 minutes for reaction time, 318 A/m^2 for current density, and 4.4 for pH value [36].

ECT in hybrid systems

Other studies have been performed to investigate the influence of using hybrid systems to minimize COD and associated indicators of contamination. Lu *et al.* [17] integrated electrocoagulation (EC) and electrooxidation (EO) technologies to remove pollutants from industrial wastewater by using aluminum electrodes. They attained 81.62 and 50.92 % removal efficiencies of COD and ammonia nitrogen, respectively, at the optimal values of operating variables of 5 mA/cm^2 CD, 60 min of contact time, and more acidic condition (pH 3) of solution. Also, Chanikya *et al*. [20] combined EC and EO to treat industrial wastewater containing COD and TOC, using Pt/Ti mesh as the anode and acrylic sheet as the cathode. The best removal of COD and TOC was 93.5 and 75 %, respectively, at pH 8.2, a current density of 10 mA/cm^2, and a reaction time of 60 min. The integration efficiency of electrocoagulation and electro-Fenton processes was studied by Can-Güven [23] in dye manufacturing wastewater treatment using monopolar-iron electrodes. The highest removal of COD was obtained at 21 mA/cm^2, pH 7.3, and 25 min of the electrolysis time. Ucevli and Kaya [47] compared membrane filtration, chemical coagulation, electrocoagulation, and their hybrid systems for minimizing COD and BOD from greywater treatment using Al/Fe electrodes. At the optimal values of 5 A/m^2 and pH 7.5, the highest elimination was achieved after 30 min of the electrolysis time. Changmai *et al*. [48] investigated the usage of electrocoagulation-microfiltration in a batch mode for the remedy of oily wastewater containing oil and grease at the side of metals such as Na, Cr, Cu, Pb, and Ni. Samples have been pre-handled with the use of electrocoagulation with various running parameters, including current density (20–80 A/m^2), electrode space (0.005 to 0.2 m), and initial pH (3.6 to 8.7). The presence of oil and grease was decreased from 35 to 10.2 mg/L in only 20 min. Microfiltration was accomplished through the use of indigenously organized ceramic membranes to take away flocs generated by the electrocoagulation technique at three specific pressures of 98, 196 and 194 kPa. The electro-coagulation effluent was introduced to a filtration cell to be filtered using a ceramic membrane. The concentration of oil and grease was minimized from 35 to 10.2 mg/L. This combination of EC and other treatment technologies assists the treatment process of different types wastewater containing COD. The same conclusions were provided by [29,37,49-53], where EC is combined with anodic oxidation,

electrooxidation, electro-Fenton, flotation, electrooxidation, ozonation, and peroxone, respectively, to eliminate organic and inorganic pollutants from wastewater.

Lia *et al*. [49] planned and built a unique incorporated system of electrocoagulation (EC)-carbon membrane coupling with electrochemical anodic oxidation (CM/EAO) for the treatment of oily wastewater. Electrocoagulation was taken as an essential unit, and the impacts of numerous boundaries, including current density, electrolyte focus, initial pH, feed oil content, and work time on the pretreatment performance, were examined and enhanced. After that, CM/EAO was established as a supplementary unit for the additional deep purification of EC effluent. The outcomes demonstrated the excellent capability of the integrated system for wastewater oil removal. The EC unit could eliminate almost 50 % of COD and TOC in the feed, and the accompanying CM/EAO unit further debased the EC emanating, and COD and TOC were diminished to 13 and 22 mg/L, separately. Rectangular metal sheets of aluminum with a total active area of 10 cm^2 were applied as electrodes concentrically. The electrolysis ranged from 0 to 60 min, the current density (0.5 to 4.5 mA/cm^2), and neutral pH. The oil removal efficiency was 87.18 %. The most suitable values of the operational parameters were 2.0 mA/cm^2 of current density, 0.5 g/L NaCl, neutral pH, stirring speed of 250 rpm, and 60 min [49].

Table 1 summarizes past studies published from 2018-2022 that discussed the application of electrocoagulation technology in the treatment of wastewater containing various contaminants, including organic and inorganic compounds and heavy metals. This table gives the reader important facts for each mentioned study, like the operating parameters and their optimal values for getting the best possible removal of different contaminants.

Table 1. *Literature summary of operational conditions for electrocoagulation removal of pollutants from wastewaters*

References	Pollutants	Current/ voltage	Reaction time, min	Anode metal	Anode shape	Cathode metal	Cathode shape	Optimum parameter values	Efficiency, %
[1]	Oil content	1.77-7.07 mA/cm^2	10-40	Al	Concentric tubes	Al	Concentric tubes	5.68 mA/cm^2 40 min, pH 6.5	85.98
[3]	Oil content	20-80 A/m^2	20	Al	Sheets	Al	Sheets	80 A/m^2 20 min, pH 8.7	70.8
[5]	COD	0.67 mA/cm^2	30	Al	Plates	Al	Plates	0.67 mA/cm^2 30 min, pH 7	77.9
[16]	TOC	0.5-2.0 A	10-40	Al	Concentric tubes	Al	Concentric tubes	1.606 A 40 min, pH 6.5	83.91
[17]	COD	5 mA/cm^2	60	Al	Plates	Al	Plates	5 mA/cm^2 60 min, pH 3	81.62
[20]	COD, TOC	10 mA/cm^2	0-60	Pt/Ti mesh	Acrylic sheet	Fe	Acrylic sheet	10 mA/cm^2 60 min, pH 8.2	COD: 93.5 TOC: 75
[21]	COD	35 mA/cm^2	120	Al	Rectangular plates	Stainless steel	Rectangular plates	35 mA/cm^2 120 min, pH 6	90
[22]	BOD	0.08-0.77 A/dm^2	0-60	Fe	Plates	Al	Plates	0.77 mA/cm^2 60 min, pH 8	75
[23]	COD	5-41 mA/cm^2	25	Fe	Plates	Fe	Plates	21 mA/cm^2 25 min pH 7.3, 50 °C	38.5
[35]	COD, oil content	1-3 A/dm^2	3-15	Mild steel	Parallel plates	Mild steel	Parallel plates	2.14 A/dm^2 3 min	COD: 86.71 Oil: 88
[36]	TOC	318–481 A/m^2	20	Fe	Plates	Fe	Plates	318 A/m^2, 0 min, pH 4.4	78.5
[37]	COD	14-56 mA/cm^2	0-280	Fe	Parallel sheets	Fe	Parallel sheets	56 mA cm^2 280 min, pH 6.8	97
[38]	COD	0.35-1.7 A	5-15	Al/Fe	Plates	Fe/Al	Plates	1.05 A, 5 min pH 8.1	96
[39]	COD	3-9 mA/cm^2	0-180	Al	Tubular	Stainless steel	Rotating tube	6 mA/cm^2 40 min pH 7±0.7	70
[40]	COD	0.05-0.3 A	0-30	Fe	Plates	Fe	Plates	0.2 A, 5 min pH 4	60
[41]	COD	4–20 mA/cm^2	10–50	Fe	Parallel sheets	Al	Parallel sheets	16 mA/cm^2 40 min, pH 8	86.70

References	Pollutants	Current/ voltage	Reaction time, min	Anode metal	Anode shape	Cathode metal	Cathode shape	Optimum parameter values	Efficiency, %
[42]	COD	15-25 V	2-80	Al	Plates	Al	Plates	17.6 V 43.8 min, pH 4	>99
[43]	TOC	1.39-6.95 A/m^2	0-30	Fe	Plates	Al	Plates	4.17 A/m^2 15 min, pH 4.3	80.2
[44]	COD	0.5-17 mA/cm^2	30–180	Al/Fe	Plates	Al/Fe	Plates	10 mA/cm^2 120 min, pH 8.5	76
[45]	COD	-	-	Al	Plates	Al	Plates	16 mA/cm^2 14.2 min, pH 8	88.3
[46]	COD	0.5-4 mA/cm^2	0-60	Al	Plates	Al	Plates	2 mA/cm^2 60 min, pH 7	85.5
[47]	COD	5-30 A/m^2	30	Al	Sheets	Fe	Sheets	5 A/m^2, 30 min pH 7.5	82
[48]	Oil content	0.5-4.5 mA/cm^2	60	Fe	Rectangular sheets	Al	Rectangular sheets	2.0 mA/cm^2 60 min neutral pH	87.18
[49]	COD	2.5 A	0-280	Al	Plates	Al	Plates	2.5 A, 140 min	90
[50]	COD	2.57-15.43 mA/cm^2	10-120	Al	Plates	Al	Plates	10.29 mA/cm^2 60 min, pH 7	85.01
[51]	COD	-	0-60	Fe	Plates	Fe	Plates	40 mA/cm^2 60 min, pH 9	91.70
[52]	COD	-	-	Al	Plates	Al	Plates	0.7 A, 45 min pH 7.35	70
[53]	COD	6-12 A	(3-40	Al	Tubular	Al	Tubular	12 V, 30 min pH 7	27
[54]	DOC	5.55-14.8 mA/cm^2	(0-20	Fe	Plates	Fe	Plates	14.8 mA/m^2 20 min, pH 8.3	74
[55]	TOC	20-100 mA	0-100	Stainless steel	Plates	Graphite	Plates	60 mA, 100 min, pH 3	30.5
[56]	COD	1.58-3.16 A	0-60	Al	plates	Al	plates	3.16 A, 60 min pH 6.4	63
[57]	COD	0-140 A/m^2	60	Al	Plates	Ti	Plates	115 A/m^2 0 min , pH 7.5	75.33
[58]	COD, BOD	20-40 mA/cm^2	10-60	Fe or Al	Plates	Stainless-steel	Plates	30 mA/cm^2 35 min pH 6.3	COD: 50.6 BOD: 10
[59]	COD	0.3-0.9 A	10-30	Pt	Sheets	Carbon-	Sheets	0.7 A, 30 min pH 10	69

Disadvantages of electrocoagulation method

The main disadvantages of the EC method and proposed solutions for improvement are summarized in Table 2.

Table 2. *Main disadvantages and proposed solutions for improving EC method*

Disadvantages	Proposed solutions
The sacrificial anodes require to be replaced periodically	New design(s) of electrode configuration could overcome this problem
Dissolved solids present in wastewater could limit the use of EC process	New design(s) of electrode configuration could overcome this problem
An oxide film generated on the cathode, which is impermeable that prevents the flow of current	Using of sodium chloride will be effective to solve this problem
High cost required due to the use of electricity	Using of green technologies such as solar and wind power can solve this economic impact

Conclusions

Petroleum has predominantly harmful ecological effects on practically all life aspects due to its toxicity. Oil pollution in the air and water could be hazardous and harmful to humans. Several conse-quences on the soil ecological system are caused by the presence of organic (petroleum hydrocarbons) and inorganic substances, such as oil content, COD, BOD, TOC, turbidity, TDS, and TSS in water. Their effects include changes in the physicochemical properties of soils and adverse effects on animals and plants. This study examines almost 50 most recent papers to provide the reader with an overview of

EC as an effective and straightforward technology and one of the most widely used strategies for removing contaminants from wastewater. It has been proven that electrochemical technologies for wastewater treatment are distinguished from other technologies by their common sense and minimum generation of current. According to the findings, electrochemical technologies attracted considerable interest among alternate strategies of byproduct treatment techniques. The process EC was operated under various parameters, including current density, voltage, initial pollutant concentration, temperature, pH, the distance between the electrodes, and their shape and arrangement. Different types of electrolytic reactors have been employed, and some studies have compared the performance of the removal of pollutants using different electrode compositions. The current research reviews the EC mechanism, the possibility of using various electrodes designs in oil water treatment and wide ranges for operating variables according to the nature of the oil water, working boundaries impacting the EC process performance and its implementation in treating oily wastewater. This work likewise sums up the key findings from the publications investigated. The core findings of this paper proved that EC innovation is eco-accommodating, practical, and of high effectiveness in eliminating various contaminants from oily wastewater using various kinds of electrode design.

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