World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Review Article)

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Systematic literature electrocoagulation for wastewater treatment: Mini-review

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World Journal of Advanced Research and Reviews, 2023, 18(02), 690–699

Publication history: Received on 27 March 2023; revised on 14 May 2023; accepted on 16 May 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.18.2.0812

Abstract

Electrocoagulation is a method that can be used to remove pollutants and nutrients from liquid waste. This method has been found for a long time but has exclusively recently been developed for wastewater treatment after a lengthy process. Electrocoagulation can remove colloidal materials, i.e., suspended solids, metals, and other dissolved solids in wastewater. Several studies have shown that electrocoagulation has been successfully operated in various industrial wastewaters, i.e., bakery, chocolate, cork boiling, olive, biodiesel, Etc. This review uses the systematic review scale mini-review method. Literature was collected from various databases using Harzing's Publish or Perris Software and analyzed by Mendeley Software. The results indicate that the electrocoagulation method has received excellent attention for development, i.e., the effectiveness and energy that must be consumed, and that research is evolving to show the best performance of electrocoagulation.

Keywords: Wastewater; Oily; Electrocoagulation; Treatment

1. Introduction

The increasing expansion of the industry must be allowed by the increase in water resources required for the operation of the industry. However, many studies aim to reduce the exploitation of these resources, including by adopting several techniques in different industries to reuse the liquid waste produced [16]. Several industries, i.e., the petrochemical, metallurgical, pharmaceutical, and food industries, have driven environmental damage due to the liquid waste they produce. The wastewater must be treated before being released into the environment [2].

The olive processing industry in Mediterranean countries, i.e., Spain, Greece, Italy, and Iran, produces olive oil and processed olives. The industry produces liquid waste released in turbid and dark effluent, a heightened hazard of environmental damage because the complex purification process is a threat. This waste furthermore has heightened organic matter, i.e., sugars, amino acids, organic acids, tannins, pectins, carotenoids, and polyphenols [13]. Lipids cannot be efficiently separated from sewer wastewater and can eventually cause environmental issues [21]. Lipids (specifically vegetable oils and long-chain fatty acids) current in wastewater are complicated to remove and degrade because they are insoluble in water and are known to inhibit methanogenic processes. Lipid metabolism involves several phases, including emulsifying and degradation. Following passing through the degradation pathway, lipids are broken down into glycerol and fatty acid(s). The fatty acids are then transformed into acetyl-CoA through the beta-oxidation pathway and finally enter the TCA cycle [18]. Another case is in the oil and biodiesel refinery industries, which produce waste with a high content of minerals and organic matter due to the application of heavy metals in the industry [2, 16].

Biologically oily liquid waste treatment techniques have lower effectiveness [13]. The incomplete reduction of oil/grease has a harmful impact [5]. Conventional methods, i.e., separation and gravity skimming, coagulation air

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flotation, emulsification, and flocculation, have intrinsic weaknesses such as low efficiency and high operational costs and cause new problems such as re-contamination to the incapability of these methods to remove microns and or sub micron-sized oil droplets [2].

The electrocoagulation method, developed for a lengthy period, is operated for wastewater treatment with a lengthy process. However, it has been found in recent years that electrocoagulation can more efficiently and satisfactorily treat different industrial wastewater (including those with a high-fat content) at a relatively low cost [2]. Electrocoagulation technology has been successfully used for the treatment and removal of pollutants from municipal wastewater, industrial wastewater, i.e., textiles, leather tanneries, pulp and paper, food processing industries, olive mill effluent, landfill leachate, dairy effluent, and oily wastewater [10, 14].

Electrocoagulation can remove nutrients as satisfactorily as suspended solids and organic carbon from wastewater. The performance of the air cathode electrocoagulation (ACEC) process has been tested utilizing raw wastewater and carbon-free synthetic solutions to simulate the removal of nutrients from wastewater treated to remove organic matter. The result can remove ammonia and phosphorus up to 99%, COD 72-81%, and TSS 78-89% within 4 hours. The energy required is 1.8 kWh/m^3. Nutrient removal using synthetic solutions ranges from 74 to 93%, Nitrogen 47-370 mg-N/L and phosphorus 44-76% [19].

Electrocoagulation is an electrochemical method to introduce coagulation and remove suspended solids, colloidal materials, and metals as satisfactorily as other dissolved solids from water and wastewater [15]. Electrocoagulation is an electrochemical process that can treat wastewater by removing organic matter and nutrients [19]. Electrocoagulation consists of the production of coagulants by the dissolution of a sacrificial anode [15]. This study aims to study electrocoagulation for oily wastewater treatment.

2. Methodology

The principal methodology for writing this review article is to analyze it from various literature with Systematic Review (PRISMA). A structured review strategy and search for appropriate international journals to determine theories and topics to be discussed in article reviews.

2.1. Data collection

Data collection was accepted by studying international journals from several databases, including Pubmed, Springer Link, Google Scholar, Semantic Scholar, and Science Direct, through Harzing's Publish or Perris software with the provisions of research articles spanning 2012-2022 (ending 15 December 2022/last date tracing) and processed with Mendeley software. Requirements were related to processing liquid waste, specifically those containing fat, especially in applying the electrocoagulation method.

The main topic is to analyze international articles on liquid waste treatment methods, including oil, their causes and effects, and other related matters. The arrangement is to determine the topics and titles to be discussed according to the abstract keywords from research journal articles in academic research databases.

2.2. Data analysis

This review's primary topic is examining the results of a total of international journal research articles on the traceability of oily wastewater treatment by electrocoagulation. The systematic review process is shown in Figure 1.

2.3. Identification

The databases used in this manuscript include Science Direct, Springer Link, Google Scholar, Semantic Scholar, and PubMed. The reference search process uses three groups in each database, i.e., wastewater, treatment method, and electrocoagulation. The three keywords are grouped using the Boolean operator combination method "AND", containing keywords from the three groups. The references used during the investigation are from 2012 to 2022, with the reference criteria existing study articles.

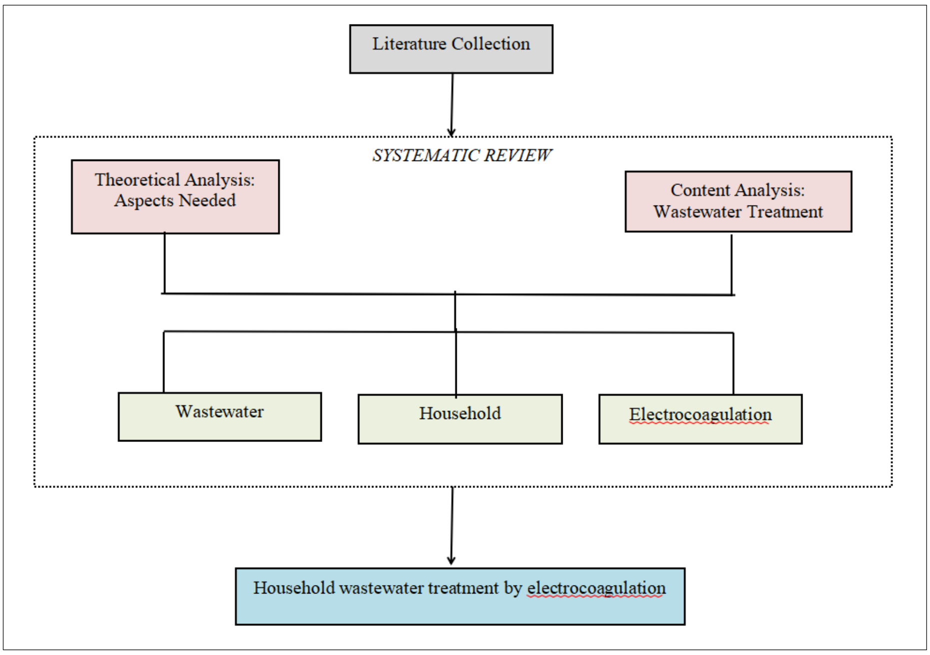

Figure 1 Systematic review procedure

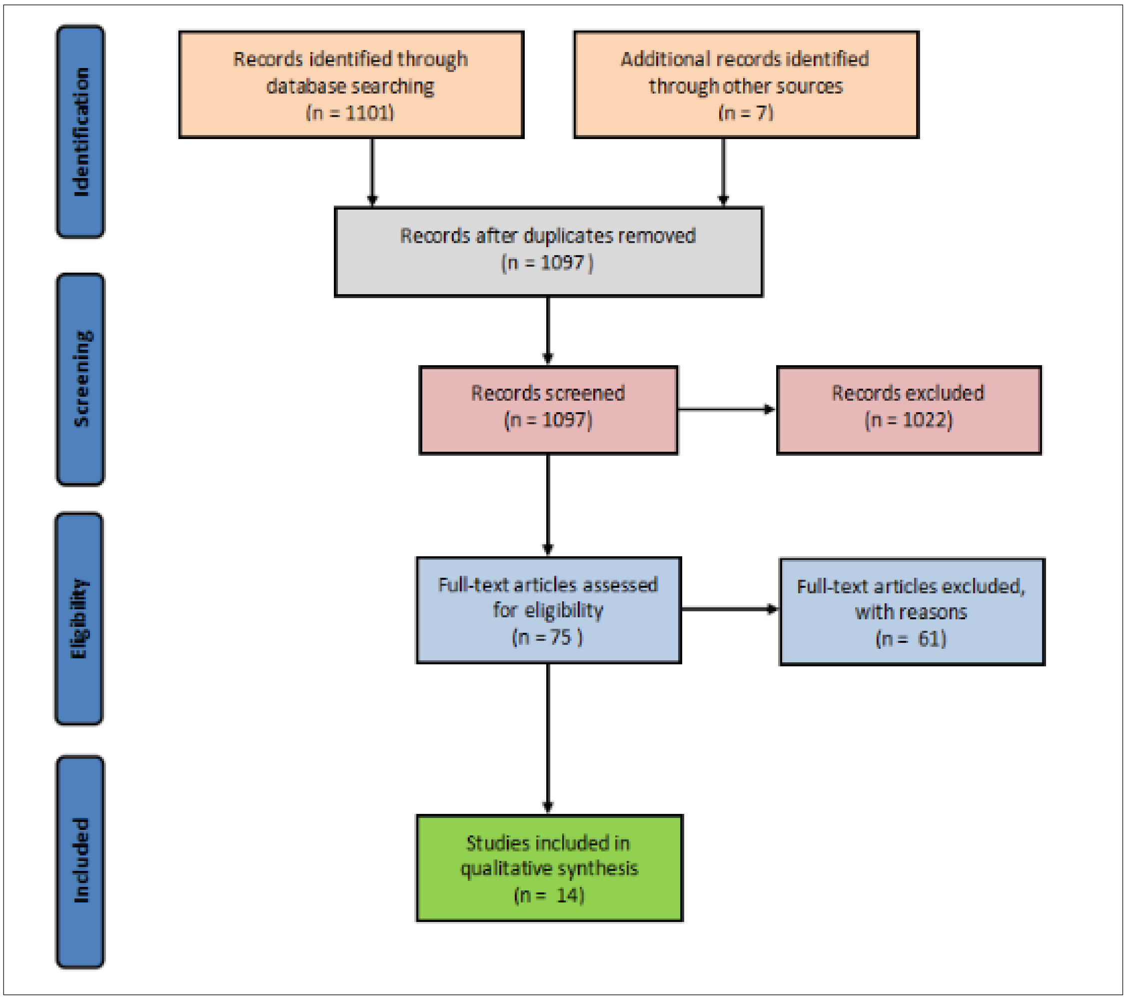

Figure 2 PRISMA flow diagram-systematic reviews

2.4. Screening

Based on search results in the database (search engine), the authors filter according to the themes to be reviewed and then transferred to Mendeley software. Match duplication is accomplished and merged (search merge). Based on the records accepted after combining the duplicates, sort the data accepted by combining keywords by evaluating the inclusion-exclusion criteria. A baseline data search was performed according to a systematic review protocol.

2.5. Eligibility

Further checks to accept eligibility criteria based on abstract screening. At the feasibility stage, the full text was selected carefully (n = 75).

2.6. Inclusions

Information relevant to the topic (electrocoagulation) and all relevant information contained in the data records were included in this review's preparation.

2.7. Data extraction

Based on the data accepted then proceed with completing a diagram (PRISMA) in Figure 2, which is arranged systematically. Figure 1 shows a systematic review to determine the discussion, supporting factors, and the tracking system from the journal literature on oily wastewater treatment by electrocoagulation. Followed by selecting the part that is a critical point in food traceability, and then the topics are discussed and summarized in detail and systematically in the review. Review the procedure to the literature and the findings that will be described systematically, structured, and analyzed from the theory of analysis and content analysis.

3. Results

The investigation based on Figure 2 shows the total articles recovered from the database (Science Direct, Springer Link, Google Scholar, Semantic Scholar, and PubMed) based on the keyword “wastewater treatment” (n=1101) and other sources (n=7). Eleven articles were identified as duplicates. The next keyword uses "electrocoagulation" and is identified manually based on the industry that has the potential to produce oily wastewater, it is excluded (n=1022), and articles in the database showing eligibility for assessment are (n=75).

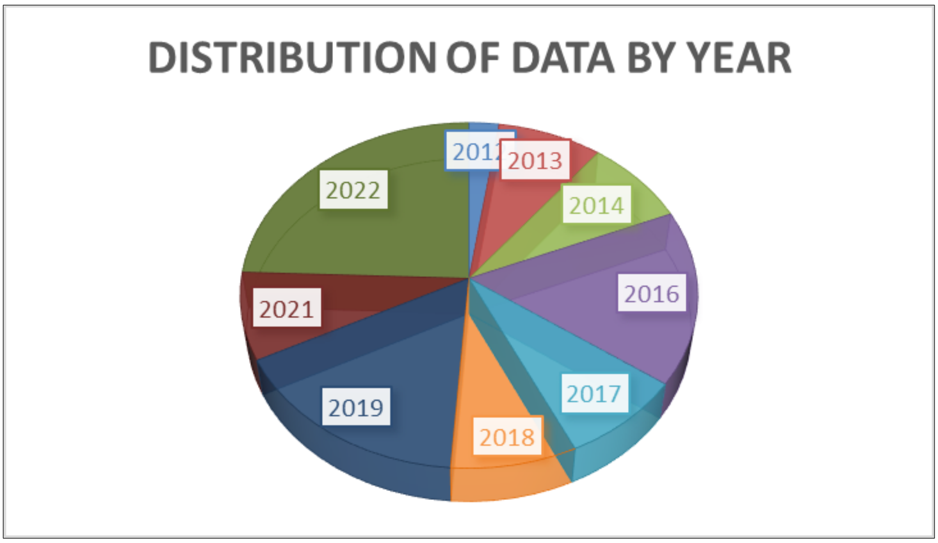

Figure 3 Distribution of data by year of article publication

The following stage indicates that the (n=61) article was excluded due to insufficient qualitative and quantitative analysis. The final stage showed (n=14) articles were synthesized, which extracted all data related to wastewater treatment by electrocoagulation. The distribution of data accepted by year according to the range is presented in Figure 3. Literature studies show the best results utilizing electrocoagulation in several industrial wastewaters (Table 1).

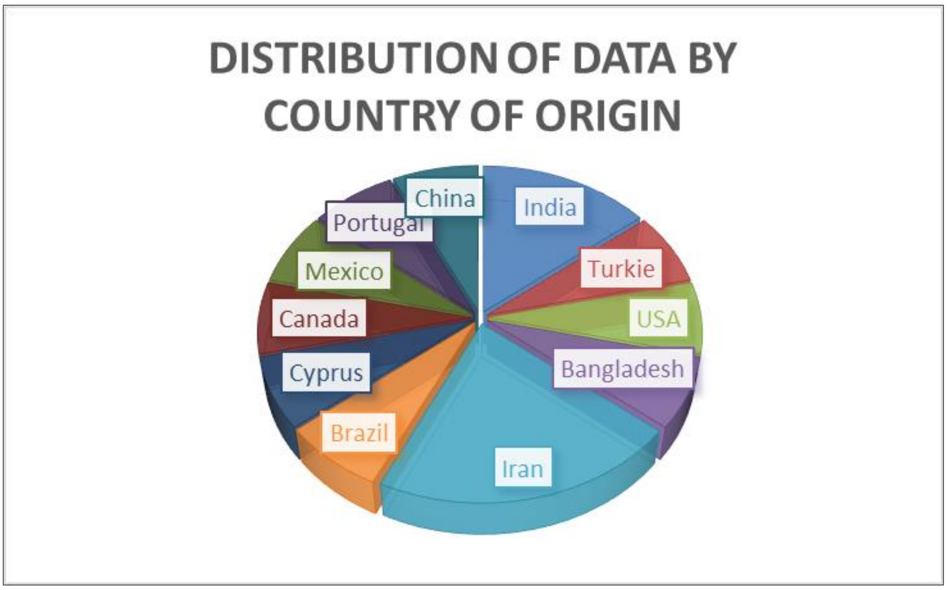

Figure 4 Distribution of data by country of origin

Table 1 Optimal conditions for several electrocoagulation measurements

No	Electrodes	pH	Density	Time	Waste	Literatur
1	Fe-Al	-	18.18 mA	40 min	Slaughterhouse	[1]
2	Fe-Fe	7	10 mA	25 min	Biodiesel	[2]
3	Fe-Al	7	12V	40 min	Bakery Industry	[5]
4	Al	-	3.16 A	After 20 min	Chocolate	[8]
5	Al-Al	4	15 mA	60 min	olives	[13]
6	Fe-Al	6	30V	150min	Oil refinery	[16]
7	Al-stainless steel	-	15V	60 min	Cork Boiling	[17]
8	ACEC	-	0.5V	4H	Wastewater	[19]

4. Discussion

4.1. Electrocoagulation for wastewater treatment

Electrocoagulation is an advanced, effective, and advantageous wastewater treatment method [1, 6]. It is a complicated process involving chemistry and physics [6]. Electrocoagulation drives it possible to treat water with organic matter and suspended solids. Electrocoagulation combines flotation, coagulation, and oxidation or reduction of pollutant compounds [8]. Electrocoagulation is effective for treating organic and inorganic pollutants, as it combines the benefits of coagulation-flocculation, flotation, and electro-oxidation/reduction [1].

Electrocoagulation-flocculation is one of the novels and efficient methods for industrial wastewater treatment [16]. The advantages, i.e., flexibility, environmental compatibility, energy efficiency, cost-effectiveness, better automation, and not requiring chemicals [13]. Electrocoagulation is considered an additional environmentally friendly process, and the efficiency of the electrocoagulation process depends on operational parameters, i.e., current density, conductivity, period, temperature, and initial pH [17]. Electrocoagulation refers to emerging technologies based on complicated mechanisms for reducing pollutants from wastewater [13].

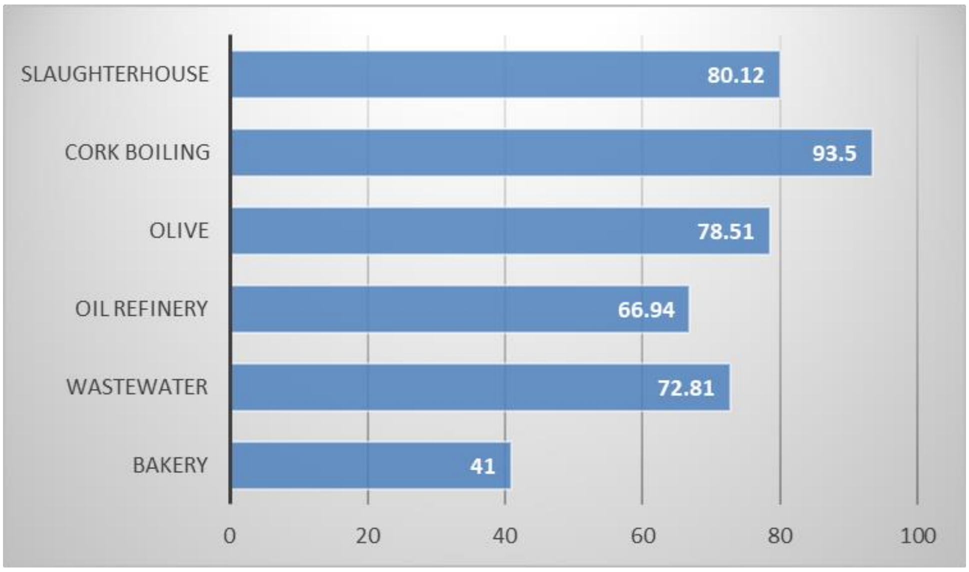

Figure 5 COD removal in some wastewater by electrocoagulation

Electrocoagulation is a process with the dissolution of a sacrificial anode, which consists of coagulant production [8]. The ions are hydrolyzed to polymeric iron or aluminum oxyhydroxides, which are coagulating agents. In the electrocoagulation procedure, coagulation ions are effected in situ by applying three steps (a) electrolytic reaction at the surface of the electrode, (b) formation of coagulant in the aqueous phase, and (c) adsorption of soluble or colloidal pollutants on the coagulant, which are removed by sedimentation or flotation. Iron (Fe) and aluminum (Al) have been widely used as sacrificial electrodes in EC processes [14]. An anode and cathode are needed in electrocoagulation to carry out the treatment. The anode acts as a sacrificial electrode and, by in-situ electro-dissolving, provides the system with a coagulating agent. These anodes can be formed of aluminum, copper, magnesium, iron, zinc, and stainless steel [8]. The electrocoagulation process's efficiency depends on operational parameters, i.e., current density, conductivity, time, temperature, and initial pH [17]. Testing on COD and TSS parameters is shown in diagrams in Figure 5 and Figure 6.

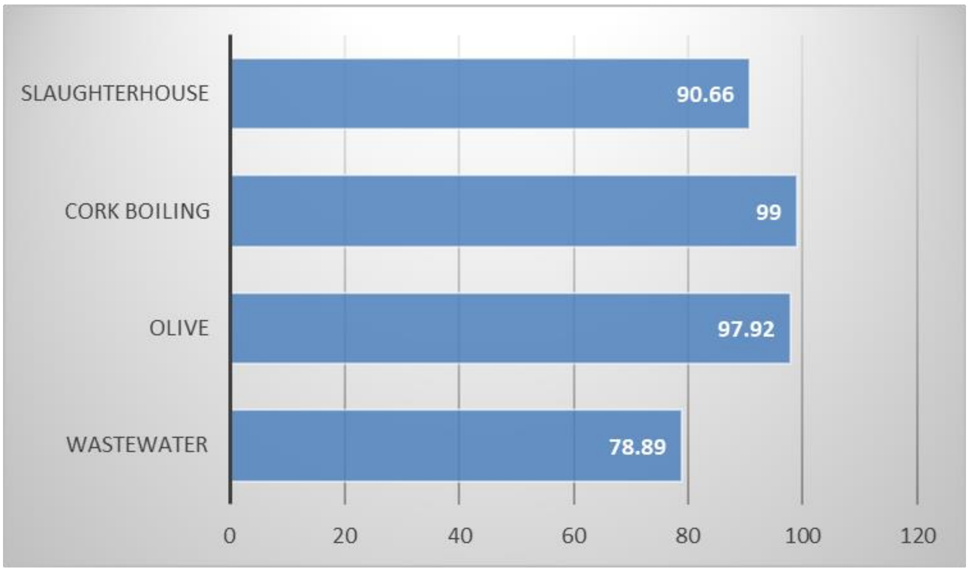

Figure 6 TSS removal in some wastewater by electrocoagulation

Chemical Oxygen Demand (COD) is the oxygen required to oxidize organic pollutants in wastewater [9]. COD is a crucial parameter in oily wastewater [3]. Electrocoagulation is one of the methods used to treat waste to remove COD [9]. COD is a residue primarily contributed by suspended insoluble organic matter and colloidal particles with a particle size greater than 13 nm [12]. Many studies have been carried out regarding the effect of electrocoagulation in removing oil, colour, COD, TPC, and turbidity from food or industrial waste [13]. The effect of different operating parameters on the efficiency of oily wastewater treatment on COD and BOD reduction [3]. The chemical dissolution rate completes one of the critical characteristics of electrocoagulation. Experiments on cork boiling wastewater, highest % COD removed after 60 minutes of reaction utilized the energy of 39.10 W [17]. The COD removal process in wastewater investigated under optimal conditions of the electrocoagulation method can be enhanced with H_2O_2 & PAC [4]. In addition, the waste's initial pH impacts the removal of COD [14].

Total Suspended Solid (TSS) is one of the determinants of the level of wastewater pollution. TSS is a sedimentary material that floats in wastewater and moves without handling the depths of the waters, exploited by inputs from land factors, river flow, and oceanography. TSS is closely correlated to sedimentation, which can harm aquatic ecosystems [20]. Wastewater contains high TSS, including oily wastewater [11]. Electrocoagulation, when approximated to conventional treatment, the major distinction is in the ability to remove COD and TSS [7]. The same results in the cork boiling wastewater experiment utilizing the electrocoagulation method after 60 minutes, utilizing an Al-Stainless steel electrode with a density of 15 V, had the best results in removing TSS of 99% [17].

4.2. Development of Electrocoagulation

Downflow Column Electrochemical Reactor (DCER) is applied to accept the electrocoagulation process to remove organic and inorganic matter from chocolate industry wastewater. Based on a study, the DCER consists of a downcast parallel flow column, cylindrical (100 cm in high and 5 cm in diameter) with a capacity of 2 L (Figure 7). This study concluded that the first 5 minutes of treatment was critical for COD and color removal. During this period, the interaction of electric current and liquid volumetric discharge was the factor that had the most significant effect on COD removal. Regarding decolourization, it was concluded that there was no significant difference in the effect of any of the studied variables until the 10 minute, where the effect of the electric current became statistically significant [8].

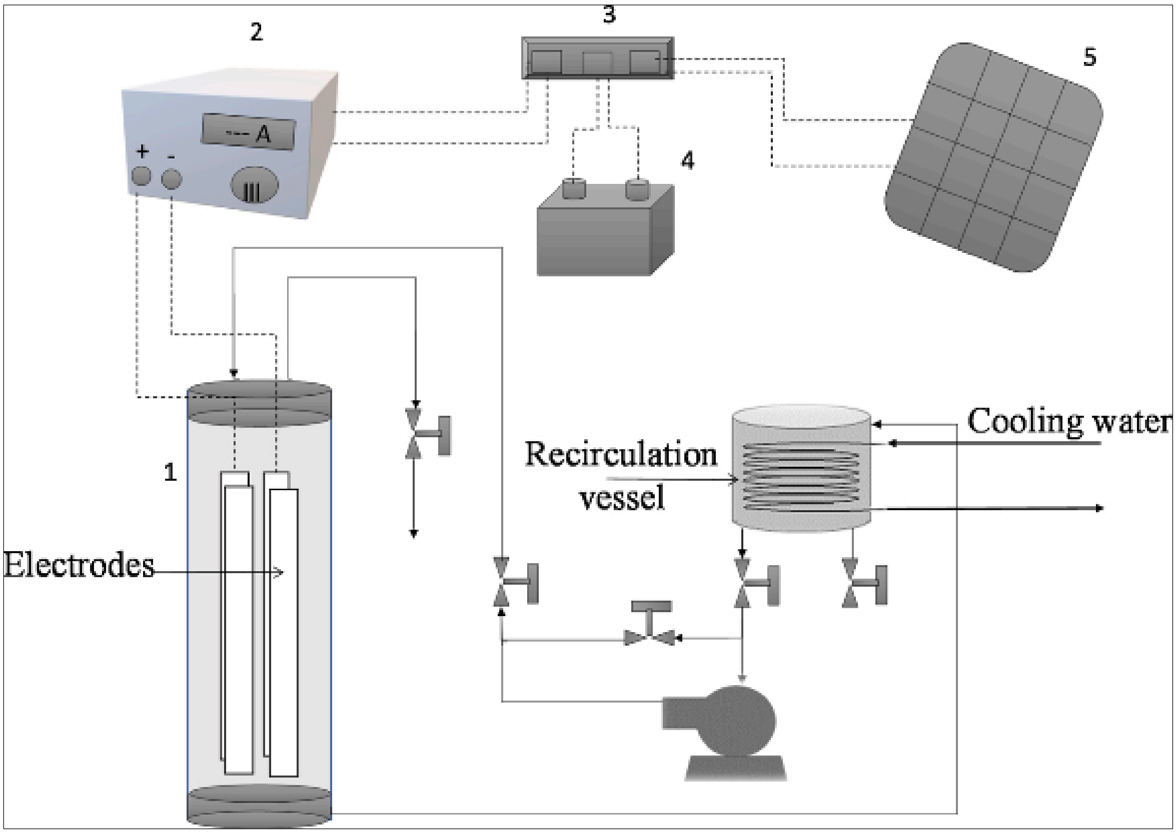

Figure 7 Downflow Column Electrochemical Reactor-DCER (1), current control (2), solar charge controller (3), battery (4), solar panel (5), and breaking vessel (6) [8]

Another applied performance in a two-stage procedure integrating anaerobic digestion and electrocoagulation was studied for slaughterhouse wastewater treatment. Anaerobic digestion is used as the primary treatment, while electrocoagulation is used as the secondary treatment [1]. Whey wastewater is considered the major polluting product of the dairy industry. Electrocoagulation and electrooxidation techniques utilizing aluminum and inactive boron-doped diamond (BDD) electrodes, respectively, are applied to reduce chemical oxygen demand (COD), total nitrogen (TN), phosphate (PO_4^{-3}), nitrate (NO^{3-}), chloride (Cl^-), total phenolic compounds (TPC), and optical density [6]. The electrocoagulation removal, particularly of the oil/fat content (usually inaccurately released in grease traps), declined to negligible values in the short treatment periods [5].

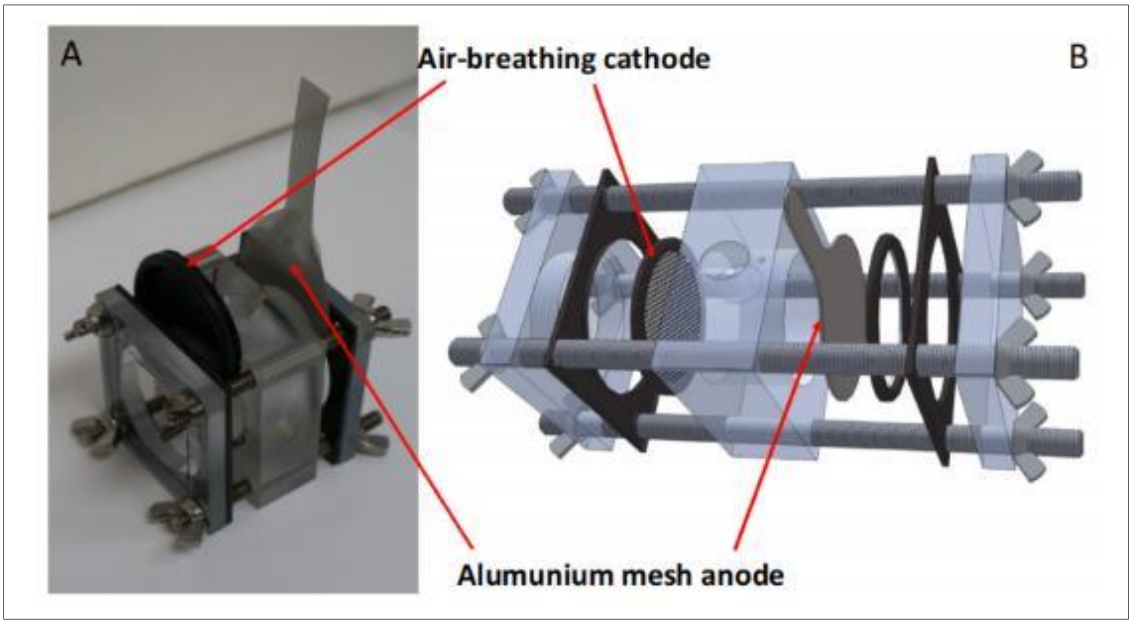

Figure 8 Schematic diagram (right) and photo of the electrocoagulation reactor with an air cathode (left) [19]

Electrocoagulation is effective for treating different types of wastewater, but its application is limited due to heightened energy requirements and current density. Operating air cathode electrocoagulation (ACEC) (Figure 8), a thermodynamically appropriate activated carbon air cathode, and a sacrificial aluminum anode can perform acceptable nutrient removal rates with declined energy requirements approximated to previous electrocoagulation methods. The air cathode developed for MFC applications does not require a precious metal catalyst. As a substitute, inexpensive activated carbon can be operated, with the cathode produced utilizing different methods of pressing or rolling [5].

5. Conclusion

Wastewater treatment utilizing the electrocoagulation method has recently accepted extensive attention in the study. However, this method has been approximately for a lengthy period, and its application in wastewater treatment has accepted extensive attention recently. Electrocoagulation is thought effective for removing COD and TSS pollutants in wastewater, including waste with oil content. Although this method utilizes a large amount of energy in its operation, several studies have developed to reduce energy consumption, i.e., DCER. Based on the experiment, the DCER consists of a downward parallel flow column shaped like a cylinder (100 cm in height and 5 cm in diameter) with a capacity of 2 L. It concluded that the first 5 min of the treatment is critical regarding COD and color removal. Another use of air cathode electrocoagulation (ACEC) (Figure 8), a thermodynamically favorable activated carbon air cathode and a sacrificial aluminum anode can achieve good levels of nutrient removal with reduced energy demands compared to previous electrocoagulation systems.

Compliance with ethical standards

Acknowledgements

All parties who supported the script of this systematic review.

Disclosure of conflict of interest

All authors declare that they have no conflicts of interest in connection with this paper, and the material described is not under publication or consideration for publication elsewhere.

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