sustainability

Review

Recent Applications of the Electrocoagulation Process on Agro-Based Industrial Wastewater: A Review

Rakhmania [1,†], Hesam Kamyab [1,2,*,†], Muhammad Ali Yuzir [1], Norhayati Abdullah [1], Le Minh Quan [1], Fatimah Azizah Riyadi [1] and Riadh Marzouki [3,4]

[1] Department of Chemical and Environmental Engineering (ChEE), Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia; rakhmania99@gmail.com (R.); muhdaliyuzir@utm.my (M.A.Y.); norhayati@utm.my (N.A.); quanmle1505@gmail.com (L.M.Q.); fatimahriyadi@gmail.com (F.A.R.)

[2] Department of Electric Power Stations, Network and Supply Systems, South Ural State University (National Research University), 454080 Chelyabinsk, Russia

[3] Chemistry Department, College of Science, King Khalid University, Abha 61413, Saudi Arabia; rmarzouki@kku.edu.sa

[4] Chemistry Department, Faculty of Sciences of Sfax, University of Sfax, Sfax 3029, Tunisia

* Correspondence: hesam_kamyab@yahoo.com

† These authors contributed equally to this work.

Citation: Rakhmania; Kamyab, H.; Yuzir, M.A.; Abdullah, N.; Quan, L.M.; Riyadi, F.A.; Marzouki, R. Recent Applications of the Electrocoagulation Process on Agro-Based Industrial Wastewater: A Review. *Sustainability* **2022**, *14*, 1985. https://doi.org/10.3390/su14041985

Academic Editor: Agostina Chiavola

Received: 1 November 2021
Accepted: 22 December 2021
Published: 10 February 2022

Abstract: Agro-based final discharge is one of the major contributors to wastewater in the world. It creates high demand for efficient treatment. The electrocoagulation process can be used for agro-based wastewater treatment. The performance of the electrocoagulation process is based on several parameters, including the electrode materials, electrolysis time, current density, and electrolyte support. Agro-based industrial wastewater (AIW) treatment processes depend on the characteristics of the wastewater. The removal of organic content from various sources of AIW can reach up to more than 80%. Some studies show that the performance of the electrochemical process can be increased using a combination with other methods. Those other methods include biological and physical treatment. The results of previous research show that organic content and color can be degraded completely. The relationship between the energy consumption and operating cost was analyzed in order to show the efficiency of electrocoagulation treatment.

Keywords: wastewater treatment; color removal; oily wastewater; energy consumption

1. Introduction

Many industrial activities nowadays have become a major source of pollutants due to their wastewater discharge [1,2]. One type of wastewater comes from the agro-industry [3]. Agro-based industrial wastewater (AIW) has a high number of organic compounds, inorganic salts and reactive dye [4]. These pollutant compounds cause several problems for the aquatic environment, such as eutrophication [5], pathogen contamination, oil and grease pollutants, etc. [6]. Therefore, it is necessary to treat the wastewater final discharge to reduce the toxicity for the environment [7,8].

There are several methods of treatment process according to the type and characteristics of the AIW, such as conventional treatment using the physicochemical method, and biological methods like microalgae treatment [9] for nitrogen [10] and phosphorus removal [11]. The selection of the method depends on the regulation of permissible wastewater released to the environment, the industrial stream capacity, the economical cost [12], the impact on the environment, and the possibility of toxic by-product formation [13]. Advanced technologies such as membrane filtration, ultrafiltration and reverse osmosis have also been used for AIW treatment [14]. The conventional treatment using physicochemical methods for AIW treatment includes coagulation–flocculation, adsorption, precipitation, and flotation etc. They have several disadvantages, such as high chemical consumption [15], high sludge production and energy costs [16].

The conventional biological method includes aerobic and anaerobic processes. They possess a large number of microorganisms for the biodegradation of organic pollutants. However, this method is laborious, produces biological sludge, has low biodegradability on certain molecules (i.e., dyes), and is energy-intensive [17,18]. The sludge formation requires further treatment, which consumes about 50% of the operational cost of the wastewater treatment plant (WWTP) [19]. The sludge treatment including lime stabilization that commonly uses calcium hydroxide [20]. It can reduce the portion of solid organic matter to 30%, and can reduce 99% of fecal coliforms [21]. Wet air oxidation (WAO) has been used for sludge treatment [22]. It is suitable for the oily sludge type; it can remove 93.1% of the oil from the sludge, and can reduce the volume of oily sludge to 85.4% [23]. The thermal drying used for sludge treatment acquires 10–80% removal of alkylphenols, polycyclic aromatic compounds and mercaptobenzothiazole [24]. The sludge is then disposed of using several methods, such as composting, incineration, or open landfill, etc. [25]. The overall biological cost analysis at WWTP resulted in 0.1345 $€/m^3$ of treated wastewater [26].

An application of microalgae on AIW treatment is used currently as a developed alternative approach. The microalgae method could remove the organic compound according to a previous study, but most of the performance achieves less than 50% removal [27,28]. A major challenge from the application of microalgae is the environmental stability of the culture when used outdoors [29]. The microbial fuel cell (MFC) system can be used for AIW treatment and the generation of bio-electricity at the same time [30]. In general, 1.06 kg of COD contained in wastewater could be converted to 4.41 kWh bio-electricity power [31]. Other than bio-electricity, this system also produces biogas during the process. The biogas usually contains H_2S, which is toxic and requires additional cost for removal [32].

Advanced-technology treatment has been applied for some types of AIW [33]. This system has been chosen due to its small space requirements and lack of chemicals required [34]. The main problem with membrane-related systems is fouling, which can reduce the membrane's efficiency performance [35]. In addition, this system also has disadvantages in terms of its high energy requirements due to high operation and maintenance costs, limited flow rates, the high expertise required for membrane selection, and not being suitable for low solution concentrations [36].

The electrocoagulation process is gaining attention for wastewater treatment due to its high efficiency to degrade pollutants, easy operation and maintenance, lack of chemical required, and relatively low energy consumption. In addition, this process can degrade organic pollutants completely into CO_2 and water [37]. Electrocoagulation has been applied and investigated in different stages of AIW wastewater treatment, including the pre-treatment, main treatment and polishing stages [13,38]. Studies conducted by some researchers show the use of the electrocoagulation process to treat different types of wastewaters, such as dairy wastewater [39], sugar industry wastewater [40], paper mill wastewater [31], and olive oil mill wastewater [41], etc. However, there is no report specifically reviewing the recent application of electrocoagulation treatment for AIW. Thus, this paper presents an exhaustive critical review of the recent application of the electrocoagulation process for the last nine years. The fundamental theories on electrocoagulation are described. The recent applications of the electrocoagulation process on various types of AIW are discussed, as well as the combination of electrocoagulation with other methods. Moreover, the relationship between specific energy consumption and the operating cost was analyzed.

2. Methods

This section analyzes all of the literature related to the AIW treatment by the electrocoagulation process identified during the period 2013–2021.

2.1. Data Source and Strategy

An exhaustive search of peer-reviewed literature was conducted in the Scopus database to select the scientific articles related to the electrocoagulation process on AIW treatment. The various types of AIW include olive oil mill wastewater, sugar industry wastewater, pulp and paper mill wastewater, palm oil mill effluent, coffee industry wastewater, vegetable oil refinery wastewater and nut processing wastewater. Because there are redundant papers for the electrocoagulation of AIW, the keywords are specified. The specified selected keywords were electrocoagulation, olive oil mill, sugar industry, pulp and paper mill, palm oil mill effluent, the coffee industry, vegetable oil and nuts. The keyword of wastewater was excluded in order to reduce the probability of redundant papers.

The literature was limited to the publications of scientific articles written in English from 2013 to May 2021, covering the period of the last nine years. The publication date, names of the authors, title and abstract of each paper found were listed to be further revised individually and manually. All of the publications with specified selected keywords were included. Review papers, conference papers, letters to the editor, books and short surveys were excluded.

2.2. Bibliometric Analysis

Figure 1 shows the annual distribution of a total of 71 publications that were found. Even though there were a number of publications from 2015 until 2021 (May), the highest number of publications in 2017 and 2019 indicate that the electrocoagulation process has become of great attention for AIW treatment. According to the selected publications, around 74% use a single treatment of electrocoagulation and 25% use electrocoagulation combined with other methods. It was also found that two scientific articles reported on biogas production from the electrocoagulation treatment of AIW.

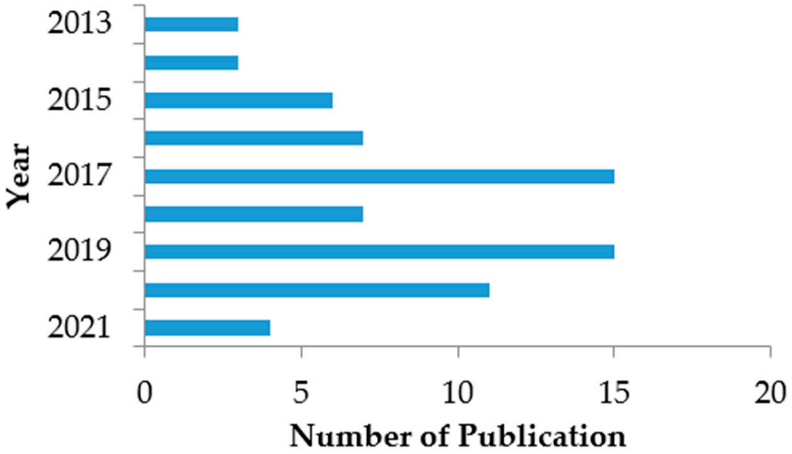

Figure 1. Number of publications by year.

Most of the publications use real AIW for the treatment by the electrocoagulation process, and only one scientific article reported on the electrocoagulation process using simulated wastewater. As the recent application of electrocoagulation is still on the laboratory scale, it was noticeable that there was one scientific article reporting the application of the electrocoagulation process at the pilot scale in 2019. This indicates an important challenge for future research on the scaling-up of the electrocoagulation process at the industrial level.

3. Fundamental

3.1. Coagulation Principal

Coagulation is a traditional physicochemical treatment using phase separation for the pollutants of wastewaters before they are released to the environment [42]. The addition of inorganic or organic compounds to the coagulation process destabilizes the particles, affecting the electrical double layer (EDL). The impact to the environment from the coagulation process in the generation of sludge makes the concern more serious in terms of management, treatment and operational cost [43]. The sludge also contains residual metal ions from the coagulation process [44].

Chemicals known as coagulants lower the energy barrier between particles. As a result of the weak bond, the particles can agglomerate more easily [45]. Aluminium and iron metal salts are common coagulants used in wastewater treatment. Both metals can produce multivalent ions such as Al^{3+}, Fe^{2+}, and Fe^{3+}, as well as a variety of hydrolysis products. Because it oxidizes to Fe (III) during the coagulation process to increase efficiency, Fe (II) is a poor coagulant [46]. Simple aluminium, iron sulfates, and chlorides are the most commonly used salts [47]. The non-hydrolyzed metal coagulants include $Al_2(SO_4)_3$, $FeSO_4$, $AlCl_3$ and $FeCl_3$ [48]. Meanwhile, there is another metal coagulant that comes with several advantages, which is named pre-hydrolyzed metal coagulant [49]. Examples of pre-hydrolyzed metal coagulants are polyaluminum chloride and sulfates [50]. The pre-hydrolyzed metal coagulants have advantages such as being more effective than non-hydrolyzed metal coagulants and less sensitive to changes in pH and temperature [51].

3.2. Electrocoagulation

Electrocoagulation by using metal hydroxide has a high ability to adsorb pollutants [52]. The electrode materials commonly use Al and Fe. When the electricity is supplied into the electrode, the electrode will generate ions (Fe^{2+}, Fe^{3+}, and Al^{3+}) and produce the coagulant. The electrocoagulation reaction is usually followed by an electro-flotation reaction [53]. The aluminium anode generates cationic forms such as Al^{3+} and $Al(OH)^{2+}$ in acidic conditions. However, in alkaline conditions, these species are transformed into Al $(OH)_3$, dimer compounds such as $Al_2(O)(OH)_4$ and $Al_2(OH)_2{}^{4+}$. They can also can be transformed into a more complex compound [54].

Figure 2 shows the schematic diagram of electrocoagulation. Several reactions happen during electrocoagulation for the production of hydroxides. For the electrode materials using aluminium, the oxidation takes place at the anode, as follows:

$$\mathrm{Al} \rightarrow \mathrm{Al}^{3+} + 3\,\mathrm{e}^{-} \tag{1}$$

$$\text{Acid medium}: \; 2\,\mathrm{H_2O} \rightarrow 4\,\mathrm{H}^{+} + \mathrm{O_2} + 4\,\mathrm{e}^{-} \tag{2}$$

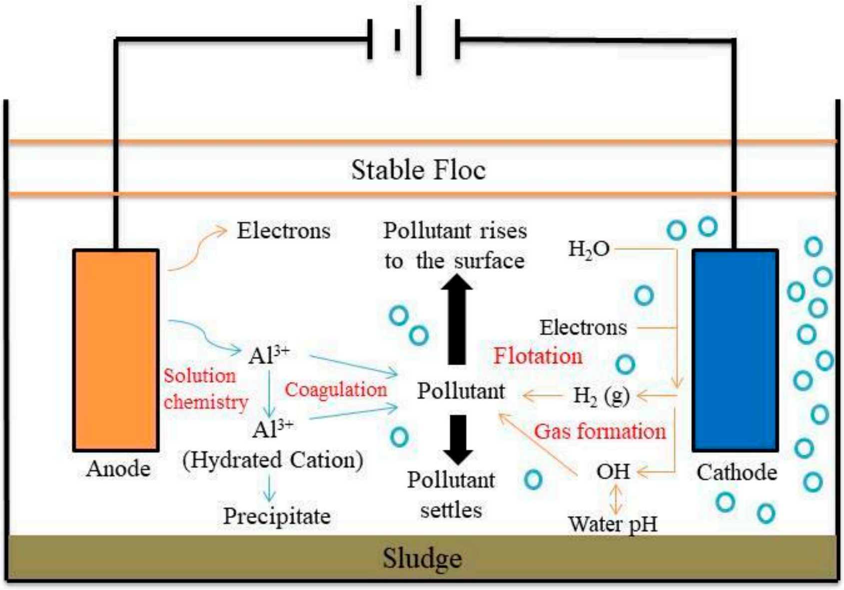

Figure 2. Schematic diagram of the electrocoagulation process.

In addition, a secondary reaction possibly occurs during the oxidation process. The formation of oxygen by the electrolysis of water is divided into two conditions: acidic and basic media.

$$\text{Basic medium}: \ 4\,OH^- \rightarrow O_2 + 2\,H_2O + 4\,e^- \quad (3)$$

$$\text{Solution medium}: \ Al^{3+}{}_{(aq)} + 3\,H_2O \rightarrow Al(OH)_{3(s)} + 3\,H^+{}_{(aq)} \quad (4)$$

$$\text{Basic medium}: \ 2\,H_2O + 2\,e^- \rightarrow 2\,OH^- + H_2 \quad (5)$$

The reaction that happened in the cathode is a reduction in water based on different conditions, as follows.

In Equation (1), the Al^{3+} produced on the electrode react to form several species, including:

- monomeric species such as $Al(OH)^{2+}$, $Al(OH)_2{}^+$, $Al_2(OH)_2{}^{4+}$, and $Al(OH)_4{}^-$;
- polymeric species such as $Al_6(OH)_{15}{}^{3+}$, $Al_7(OH)_{17}{}^{4+}$, $Al_8(OH)_{20}{}^{4+}$, $Al_{13}O_4(OH)_{24}{}^{7+}$ and $Al_{13}(OH)_{34}{}^{5+}$;
- amorphous species with very low solubility, such as $Al(OH)_3$ and Al_2O_3 [55].

The formation of amorphous $Al(OH)_3$, also called sweep flocs, needs surface areas which are useful for the adsorption of soluble pollutants and the trapping of the colloidal compounds [56]. The polymerization of flocs is as follows:

The flocs can be easily removed from an aqueous medium using the sedimentation method and H_2 flotation. However, aluminium hydroxide usually acts as an adsorbent or traps the pollutants. It would be a great composition for the removal of the organic compound from the solution [57].

4. Factors Affecting Electrocoagulation

There are several factors that affect anodic oxidation performance in wastewater treatment. There are electrode materials, electrode distance, electrode arrangements, pH, current density, reaction time, conductivity and temperature.

4.1. Electrode Materials

Electrode materials are one of the important factors affecting the electrocoagulation process performance [58]. Several types of anode materials have been used in the electrocoagulation process, such as Fe, Graphite, Al, stainless steel, and steel wool, etc. [59–61]. One of the anode materials available in the electrochemical industry is a lead-based anode. It is widely used due to its low cost in comparison to other materials. They are including lead–calcium (0.7%)–tin, lead–strontium (0.05%)–tin (0.6%), and lead–antimony (6%) [62]. The lead-based anode has significant drawbacks, including high energy consumption and low corrosion resistance [63]. Corrosion gives effects in terms of the electrode lifespan and the production of a poor quality of electrochemical reaction [64].

Three-phase-3D electrode electrocoagulation can potentially be used for agro-based industrial wastewater. The previous study reported the performance of chromium removal from wastewater using 3D NiO/NF electrodes. This achieved the 99.5% removal of chromium within 20 min at the applied potential of 0.97 V [65]. Another study reported on ground wastewater treatment using 3D Al electrode resulted in 98.6% arsenic removal [66].

4.2. Electrode Distance

The distance between the anode and the cathode has a crucial role due to the electrostatic field that forms in the gap [67]. The electrostatic field strength is substantial, as it attracts the ions generated from the plates during the EC process [68]. The distance between the electrodes varies from 1 cm to 11.5 cm. When the distance is too close, the transfer of solids and fluids is hampered. The accumulation of solid particles and bubbles between the anodes and cathodes results in increased electrical resistance. However, when the distance is longer, it increases the travel time of the ions, thus leading to a decrease in the electrostatic attraction which subsequently reduces the formation of flocs [69].

$$n\text{Al(OH)}_3 \rightarrow \text{Al}n\text{(OH)}_{3n} \tag{6}$$

4.3. Electrolysis Time

Faraday's law states that the amount of metal ions released from an anode is proportional to the electrolysis time and current intensity. The equation is expressed as follows:

$$m = \frac{i \times t \times M}{n \times F} \tag{7}$$

where m is mass of metal dissolution (g), i is current density (A), t is the electrolysis time, M is the molecular weight of the metal, n is the number of electrons involved in the oxidation reaction, and F is Faraday's constant (96,500 Cmol^{-1}). When the electrolysis time is increased, then the metal ions released are high. Therefore, the performance of organic pollutant removal is also increased. However, at a certain point of electrolysis time, the rate of removal is slowed down [70]. This is due to the occurrence of electrode passivation, which occurs when the electrolysis process is operated for an extended period of time; it is recognized as being detrimental to the electrochemical process performance. The electrode material is also a factor in electrode passivation [71].

4.4. Current Density

One of the parameters is the current density, which is used in EC specifically for the kinetics of reduction of COD and decolourization. Because of the high dissolution of the electrodes, the electrolysis time decreases as the current density increases. This results in the further destabilization of the pollutant particles. Furthermore, as the current density increases, the rate of production of hydrogen bubbles increases, while their size decreases. All of these effects are advantageous for efficient pollutant removal via flotation [72].

4.5. Electrolyte Support

The role of electrolyte support is to increase conductivity [73]. Therefore, the voltage applied between the electrodes at a constant current density due to the decrease in the resistance of the polluted water can be reduced [74]. Some of the electrolyte supports that have been used for the electrochemical process include NaCl, Na_2SO_4, and $NaCO_3$, etc. Most of the studies use NaCl as the electrolyte support. This is because of the properties of NaCl which produce chloride ions. The chloride ions can reduce the significantly undesirable effects of other anions [75]. NaCl is also known as a contributor of strong oxidizing agents and hence the increase of color removal [76]. In comparison to sulfate and nitrate, chloride was the best supporting electrolyte for the electrochemical oxidation of refractory organic pollutants [77].

5. Type of Agro-Based Wastewater

5.1. Olive Oil Mill Wastewater

In general, olive oil mill wastewater (OOMW) consists of 80–83% water, 15–18% organic compounds, and 2% inorganic compounds [78]. OOMW has the characteristics of being dark in color, having an acidic pH (~5), and having highly toxic components including tannins, phenols and acid compounds making up about 37% of the total mass [79,80]. It has been reported that more than thirty types of phenolic compounds have been identified. Table 1 shows the characteristics of OOMW. The concentration ranges between 0.5 and 24 g/L. The COD content in OOMW is quite high, and can reach up to 175,000 mg/L. The BOD content is 25,000 mg/L, while the total solid content is 99,000 mg/L [81].

Table 1. Characteristics of olive oil mill wastewater [82,83].

Parameters	Units	OOMW
COD	mg/L	175,000
BOD	mg/L	25,000
pH	-	4
Oil and Grease	mg/L	13,000
NH_3-N	mg/L	37
TSS	mg/L	99,000
PO_4^{3-}	mg/L	57.5
NO_3^-	mg/L	395

The electrocoagulation process can be used for OOMW because it decomposes the organic compound and is commonly used for OOMW treatment [84]. Electrocoagulation has stability for colloids, suspension and emulsion, which is affected by electric charge. When an electric charge is supplied into a suitable electrode, the compound will be neutralized and the rest of it will aggregate together into a larger and separable compound [85].

A study showed that electrocoagulation can remove COD by up to 78% after 1 h of electrolysis time using Fe as the electrode. The energy consumption reaches 55 kWh m^{-3}. However, using Al as the electrode, the removal of COD has a lower value than that using Fe. The removal efficiency is only 55% for 1 h of electrolysis time. It also acquires higher energy consumption until 62 kWh m^{-3} [86]. The reduction of the energy consumption using Al as an electrode can be acheived by diluting the sample 10 times. The study reported that the energy consumption was decreased to 1 kWh/L with 57% COD removal [87]. The kinetic model of the electrocoagulation process using the one-factor method increases the performance of COD removal to 99% with conditions of 60 min electrolysis time, with the current density at 12.5 mA/cm^2 and the addition of 400 mg/L NaCl [88]. The study conducted by Benekos [89] compared the performance of electrocoagulation on a laboratory scale and pilot scale. The results show on the laboratory scale that the COD and color removal (50% and 100%, respectively) is higher than that at the laboratory scale (42.5% and 85.3%, respectively).

The electrocoagulation process on OOMW is useful as a pre-treatment for biofuel production [85]. The methane production reaches 1902 kJ/L_{OOMW}. The treatment of COD removal also produces biogas, as reported by a previous study. The result shows that the COD removal of OOMW using the electrocoagulation process produces biogas around 0.741 g/L_{COD} [90].

5.2. Sugar Industry Wastewater

The sugar industry categorized as one of the largest agro-based industries. It uses about 1500–2000 dm^3 water and produces about 1000 dm^3 wastewater per ton of processing [91]. The wastewater mainly results from the process of floor washing, condensation, leakage, and spillage of solutions from the pipeline and valve [92]. The sugar wastewater industries (SIWW) have a high concentration of organic materials due to the presence of sugar and organic material in the cane or beet. SIWW contains organic compounds including COD ranging between 2300 and 8000 mg/dm^{-3}, BOD of about 1700–6600 mg/dm^{-3}, and TSS of about 5000 mg/dm^{-3} [93]. In addition, SIWW also possibly contains pesticides, herbicides and pathogens from the contaminated material and processes which are produced [91].

The electrocoagulation process becomes one of the choices to be considered for SIWW treatment when the conventional method can not reduce the pollution [94]. The previous study reported that COD removal on SIWW treatment can reach 86.36% for 8 h of electrolysis time. The 12 V voltage is applied to the system without any pre-treatment. Using iron as an electrode increases the COD removal of SIWW, which reaches up to 84% for 2 h electrolysis time. The color reduction is about 86% with the current density of 178 A/m^2. The lowest energy consumption utilized is 16.75 kWh/L. However, the performance of

COD removal decreases to 62%. This result does not suffice for the final discharge of wastewater; therefore, further advanced methods could possibly be applied to bring the wastewater to meet the final discharge [95].

Different cases happened with simulated sugar industrial effluent using the research surface method to study the effects of various parameters using the research surface method (RSM). The maximum COD removal of about 83.94% is obtained with the energy consumption of 6.64 kWh kg^{-1}. This system requires less energy. This study suggested that electrocoagulation potentially can be applied for the treatment of real sugar effluent [96].

5.3. Pulp and Paper Mill Wastewater

The pulp and paper industry produces highly polluted wastewater [97]. It forms black liquor as the main by-product, which contains about 50% lignin. The pulp and paper industry discards lignin to make a good quality of paper [98]. The release of lignin comes from the process of alkaline extraction at the bleaching stage. Lignin is a heterogeneous three-dimensional polymer that consists of oxy phenylpropanoid components. The contamination of phenolic compounds to the environment could damage the underground water and receiving water bodies [43].

The electrocoagulation process is one of the great alternatives to treat pulp and paper mill wastewater. Aluminium and iron are widely used as electrodes for the electrocoagulation process. A study showed that iron has greater efficiency for BOD and COD removal compared to aluminium. The performance of iron can reach up to the complete removal of COD and 90% removal of BOD within a 60 min reaction [99]. Other concerns for pulp and paper mill wastewater are lignin and phenol. By using iron as an electrode material, the electrochemical process can degrade lignin and phenol by up to 90% [93].

5.4. Palm Oil Mill Effluent

Palm oil mill effluent (POME)'s typical liquid waste results from the extraction of fresh fruit bunch (FFB) in the palm oil industry [100,101]. The characteristic of POME is a thick brownish liquid color due to the decomposition of lignocellulosic materials [102,103]. Table 2 shows the characteristics of POME. POME has acidity ranging from pH 4.0 to 5.0, chemical oxygen demand, biological oxygen demand, and total suspended solids ranging from 15,000 to 100,000 mg/L, 10,250 to 43,750 mg/L and 5000 to 54,000 mg/L, respectively [104].

Some studies have found the performance of the electrochemical process for POME treatment. Using Al as the electrode shows little removal of COD and BOD. The percentage of COD and BOD removal is 30% and 38%, respectively [105]. However, the addition of $NaNO_3$ could improve the performance of the electrochemical process using Al. The efficiency of COD removal increases by 64%. Using $NaNO_3$ as the electrolyte support is also beneficial for subsequent biological treatment [106].

Table 2. Characteristics of palm oil mill effluent [107–109].

Parameters	Units	POME
COD	mg/L	75,000
BOD	mg/L	18,200
pH	-	4.6
Oil and Grease	mg/L	2000
NH_3-N	mg/L	20
TSS	mg/L	50,000
PO_4^{3-}	mg/L	15
NO_3^-	mg/L	500

Another method uses iron for the electrochemical process. The performance of iron is quite great, with 89.2% removal of COD in 15 min of electrolysis time. For another good value, using iron as an electrode could remove the color by up to 90.4% [110]. In addition, steel wool can be used as an electrode. It could remove COD by up to 74% and BOD by up to 70% with the improvement of the electrode arrangement [111].

5.5. Coffee Industry Wastewater

Coffee is one of the world's most well-known beverages, and it is the world's second-most-traded commodity after petroleum [112]. The wastewater produced from the coffee processing industry ranges from 40 to 45 L for every kg of coffee [113]. The process requires large amounts of water for every step; therefore, the wastewater produced is high [114]. Coffee fruits themselves are rich in caffeine, sugars, phenolic compounds, fatty acids, lignin, cellulose, pectic substances and other macromolecules [115]. Those compounds are not suitable to be released into the environment due to their toxicity [116].

Coffee processing wastewater (CPWW) is characteristically black in color. It is high in persistent compounds known as melanoidins, which are toxic, recalcitrant and non-biodegradable [117]. Releasing the untreated CPWW to the water body can promote eutrophication, reduce Secchi depth and prevent sunlight penetration. The concentration of oxygen in the water body will be depleted [118]. The electrocoagulation process can be used for the decolorization of CPWW treatment [119]. The addition of electrolyte support such as sodium chloride affects the removal efficiency due to the generation of active chlorine during the electrolysis process interacting with substances such as melanoidins [120]. Other than meloinidins, the mineralization of proteins and lipids are adsorbed on the surface of the precipitated hydroxides [121].

Previous studies reported that the use of a combination of iron and stainless steel as electrodes achieves 87% COD removal and 97.1% color removal [122]. When using iron alone as an electrode material, it removes 97% of COD and 89% of color [123]. The electrocoagulation process can also be used for caffeine recovery that reaches 96% recovery performance [124]. However, there is still no report for polygalacturonase characterization and production in the coffee industry using the electrocoagulation process.

5.6. Vegetable Oil Refinery Wastewater

Vegetable oil refinery wastewater (VORW) has a high amount of COD, phosphorus, sulphate, oil and grease [125]. The sources of vegetable oil manufacture are soybeans, groundnut, rapeseed, sunflower, safflower, cotton, sesame, coconut, mustard, rice bran, watermelon, and neem, etc. [126]. Another characteristic of VORW is that it has a low ratio of BOD/COD; therefore, it is not useful for the biodegradation method. Based on some studies, electrochemical technology could overcome that limitation [127].

A previous study reported that using iron as the electrode could remove 93.3% of COD after 60 min electrolysis time [128]. However, when aluminium is used as an electrode, the COD removal increases up to 98.9%, with 100% color removal in 90 min [129]. Another study using the Box-Behnken design for optimization attained 70.8% COD removal. Aluminium was used as an electrode, and the electrolysis time was 60 min [130]. On the other hand, another study reported that using the Box-Behnken design for the optimization of the electrocoagulation process of sunflower oil refinery could achieve 95% COD removal with a shorter time (18 min) [131].

5.7. Nuts Processing Wastewater

The nut processing industry includes many various types, including pistachio, almond, and cashew nut, etc. Pistachio is a kind of nut rich in organic nutrients. It contains 5.6% water, 19.6% protein, 53.2% fat, 19% carbohydrate, and 2.6% ash [132]. The pistachio industry produces approximately 1 Mm^3 of wastewater and 50,000 tons of solid waste per year. Pistachio processing wastewater (PPW) has high COD, phenolic compounds and turbidity, which can cause harm to the aquatic ecosystem and terrestrial environment if no treatment of the PPW is performed [133].

Several processes are required in the almond processing industry, including cracking and blanching [134]. In the blanching step, the resulting product contains high levels of organic compounds, suspended solids, turbidity, COD and color [135]. The effect of the blanching time on the moisture content is inversely proportional. This means that when the blanching time is longer, it results in a decreased moisture content. Meanwhile, the effect of the blanching time on the lipid content and color intensity is directly proportional. The longer blanching time will increase the lipid content and color intensity [136]. A previous study reported that the polyphenol content recovery in the almond industry using the blanching process acquired 0.53 g gallic acid equivalents (GAE)/kg [137], while the use of the microwave process recovered 0.42 g gallic acid equivalents (GAE)/kg [138]. Based on these studies, the polyphenol content recovery is higher using the blanching process. The use of blanching and microwave processes is recommended according to a previous study. It was reported that by conducting the blanching and microwave simultaneously, we can increase the polyphenol content recovery up to 11.9 g gallic acid equivalents (GAE)/kg [139].

The kinetic study showed that the sonicated almond acquires higher total phenolic compounds than non-sonicated almonds after 20 min extraction at room temperature (25 °C) [140]. Table 3 shows the performance of the electrocoagulation process on different types of nut processing wastewater. The electrocoagulation process has been shown to be a suitable method for the reduction of pollutants from cashew nut processing wastewater, as was reported in a previous work where COD reduced it by up to 80% [141]. According to a previous study, even though the COD removal for PPW is categorized as low, the phenolic compound removal shows greater efficiencies. In addition, using graphite as the electrode material on PPW could achieve the complete removal of phenolic compounds and the 99.79% removal of COD [142].

Table 3. Performance of the electrochemical process on nut processing wastewater.

Type of Nuts	Electrode Material	Electrode Type	COD removal	Phenolic removal	References
Pistachio processing industry wastewater	Al	Unipolar	60.1%	77.3%	[143]
Pistachio processing industry wastewater	Graphite	Unipolar	99.79%	100%	[144]
Pistachio processing industry wastewater	Al	Unipolar	57.4%	-	[134]
Pistachio processing industry wastewater	Al and stainless steel	Unipolar	60%	95%	[144]
Cashew nut processing industry wastewater	Fe, BDD (Boron Doped-Diamond) and stainless steel	Multipolar	80%	-	[145]

6. Integration of Electrochemical Treatment with Other Methods

Electrochemical treatment can be integrated with other methods. The processes includes a combination of pre-treatment and main treatment. The purpose of this integration is to mitigate the limitations of other treatments. It could be an integration of the electrochemical method with physical, chemical, biological methods. The advantages of this integration are the effective removal of organic and inorganic pollutants [146], low operating costs [142], the increase of the performance of the electrodes and the reduction of the energy demand of the electrochemical method [147].

Table 4 shows the performance of the electrochemical method with other treatments. In the case of coffee industry wastewater, the electrochemical method is integrated with the coagulation method. The coagulation method was used as the pre-treatment. Several types of coagulants were used in the study, including $FeSO_4$, $FeCl_3$, $Al_2(SO_4)_3$, and $AlCl_3$. Based on those coagulation processes, $AlCl_3$ shows the highest performance of TOC removal, at up to 28%. The treatment was continued with the electrochemical process.

A study on the treatment of pistachio processing wastewater showed improvement by combining electrochemical treatment with fungal treatment. The use of Al as an electrode showed the higher removal of COD and phenol compared to BDD, Fe and stainless steel. After the treatment with the electrochemical process, the treatment with the fungus was conducted. From the various types of fungal selection, *Penicillium glabrum* was chosen because it has a high capability to remove COD and phenol. The two combinations of this process could remove 90.1% of COD and 88.7% of phenol [148].

Table 4. Performance of the electrochemical process integrated with other methods on agro-based wastewater treatment.

Type of Agro-Based Wastewater	Electrode	Electrocoagulation with Other Methods	COD Removal	Color removal	References
Wood-based industry wastewater	Al	Adsorption and filtration	77%	-	[149]
Coffee wastewater	Al	Sequential batch reactor	84%	93%	[150]
Coffee pulp industry wastewater	Al	Anaerobic sequencing batch reactor	96%	-	[151]
Olive oil mill effluents	Fe	Electro-oxidation and electro-fenton	96%	-	[152]
Pulp and paper wastewater	Fe	UV-based sulfate radical	61%	-	[153]
Sugar industry wastewater	Fe	Thermal method	97.8%	99.7%	[154]
Palm oil mill effluent	Al and Fe	H_2O_2 and coagulation	95.08%	-	[143]
Pulp and paper wastewater	Fe	H_2O_2, Co_3O_4/UV/ peroxymonosulfate and permanganate	95%	92%	[155]
Pulp and paper wastewater	Al	Sonication	90%	100%	[156]
Sugarcane industry wastewater	Al	Coagulation method	98%	99.5%	[157]
Olive oil mill effluents	Al	Coagulation	92%	-	[158]
Olive oil mill effluents	Fe	Photo-catalytic degradation	88%	100%	[155]
Coffee industry wastewater	Al	Electro-oxidation	74%	-	[159]
Coffee industry wastewater	Fe and stainless steel	PAC	80%	92%	[160]
Pistachio processing wastewater	Al and Fe	Anaerobic digestion	43.7%	-	[161]
Sugar industry wastewater	Fe	Thermal	97.8%	-	[124]
Soybean oil wastewater	Fe	H_2O_2	94%	-	[162]
Palm oil mill effluent	Fe	Coagulation	68.84%	-	[163]
Olive oil mill wastewater	Al	Bio-augmentation	63.9	-	[164]
Sugar industry wastewater	Fe	Chemical method	82%	84%	[165]
Olive oil mill wastewater	Al	External loop airlift reactor	79.24%	-	[166]
Olive oil mill wastewater	Al	Catalytic ozonation and bio-degradation	98.4%	-	[167]
Sugar industry wastewater	Fe	Sequential batch reactor	87%	-	[168]
Pistachio processing industry wastewater	Fe, stainless steel, Al and BDD	Fungal treatment	90.1%	-	[169]
Palm oil mill effluent	Al	Adsorption method	44%	89%	[170]
Olive oil mill wastewater	Al	Impregnation method	78%	-	[150]
Olive oil mill wastewater	Al	Peroxone process	79.8%	-	[171]

7. Energy Consumption and Cost

Energy consumption is one of the main factors for cost evaluation in electrochemical treatment on a large scale. Less energy was consumed, thereby reducing the cost required for the treatment [172]. The amount of energy consumed per unit mass of organic material removed is referred to as the specific energy consumption. It could be COD, ammoniacal nitrogen, or dye, etc. [147]. Specific energy consumption can be evaluated as follows:

$$SEC = \frac{U \times I \times t}{(COD_x - COD_y) \times V} \tag{8}$$

where SEC is the specific energy consumption (kWh/kg of $\text{COD}_{\text{removed}}$), U is the applied voltage, I is the current intensity, t is the retention time, COD_x is the chemical oxygen demand before treatment, COD_y is the chemical oxygen demand after treatment, and V is the volume of treated wastewater [173].

Some studies have shown that the energy consumption is based on the electrode and operating parameters. Using Al electrodes on pulp and paper wastewater, the specific energy consumption is 11.055 kWh/m^3 and requires an operating cost of 1.56 USD/m^3 [174]. A previous study on the electrochemical treatment of carwash wastewater reported that the total operating costs under optimum conditions using aluminium and iron as the electrode materials are US$ 0.3/m^3 and US$ 0.6/m^3, respectively. Their performance could achieve 88% COD removal and 90% oil and grease removal using iron, and 88% COD removal and 68% oil and grease removal using aluminium [175]. Using graphite as the electrode material on textile wastewater treatment results in 85% color removal; the initial COD concentration was 724.75 mg/L, and the operating costs reached US$ 338.42/kg [176]. The increment happened for the specific energy consumption of pulp and paper mill wastewater treatment when using the electrocoagulation process within the membrane reactor. Its specific energy consumption is 67.5 kWh/m^3, and it costs around 21.03 USD/m^3 [177].

8. Conclusions

The treatment of agro-based industrial wastewater can be achieved using the electrocoagulation process combined with other methods, such as physical, chemical and biological methods. However, the application of the electrocoagulation process at the full scale still faces several challenges, as follows:

i It requires the understanding of economic feasibility and the effective power consumption method.
ii Different types of wastewaters require different types of electrode materials. They should fulfil the criteria to enhance the performance of the treatment. Future studies of the development of electrode materials and the design are required.
iii Ultra-stable electrolyte support may be required to achieve complete degradation and prevent the formation of unwanted by-products.

The electrocoagulation process offers several advantages for the treatment of agro-based industrial wastewater. A little study shows the specific component removal, such as for oil and grease, phenolic compound, carboxylic acid, and palmitic acid, etc. In the future, these studies need to be further conducted in order to give a better understanding and broaden knowledge on the electrocoagulation process.

Author Contributions: Conceptualization, R. and M.A.Y.; methodology, R.; resources, F.A.R. and R.M.; data curation, R. and F.A.R.; writing—original draft preparation, R. and L.M.Q.; writing—review and editing, H.K. and N.A. and R.M.; supervision, M.A.Y. and H.K.; funding acquisition, M.A.Y., L.M.Q. and R.M. All authors have read and agreed to the published version of the manuscript.

Funding: The Deanship of Scientific Research at King Khalid University has funded this work through a group research program under grant number RGP. 2/71/42. The work was also sponsored by Ministry of Higher Education (MOHE) under Fundamental Research Grant Scheme (FRGS No. FRGS/1/2019/WAB05/UTM/02/2).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through group research program under grant number RGP. 2/71/42. All authors are grateful for help and support from staff at the Department of Chemical and Environmental Engineering (ChEE) Laboratory, Malaysia-Japan International Institute of Technology (MJIIT). The authors gratefully acknowledge support from the Universiti Teknologi Malaysia and Post-Doctoral fellow (Teaching & Learning) Scheme under MJIIT-UTM and are thankful to the South Ural State University (SUSU) for extending support for research collaboration and invitation as visiting senior researcher.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zaied, M.; Bellakhal, N. Electrocoagulation treatment of black liquor from paper industry. *J. Hazard. Mater.* **2009**, *163*, 995–1000. [CrossRef]
2. Kamyab, H.; Chelliapan, S.; Lee, C.T.; Khademi, T.; Kumar, A.; Yadav, K.K.; Ebrahimi, S.S. Improved production of lipid contents by cultivating Chlorella pyrenoidosa in heterogeneous organic substrates. *Clean Technol. Environ. Policy* **2019**, *21*, 1969–1978. [CrossRef]
3. Aljerf, L. Data of thematic analysis of farmer's use behavior of Recycled Industrial Wastewater. *Data Brief* **2018**, *21*, 240–250. [CrossRef] [PubMed]
4. Labiadh, L.; Barbucci, A.; Cerisola, G.; Gadri, A.; Ammar, S.; Panizza, M. Role of anode material on the electrochemical oxidation of methyl oranges. *J. Solid State Electrochem.* **2015**, *19*, 3177–3183. [CrossRef]
5. Lin, S.S.; Shen, S.L.; Zhou, A.; Lyu, H.M. Assessment and management of lake eutrophication: A case study in Lake Erhai, China. *Sci. Total Environ.* **2021**, *751*, 141618. [CrossRef]
6. Breida, B.M.; Younssi, S.A.; Ouammou, M.; Bouhria, M.; Hafsi, M. *Pollution of Water Sources from Agricultural and Industrial Effluents: Special Attention to $NO_3{}^-$, Cr(VI), and Cu(II)*; Water Chemistry; Intechopen: London, UK, 2019. [CrossRef]
7. Sarkar, B.; Chakrabarti, P.P.; Vijaykumar, A.; Kale, V. Wastewater treatment in dairy industries-possibility of reuse. *Desalination* **2006**, *195*, 141–152. [CrossRef]
8. Kamyab, H.; Din, M.F.M.; Tin, C.L.; Ponraj, M.; Soltani, M.; Mohamad, S.E.; Roudi, A.M. Micro-macro algal mixture as a promising agent for treating POME discharge and its potential use as animal feed stock enhancer. *J. Teknol.* **2014**, *68*, 1–4. [CrossRef]
9. Kamyab, H.; Din, M.F.M.; Keyvanfar, A.; Majid, M.Z.A.; Talaiekhozani, A.; Shafaghat, A.; Ismail, H.H. Efficiency of microalgae Chlamydomonas on the removal of pollutants from palm oil mill effluent (POME). *Energy Procedia* **2015**, *75*, 2400–2408. [CrossRef]
10. Keerio, H.A.; Bae, W. Experimental Investigation of Substrate Shock and Environmental Ammonium Concentration on the Stability of Ammonia-Oxidizing Bacteria (AOB). *Water* **2020**, *12*, 223. [CrossRef]
11. Liang, Z.; Soranno, P.A.; Wagner, T. The role of phosphorus and nitrogen on chlorophyll a: Evidence from hundreds of lakes. *Water Res.* **2020**, *185*, 116236. [CrossRef]
12. Pouran, S.R.; Aziz, A.R.A.; Daud, W.M.A.W. Review on the main advances in photo-fenton oxidation system for recalcitrant wastewaters. *J. Ind. Eng. Chem.* **2015**, *21*, 53–69. [CrossRef]
13. Crini, G.; Lichtfouse, E. Advantages and disadvantages of technique used for wastewater treatment. *Environ. Chem. Lett.* **2019**, *17*, 145–155. [CrossRef]
14. Oller, I.; Malato, S.; Perez, J.A.S. Combination of advanced oxidation processes and biological treatments for wastewater decontamination—A review. *Sci. Total Environ.* **2011**, *409*, 4141–4166. [CrossRef] [PubMed]
15. Chen, G. Electrochemical technologies in wastewater treatment. *Sep. Purif. Technol.* **2004**, *38*, 11–41. [CrossRef]
16. Cox, M.; Negre, P.; Yurramendi, L. *Industrial Liquid Effluent*; INASMET Tecnalia: San Sebastian, Spain, 2007; p. 283.
17. Kharayat, Y. Distillery wastewater: Bioremediation approaches. *J. Integr. Environ. Sci.* **2012**, *9*, 69–91. [CrossRef]
18. Chowdhary, P.; Raj, A.; Bharagava, R.N. Environmental pollution and health hazards from distillery wastewater and treatment approaches to combat the environmental threats: A review. *Chemosphere* **2018**, *194*, 229–246. [CrossRef] [PubMed]
19. Kroiss, H. What is the potential for utilizing the resources in sludge? *Water Sci. Technol.* **2004**, *49*, 1–10. [CrossRef] [PubMed]
20. Wong, J.W.; Selvam, A. Speciation of heavy metals during co-composting of sewage sludge with lime. *Chemosphere* **2006**, *63*, 980–986. [CrossRef] [PubMed]
21. Farzadkia, M.; Bazrafshan, E. Lime Stabilization of Waste Activated Sludge. *Health Scope* **2014**, *3*, 16035. [CrossRef]
22. Appels, L.; Baeyens, J.; Degrève, J.; Dewil, R. Principles and potential of the anaerobic digestion of waste-activated sludge. *Prog. Energy Combust. Sci.* **2008**, *34*, 755–781. [CrossRef]
23. Zhao, Y.; Yan, X.; Zhou, J.; Li, R.; Yang, S.; Wang, B.; Deng, R. Treatment of oily sludge by two-stage wet air oxidation. *J. Energy Inst.* **2019**, *92*, 1451–1457. [CrossRef]
24. Mailler, R.; Gasperi, J.; Chebbo, G.; Rocher, V. Priority and emerging pollutants in sewage sludge and fate during sludge treatment. *Waste Manag.* **2014**, *34*, 1217–1226. [CrossRef] [PubMed]
25. Kelessidis, A.; Stakinasis, A.S. Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries. *Waste Manag.* **2012**, *32*, 1186–1195. [CrossRef]

26. Sid, S.; Volant, A.; Lesage, G.; Heran, M. Cost minimization in a full-scale conventional wastewater treatment plant: Associated costs of biological energy consumption versus sludge production. *Water Sci. Technol.* **2017**, *76*, 2473–2481. [CrossRef]
27. Mattos, L.F.A.; Bastos, R.G. COD and nitrogen removal from sugarcane vinasse by heterotrophic green algae *Desmodesmus* sp. *Desalin. Water Treat.* **2016**, *57*, 9465–9473. [CrossRef]
28. Santana, H.; Cereijo, C.R.; Teles, V.C.; Nascimento, R.C.; Fernandes, M.S.; Brunale, P.; Campanha, R.C.; Soares, I.P.; Silva, F.C.P.; Sabaini, P.S.; et al. Microalgae cultivation in sugarcane vinasse: Selection, growth and biochemical characterization. *Bioresour. Technol.* **2017**, *228*, 133–140. [CrossRef] [PubMed]
29. Gupta, S.; Pawar, S.B.; Pandey, R.A. Current practices and challenges in using microalgae for treatment of nutrient rich wastewater from agro-based industries. *Sci. Total Environ.* **2019**, *687*, 1107–1126. [CrossRef]
30. Bolognesi, S.; Cecconet, D.; Capodaglio, A.G. Agro-industrial wastewater treatment in microbial fuel cells. In *Integrated Microbial Fuel Cells for Wastewater Treatment*; Butterworth-Heinnman: Oxford, UK, 2020; pp. 93–133. [CrossRef]
31. Mo, J.; Yang, Q.; Zhang, W.; Zheng, Y.; Zhang, Z. A review on agro-industrial waste (AIW) derived adsorbents for water and wastewater treatment. *J. Environ. Manag.* **2018**, *227*, 395–405. [CrossRef]
32. Rabaey, K.; Verstraete, W. Microbial fuel cells: Novel biotechnology for energy generation. *Trends Biotechnol.* **2005**, *23*, 291–298. [CrossRef]
33. Angenent, L.T.; Karim, K.; Al-Dahhan, M.H.; Wrenn, B.A.; Domíguez-Espinosa, R. Production of bioenergy and biochemicals from industrial and agricultural wastewater. *Trends Biotechnol.* **2004**, *22*, 477–485. [CrossRef]
34. Sinha, S.; Yoon, Y.; Amy, G.; Yoon, J. Determining the effectiveness of conventional and alternative coagulants through effective characterization schemes. *Chemosphere* **2004**, *57*, 1115–1122. [CrossRef]
35. Morin, N.; Crini, G. *Eaux Industrielles Contaminees*; PUFC: Besancon, France, 2017. Available online: https://www.researchgate.net/profile/Isabelle-Ghillebaert/publication/317013318_Eaux_industrielles_contaminees_Reglementation_parametres_chimiques_et_biologiques_procedes_d\T1\textquoterightepuration_innovants_Chapitre_6_Evaluation_du_risque_chimique_en_milieu_aquatique/links/591eefa90f7e9b64281df637/Eaux-industrielles-contaminees-Reglementation-parametres-chimiques-et-biologiques-procedes-depuration-innovants-Chapitre-6-Evaluation-du-risque-chimique-en-milieu-aquatique.pdf (accessed on 11 November 2021).
36. Stoller, M.; Azizova, G.; Mammadova, A.; Vilardi, G.; Palma, L.D.; Chianese, A. Treatment of olive oil processing wastewater by ultrafiltration, nanofiltration, reverse osmosis and bio-filtration. *Chem. Eng. Trans.* **2016**, *47*, 409–414. [CrossRef]
37. Wu, B. Membrane-based technology in greywater reclamation: A review. *Sci. Total Environ.* **2019**, *656*, 184–200. [CrossRef] [PubMed]
38. Lee, C.S.; Robinson, J.; Chong, M.F. A review on application of flocculants in wastewater treatment. *Process Saf. Environ. Prot.* **2014**, *92*, 489–508. [CrossRef]
39. Sarkka, H.; Bhatnagar, A.; Sillanpaa, M. Recent developments of electro-oxidation in water treatment d a review. *J. Electroanal. Chem.* **2015**, *754*, 46–56. [CrossRef]
40. Chellam, S.; Sari, M.A. Aluminum electrocoagulation as pretreatment during microfiltration of surface containing NOM: A review of fouling, NOM, DBP and virus control. *J. Hazard. Mater.* **2016**, *304*, 490–501. [CrossRef]
41. Bashir, M.J.K.; Han, T.M.; Wei, L.J.; Aun, N.C.; Amr, S.S.A. Polishing of treated palm oil mill effluent (POME) from the ponding system by electrocoagulation process. *Water Sci. Technol.* **2016**, *73*, 2704–2712. [CrossRef]
42. Markou, V.; Kontogianni, M.; Frontistis, Z.; Tekerlekopoulou, A.G.; Katsaounis, A.; Vayenas, D. Electrochemical treatment of biologically pre-treated dairy wastewater using dimensionally stable anodes. *J. Environ. Manag.* **2017**, *202*, 217–224. [CrossRef]
43. Sahu, O.P.; Chaudhari, P.K. Electro-chemical treatment of sugar industry wastewater: COD and color removal. *J. Electroanal. Chem.* **2015**, *739*, 122–129. [CrossRef]
44. Klidi, N.; Clematis, D.; Delucchi, M.; Gadria, A.; Ammara, A.; Panizza, M. Applicability of electrochemical methods to paper mill wastewater for reuse:Anodic oxidation with BDD and TiRuSnO2 anodes. *J. Electroanal. Chem.* **2018**, *815*, 16–23. [CrossRef]
45. Ellouze, S.; Panizza, M.; Barbucci, A.; Cerisola, G.; Mhiria, T.; Elaouda, S.C. Ferulic acid treatment by electrochemical oxidation using a BDD anode. *J. Taiwan Inst. Chem. Eng.* **2016**, *59*, 132–137. [CrossRef]
46. Brillas, E. A review on the photoelectro-Fenton process as efficient electrochemical advanced oxidation for wastewater remediation. Treatment with UV light, sunlight, and coupling with conventional and other photo-assisted advanced technologies. *Chemosphere* **2020**, *250*, 126–198. [CrossRef] [PubMed]
47. Nowacka, A.; Makula, M.M.; Macherzynski, B. Comparison of effectiveness of coagulation with aluminum sulfate and pre-hydrolyzed aluminum coagulants. *Desalin. Water Treat.* **2014**, *52*, 3843–3851. [CrossRef]
48. Ghernaout, D.; Ghernaout, B.; Kellil, A. Natural organic matter removal and enhanced coagulation as a link between coagulation and electrocoagulation. *Desalin. Water Treat.* **2009**, *2*, 203–222. [CrossRef]
49. Guminska, J.; Kłos, M. Analysis of post-coagulation properties of flocs in terms of coagulant choice. *Environ. Prot. Eng.* **2012**, *38*, 103–113. Available online: https://www.infona.pl/resource/bwmeta1.element.baztech-article-BPW8-0022-0035 (accessed on 14 November 2021).
50. Naje, A.S.; Chelliapan, S.; Zakaria, Z.; Ajeel, M.A.; Alaba, P.A. A review of electrocoagulation technology for the treatment of textile wastewater. *Rev. Chem. Eng.* **2017**, *33*, 263–292. [CrossRef]
51. Hakizimana, J.N.; Gourich, B.; Chafi, M.; Stiriba, Y.; Vial, C.; Drogui, P.; Naja, J. Electrocoagulation process in water treatment: A review of electrocoagulation modeling approaches. *Desalination* **2017**, *404*, 1–21. [CrossRef]

52. Verma, A.K.; Dash, R.R.; Bhunia, P. A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. *J. Environ. Manag.* **2012**, *93*, 154–168. [CrossRef]
53. Dura, A.; Breslin, C. Electrocoagulation for the Effective Removal of Pollutants. *ECS Meet. Abstr.* **2012**, 1417. Available online: https://mural.maynoothuniversity.ie/6744/1/adelaide-dura.pdf (accessed on 15 November 2021). [CrossRef]
54. Aoudj, S.; Khelifa, A.; Drouiche, N.; Hecini, M.; Hamitouche, H. Electrocoagulation process applied to wastewater containing dyes from textile industry. *Chem. Eng. Processing Process Intensif.* **2010**, *49*, 1176–1182. [CrossRef]
55. Emamjomeh, M.M.; Sivakumar, M. Review of pollutants removed by electrocoagulation and electrocoagulation/flotation processes. *J. Environ. Manag.* **2009**, *90*, 1663. [CrossRef] [PubMed]
56. Yassine, W.; Akazdam, S.; Zyade, S.; Gourich, B. Treatment of olive mill wastewater using electrocoagulation process. *J. Appl. Surf. Interfaces* **2019**, *4*, 24–30. Available online: https://revues.imist.ma/index.php/jasi/article/view/14006 (accessed on 10 November 2021).
57. Rakhmania; Kamyab, H.; Yuzir, M.A.; Al-Qaim, F.F.; Purba, L.D.A.; Riyadi, F.A. Application of Box-Behnken design to mineralization and color removal of palm oil mill effluent by electrocoagulation process. *Environ. Sci. Pollut. Res.* **2021**, 1–13. [CrossRef]
58. Gurses, A.; Yalcin, M.; Dogan, C. Electrocoagulation of some reactive dyes: A statistical investigation of some electrochemical variable. *Waste Manag.* **2002**, *22*, 491–499. [CrossRef]
59. Bazrafshan, E.; Mahvi, A.H.; Nasseri, S.; Mesdaghinia, A.R.; Vaezi, F.; Nazmara, S.H. Removal of cadmium from industrial effluents by electrocoagulation process using iron electrodes. *Iran. J. Environ. Health Sci. Eng.* **2006**, *3*, 261–266. Available online: https://www.hindawi.com/journals/jchem/2013/640139/ (accessed on 10 November 2021).
60. Ridruejo, C.; Centellas, F.; Cabot, P.L.; Sires, I.; Brillas, E. Electrochemical Fenton-based treatment of tetracaine in synthetic and urban wastewater using active and non-active anodes. *Water Res.* **2018**, *128*, 71–81. [CrossRef] [PubMed]
61. Mussa, Z.H.; Al-Qaim, F.F.; Othman, M.R.; Abdullah, M.P. Removal of simvastatin from aqueous solution by electrochemical process using graphite-PVC as anode: A case study of evaluation of the toxicity, kinetics and chlorinated by-products. *J. Environ. Chem. Eng.* **2016**, *4*, 3338–3347. [CrossRef]
62. Aljerf, L. High-efficiency extraction of bromocresol purple dye and heavy metals as chromium from industrial effluent by adsorption onto a modified surface of zeolite: Kinetics and equilibrium study. *J. Environ. Manag.* **2018**, *225*, 120–132. [CrossRef] [PubMed]
63. Tiwari, A.; Sahu, O. Treatment of food-agro (sugar) industry wastewater with copper metal and salt: Chemical oxidation and electro-oxidation combined study in batch mode. *Water Resour. Ind.* **2017**, *17*, 19–25. [CrossRef]
64. Wang, Z.; Shen, Q.; Xue, J.; Guan, R.; Li, Q.; Liu, X.; Jia, H.; Wu, Y. 3D hierarchically porous NiO/NF electrode for the removal of chromium(VI) from wastewater by electrocoagulation. *Chem. Eng. J.* **2020**, *402*, 126151. [CrossRef]
65. Goren, A.Y.; Kobya, M. Arsenic removal from groundwater using an aerated electrocoagulation reactor with 3D Al electrodes in the presence of anions. *Chemosphere* **2021**, *263*, 128253. [CrossRef]
66. Msindo, Z.S.; Sibanda, V.; Potgieter, J.H. Electrochemical and physical characterisation of lead-based anodes in comparison to Ti–(70%) IrO_2/(30%) Ta_2O_5 dimensionally stable anodes for use in copper electrowinning. *J. Appl. Electrochem.* **2010**, *40*, 691–699. [CrossRef]
67. Moats, M.; Hardee, K.; Brown, C. Mesh-on-lead anodes for copper electrowinning. *J. Miner. Met. Mater. Soc.* **2003**, *55*, 46–48. [CrossRef]
68. Khandegar, V.; Saroha, A.K. Electrochemical treatment of distillery spent wash using aluminium and iron electrodes. *Chin. J. Chem. Eng.* **2012**, *20*, 439–443. [CrossRef]
69. Bouhezila, F.; Hariti, M.; Lounici, H.; Mameri, N. Treatment of the OUED SMAR town landfill leachate by an electrochemical reactor. *Desalination* **2011**, *280*, 347–353. [CrossRef]
70. Phalakornkule, C.; Polgumhang, S.; Tongdaung, W. Performance of an electrocoagulation process in treating direct dye: Batch and continuous up flow processes. *World Acad. Sci. Eng. Technol.* **2009**, *57*, 277–282. [CrossRef]
71. Nasrullah, M.; Zularisam, A.W.; Krishnan, S.; Sakinah, M.; Singh, L.; Fen, Y.W. High performance electrocoagulation process in treating palm oil mill effluent using high current intensity application. *Chin. J. Chem. Eng.* **2019**, *27*, 208–217. [CrossRef]
72. Holt, P.K.; Barton, G.W.; Mitchell, C.A. The future for electrocoagulation as a localised water treatment technology. *Chemosphere* **2005**, *59*, 355–367. [CrossRef] [PubMed]
73. Medeiros, M.C.; Santos, E.V.; Martínez-Huitlea, C.A.; Fajardo, A.S.; Castro, S.S.L. Obtaining high-added value products from the technical cashew-nut shell liquid using electrochemical oxidation with BDD anodes. *Sep. Purif. Technol.* **2020**, *250*, 117099. [CrossRef]
74. Byoud, F.; Wakrim, A.; Benhsinat, C.; Zaroual, Z.; El-Ghachtouli, S.; Tazi, A.; Chaair, H.; Assabbane, A.; Azzi, M. Electrocoagulation treatment of the food dye waste industry: Theoretical and experimental study. *J. Mater. Environ. Sci.* **2017**, *12*, 4301–4312. [CrossRef]
75. Hamdi, M.; Khadir, A.; Garcia, J.L. The use of Aspergillus niger for the bioconversion of olive mill waste-waters. *Appl. Microbiol. Biotechnol.* **1991**, *34*, 828–831. [CrossRef]
76. Chen, X.; Chen, G.; Yue, P.L. Investigation on the electrolysis voltage ofelectrocoagulation. *Chem. Eng. Sci.* **2002**, *57*, 2449–2455. [CrossRef]

77. Parama, K.S.K.; Balasubramanian, N.; Srinivasakannan, C. Decolorization and COD reduction of paper industrial effluent using electro-coagulation. *Chem. Eng. J.* **2009**, *151*, 97–104. [CrossRef]
78. Chiang, L.C.; Chang, J.E.; Tseng, S.C. Electrochemical oxidation pretreatment of refractory organic pollutants. *Water Sci. Technol.* **1997**, *36*, 123–130. [CrossRef]
79. Niaounakis, M.; Halvadakis, C.P. *Olive-Mill Waste Management*, 2nd ed.; Typothito: Athens, Greece, 2006; Available online: https://www.sciencedirect.com/bookseries/waste-management-series/vol/5/suppl/C (accessed on 11 November 2021).
80. Dellagreca, M.; Previtera, L.; Temussi, F.; Zarrelli, A. Low-molecular-weight components of olive oil mill waste-waters. *Phytochem. Anal.* **2004**, *15*, 184–188. [CrossRef] [PubMed]
81. Pulido, J.M.O.; Ortega, M.D.V.; Hodaifa, G.; Ferez, A.M. Physicochemical analysis and adequation of olive oil mill wastewater after advanced oxidation process for reclamation by pressure-driven membrane technology. *Sci. Total Environ.* **2014**, *503–504*, 113–121. [CrossRef]
82. Panizza, M.; Cerisola, G. Olive mill wastewater treatment by anodic oxidation with parallel plate electrodes. *Water Res.* **2006**, *40*, 1179–1184. [CrossRef]
83. Rehim, S.S.A.E.; Mohamed, N.F. Passivity breakdown of lead anode in alkaline nitrate solutions. *Corros. Sci.* **1998**, *40*, 1883–1896. [CrossRef]
84. Sounni, F.; Aissam, H.; Ghomari, O.; Merzouki, M.; Benlemlih, M. Electrocoagulation of olive mill wastewaters to enhance biogas production. *Biotechnol. Lett.* **2018**, *40*, 297–301. [CrossRef]
85. Ghahrchi, M.; Rezaee, A.; Adibzadeh, A. Study of kinetic models of olive oil mill wastewater treatment using electrocoagulation process. *Desalin. Water Treat.* **2021**, *211*, 123–130. [CrossRef]
86. Razali, N.A.M.; Salleh, W.N.W.; Rosman, N.; Ismail, N.H.; Ahmad, S.Z.N.; Aziz, F.; Jye, L.W.; Ismail, A.F. Palm oil mill effluent treatment using tungsten trioxide: Adsorption and photocatalytic degradation. *Mater. Today Proc.* **2021**, *42*, 22–27. [CrossRef]
87. Longhi, P.; Vodopivec, B.; Fiori, G. Electrochemical treatment of olive oil mill wastewater. *Ann. Chim.* **2001**, *91*, 169–174.
88. Tezcan-Un, U.; Ugur, S.; Koparal, A.S.; Bakir-Ogutveren, U. Electrocoagulation of olive mill wastewaters. *Sep. Purif. Technol.* **2006**, *52*, 136–141. [CrossRef]
89. Syaichurrozi, I.; Sarto, S.; Sediawan, W.B.; Hidayat, M. Effect of Current and Initial pH on Electrocoagulation in Treating the Distillery Spent Wash with Very High Pollutant Content. *Water* **2020**, *13*, 11. [CrossRef]
90. Benekos, A.K.; Zampeta, C.; Argyriou, R.; Economou, C.N.; Triantaphyllidou, I.E.; Tatoulis, T.I.; Tekerlekopoulou, A.G.; Vayenas, D.G. Treatment of table olive processing wastewaters using electrocoagulation in laboratory and pilot-scale reactors. *Process Saf. Environ. Prot.* **2019**, *131*, 38–47. [CrossRef]
91. Ntaikou, I.; Antonopoulou, G.; Vayenasa, D.; Lyberatosa, G. Assessment of electrocoagulation as a pretreatment method of olive mill wastewater towards alternative processes for biofuels production. *Renew. Energy* **2020**, *154*, 1252–1262. [CrossRef]
92. Sahu, O.P.; Gupta, V.; Chaudhari, P.K.; Srivastava, V.V. Electrochemical treatment of actual sugar industry wastewater using aluminum electrodes. *Int. J. Environ. Sci. Technol.* **2015**, *12*, 3519–3530. [CrossRef]
93. Asaithambhi, P.; Matheswaran, M. Electrochemical treatment of simulated sugar industrial effluent: Optimization and modeling using a response surface methodology. *Arab. J. Chem.* **2016**, *9*, 981–987. [CrossRef]
94. Kolhe, A.S.; Sarode, A.G.; Ingale, S.R. Study of effluent from the sugar cane industry. *Sodh Samiksha Aur Mulyankan* **2009**, *2*, 303–306. Available online: https://www.researchgate.net/publication/351249954_Quality_and_Treatment_of_Sugar_Industry_Effluent_-A_Study (accessed on 12 November 2021).
95. Guven, G.; Perendeci, A.; Tanylac, A. Electrochemical treatment of simulated beet sugar factory wastewater. *Chem. Eng. J.* **2009**, *151*, 149–159. [CrossRef]
96. Aljerf, L. Green technique development for promoting the efficiency of pulp slurry reprocess. *Sci. J. King Faisal Univ.* **2016**, *17*, 1–10. [CrossRef]
97. Brillas, E.; Sauleda, R.; Casado, J. Degradation of4-chlorophenol by anodic oxida- tion, electro-Fenton, photoelectro-Fenton and peroxi-coagulation processes. *J. Electrochem. Soc.* **1998**, *145*, 759–765. [CrossRef]
98. Chindaphan, K.; Thaveesangsakulthai, I.; Naranaruemol, S.; Nhujak, T.; Panchompoo, J.; Chailapakol, O.; Kulsing, C. Miniaturized electrocoagulation approach for removal of polymeric pigments and selective analysis of non- and mono-hydroxylated phenolic acids in wine with HPLC-UV. *RSC Adv.* **2021**, *11*, 5885–5893. [CrossRef]
99. Ksibi, M.; Amor, S.B.; Cherif, S.; Elaloui, S. Photodegradation of lignin from black liquor using a UV/TiO_2 system. *J. Photochem. Photobiol. A* **2003**, *154*, 211–218. [CrossRef]
100. Ali, M.; Sreekrishnan, T.R. Aquatic toxicity from pulp and paper mill effluents: A review. *Adv. Environ. Res.* **2001**, *5*, 175–196. [CrossRef]
101. Kamyab, H.; Chelliapan, S.; Din, M.F.M.; Rezania, S.; Khademi, T.; Kumar, A. Palm oil mill effluent as an environmental pollutant. *Palm Oil* **2018**, *13*, 13–28. Available online: https://www.intechopen.com/chapters/60482 (accessed on 13 November 2021).
102. Zazouli, M.A.; Ahmadi, M. Pretreatment of paper recycling plant wastewater by electrocoagulation using aluminum and iron electrodes. *J. Mater. Environ. Sci.* **2017**, *8*, 2140–2146.
103. Ugurlu, M.; Gurses, A.; Dogar, C.; Yalcin, M. The removal of lignin and phenol from paper mill effluents by electrocoagulation. *J. Environ. Manag.* **2007**, *87*, 420–428. [CrossRef]
104. Valenzuela, L.S.T.; Jimenez, J.A.S.; Martinez, K. Coffee By-Products: Nowadays and Perspectives. In *Coffee—Production and Research*; Intechopen: London, UK, 2020. [CrossRef]

105. Chin, M.J.; Eong, P.P.; Ti, T.B.; Seng, C.E.; Ling, C.K. Biogas from palm oil mill effluent (POME): Opportunities and challenges from Malaysia's perspective. *Renew. Sustain. Energy Rev.* **2013**, *26*, 717–726. [CrossRef]
106. Kamyab, H.; Chelliapan, S.; Din, M.F.M.; Shahbazian, R.Y.; Rezania, S.; Khademi, T.; Azimi, M. Evaluation of Lemna minor and Chlamydomonas to treat palm oil mill effluent and fertilizer production. *J. Water Process Eng.* **2017**, *17*, 229–236. [CrossRef]
107. Tan, Y.H.; Goha, P.S.; Lai, G.S.; Lau, W.J.; Ismail, A.F. Treatment of aerobic treated palm oil mill effluent (AT-POME) by using TiO_2 photocatalytic process. *J. Technol. Sci. Eng.* **2014**, *70*, 61–63. [CrossRef]
108. Kamyab, H.; Chelliapan, S.; Din, M.F.M.; Lee, C.T.; Rezania, S.; Khademi, T.; Bong, C.P.C. Isolate new microalgal strain for biodiesel production and using FTIR spectroscopy for assessment of pollutant removal from palm oil mill effluent (POME). *Chem. Eng. Trans.* **2018**, *63*, 91–96. [CrossRef]
109. Baranitharan, E.; Khan, R.M.; Prasad, D.M.R. Treatment of palm oil mill effluent in microbial fuel cell using polyacrylonitrile carbon felt electrodes. *J. Med. Bioeng.* **2013**, *2*, 252–256. [CrossRef]
110. Agustin, M.B.; Sengpracha, W.P.; Phutdhawong, W. Electrocoagulation of Palm Oil Mill Effluent. *Int. J. Environ. Res. Public Health* **2008**, *5*, 177–180. [CrossRef]
111. Phalakornkule, C.; Mangmeemak, J.; Intrachod, K.; Nuntakumjorn, B. Pretreatment of palm oil mill effluent by electrocoagulation and coagulation. *ScienceAsia* **2010**, *36*, 142–149. [CrossRef]
112. Bouknana, D.; Hammoutia, B.; Salghid, R.; Jodehe, S.; Zarrouka, A.; Warade, I.; Aouniti, A.; Sbaa, M. Physicochemical Characterization of Olive Oil Mill Wastewaters in the eastern region of Morocco. *J. Mater. Environ. Sci.* **2014**, *5*, 1039–1058.
113. Phan, H.Q.H.; Hoan, N.X.; Huy, N.N.; Duc, N.D.D.; Anh, N.T.N.; Que, N.T.; Thuy, N.T. Pre-treatment potential of electrocoagulation process using aluminum and titanium electrodes for instant coffee processing wastewater. *J. Environ. Sustain.* **2019**, *3*, 170–185. [CrossRef]
114. Rigueto, C.V.T.; Nazari, M.T.; De Souza, C.F.; Cadore, J.S.; Brião, V.B.; Piccin, J.S. Alternative techniques for caffeine removal from wastewater: An overview of opportunities and challenges. *J. Water Proc. Eng.* **2020**, *35*, 101231. [CrossRef]
115. Gomez, I.D.; Garcia, M.A.G. Integration of environmental and economic performance of Electro-Coagulation-Anodic Oxidation sequential process for the treatment of soluble coffee industrial effluent. *Sci. Total Environ.* **2021**, *764*, 142818. [CrossRef]
116. Sontaya, K.; Pitiyont, B.; Punsuvon, P. Decolorization and COD Removal of Palm Oil Mill Wastewater by Electrocoagulation. *Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng.* **2013**, *7*, 606–609. [CrossRef]
117. Nasrullah, M.; Singh, L.; Krishnan, S.; Sakinah, M.; Zularism, A.W. Electrode design for electrochemical cell to treat palm oil mill effluent by electrocoagulation process. *Environ. Technol. Innov.* **2018**, *9*, 323–341. [CrossRef]
118. Murthy, P.S.; Naidu, M.M. Sustainable management of coffee industry by-products and value addition—A review. *Resour. Conserv. Recycl.* **2012**, *66*, 45–58. [CrossRef]
119. Rodríguez, P.S.; Pérez, S.R.M.; Fern¢ndez, B.M. Studies of anaerobic biodegradability of the wastewater of the humid benefit the coffee. *J. Interciencia* **2000**, *25*, 386–390. Available online: https://www.researchgate.net/publication/297388993_Study_of_the_anaerobic_biodegradability_of_the_wastewaters_of_the_humid_benefit_of_the_coffee (accessed on 11 November 2021).
120. Mussatto, S.I.; Carneiro, L.M.; Silva, J.P.A.; Roberto, I.C.; Teixeira, J.A. A study on chemical constituents and sugars extraction from spent coffee grounds. *Carbohydr. Polym.* **2011**, *83*, 368–374. [CrossRef]
121. Pujol, D.; Liu, C.; Gominho, J.; Olivella, M.À.; Fiol, N.; Villaescusa, I.; Pereira, H. The chemical composition of exhausted coffee waste. *Ind. Crops Prod.* **2013**, *50*, 423–429. [CrossRef]
122. Gengec, E.; Kobya, M.; Demirbas, E.; Akyol, A.; Oktor, K. Optimization of baker's yeast wastewater using response surface methodology by electrocoagulation. *Desalination* **2012**, *286*, 200–209. [CrossRef]
123. Khansorthong, S.; Hunsom, M. Remediation of wastewater from pulp and paper mill industry by the electrochemical technique. *J. Chem. Eng.* **2009**, *151*, 228–234. [CrossRef]
124. Sahana, M.; Srikantha, H.; Mahesh, H.; Swamy, M.H. Coffee processing industrial wastewater treatment using batch electrochemical coagulation with stainless steel and Fe electrodes and their combinations, and recovery and reuse of sludge. *Water Sci. Technol.* **2018**, *78*, 279–289. [CrossRef]
125. Asha, G.; Kumar, B.M. Comparison of Aluminum and Iron Electrodes for COD Reduction from Coffee Processing Wastewater by Electrocoagulation Process. *J. Sci. Res. Rep.* **2016**, *9*, 22815. [CrossRef]
126. Waldron, K.W.; Moates, G.K.; Faulds, C.B. Prebiotic Potential and Antimicrobial Effect from a By-Product of the Almond Processing Industry. In *Total Food*; RSC Publishing: Cambridge, UK, 2009; pp. 86–89. [CrossRef]
127. Pandey, R.A.; Sanyal, P.B.; Chattopadhyay, N.; Kaul, S.N. Treatment and reuse of wastes of a vegetable oil refinery. *Resour. Conserv. Recycl.* **2003**, *37*, 101–117. [CrossRef]
128. Bucas, G.; Saliot, A. Sea transport of animal and vegetable oils and its environmental consequences. *Mar. Pollut. Bull.* **2002**, *44*, 1388–1396. [CrossRef]
129. Sridhar, S.; Kale, A.; Khan, A.A. Reverse osmosis of edible vegetable oil industry effluent. *J. Membr. Sci.* **2002**, *205*, 83–90. [CrossRef]
130. Tezcan-Un, U. Treatment of vegetable oil refinery wastewater by electrocoagulation. *Fresenius Environ. Bull.* **2007**, *16*, 1056–1060.
131. Tezcan-Un, U.; Koparal, A.S.; Ogutveren, U.B. Electrocoagulation of vegetable oil refinery wastewater using aluminum electrodes. *J. Environ. Manag.* **2009**, *90*, 428–433. [CrossRef] [PubMed]

132. Preeti, V.; Ramesh, S.T.; Gandhimathi, R.; Nidhessh, P.V. Optimization of batch electrocoagulation process using Box-Behnken experimental design for the treatment of crude vegetable oil refinery wastewater. *J. Dispers. Sci. Technol.* **2019**, *41*, 592–599. [CrossRef]
133. Sharma, S.; Aygun, A.; Simsek, H. Electrochemical treatment of sunflower oil refinery wastewater and optimization of the parameters using response surface methodology. *Chemosphere* **2020**, *249*, 126511. [CrossRef] [PubMed]
134. Bayar, S.; Boncukcouglu, R.; Yilmaz, A.E.; Fil, B.A. Pre-Treatment of Pistachio Processing Industry Wastewaters (PPIW) by Electrocoagulation using Al Plate Electrode. *J. Sep. Sci. Technol.* **2014**, *49*, 1008–1018. [CrossRef]
135. Celik, I.; Demirer, G.N. Biogas production from pistachio (*pistacia vera* L.) processing waste. *Biocatal. Agric. Biotechnol.* **2015**, *4*, 767–772. [CrossRef]
136. Pasqualone, A.; Laddomada, B.; Spina, A.; Todaro, A.; Guzman, C.; Summo, C.; Mita, G.; Giannone, V. Almond by-products: Extraction and characterization of phenolic compounds and evaluation of their potential use in composite dough with wheat flour. *LWT* **2018**, *89*, 299–306. [CrossRef]
137. Lipan, L.; Moriana, A.; Lluch, D.B.L.; Lamadrid, M.C.; Sendra, E.; Hernandez, F.; Araujo, L.V.; Corell, M.; Barrachina, A.A.C. Nutrition Quality Parameters of Almonds as Affected by Deficit Irrigation Strategies. *Molecules* **2019**, *24*, 2646. [CrossRef] [PubMed]
138. Bodoira, R.; MAestri, D. Phenolic Compounds from Nuts: Extraction, Chemical Profiles, and Bioactivity. *J. Agric. Food Chem.* **2020**, *68*, 927–948. [CrossRef] [PubMed]
139. Valdes, A.; Vidal, L.; Beltran, A.; Canals, A.; Garrigos, M.C. Microwave-Assisted Extraction of Phenolic Compounds from Almond Skin Byproducts (*Prunus amygdalus*): A Multivariate Analysis Approach. *J. Agric. Food Chem.* **2015**, *63*, 5395–5402. [CrossRef]
140. Tabib, M.; Tao, Y.; Ginies, C.; Bornard, I.; Rakotomanomana, N.; Remmal, A.; Chemat, F. A One-Pot Ultrasound-Assisted Almond Skin Separation/Polyphenols Extraction and its Effects on Structure, Polyphenols, Lipids, and Proteins Quality. *Appl. Sci.* **2020**, *10*, 3628. [CrossRef]
141. Valero, D.; Ortiz, J.M.; García, V.; Expósito, E.; Montiel, V.; Grupo, A.A. Electrocoagulation of wastewater from the almond industry. *Chemosphere* **2011**, *84*, 1290–1295. [CrossRef]
142. Costa, P.R.F.D.; Costa, E.C.T.D.A.; Castro, S.S.L.; Fajardo, A.S.; Huitle, C.A.M. A sequential process to treat a cashew-nut effluent: Electrocoagulation plus electrochemical oxidation. *J. Electroanal. Chem.* **2019**, *834*, 79–85. [CrossRef]
143. Jaafarzadeh, N.; Omidinasab, M.; Ghanbari, F. Combined electrocoagulation and UV-based sulfate radical oxidation processes for treatment of pulp and paper wastewater. *Process Saf. Environ. Prot.* **2016**, *102*, 462–472. [CrossRef]
144. Fil, B.A.; Boncukcouglu, R.; Yilmaz, A.E.; Bayar, S. Electro-Oxidation of Pistachio Processing Industry Wastewater Using Graphite Anode. *Soil Air Water* **2014**, *42*, 1232–1238. [CrossRef]
145. Guclu, D. Optimization of electrocoagulation of pistachio processing wastewaters using the response surface methodology. *Desalin. Water Treat.* **2015**, *54*, 3338–3347. [CrossRef]
146. Bayar, S.; Yilmaz, A.E.; Koksal, Z.; Boncukcouglu, R.; Fil, B.A.; Yilmaz, M.T. The Effect of Initial pH on Pistachio Processing Industrial Wastewater Pre-treatment by Electrocoagulation Method. *Adv. Res. Eng.* **2015**, *37*, 151–154. [CrossRef]
147. Sharma, S.; Simsek, H. Treatment of canola-oil refinery effluent using electrochemical methods: A comparison between combined electrocoagulation and electrooxidation and electrochemical peroxidation methods. *Chemosphere* **2019**, *221*, 630–639. [CrossRef] [PubMed]
148. Chanworrawoot, K.; Hunsom, M. Treatment of wastewater from pulp and paper mill industry by electrochemical methods in membrane reactor. *J. Environ. Manag.* **2012**, *113*, 399–406. [CrossRef] [PubMed]
149. Can, O.T.; Gengec, E.; Kobya, M. TOC and COD removal from instant coffee and coffee products production wastewater by chemical coagulation assisted electrooxidation. *J. Water Process Eng.* **2019**, *28*, 28–35. [CrossRef]
150. Isik, Z.; Arikan, E.B.; Ozay, Y.; Bouras, H.D.; Dizge, N. Electrocoagulation and electrooxidation pre-treatment effect on fungal treatment of pistachio processing wastewater. *Chemosphere* **2020**, *244*, 125383. [CrossRef]
151. Hansson, H.; Marques, M.; Laohaprapanon, S.; Hogland, W. Electrocoagulation coupled to activated carbon sorption/filtration for treatment of cleaning wastewaters from wood-based industry. *Desalin. Water Treat.* **2013**, *52*, 5243–5251. [CrossRef]
152. Mahesh, S.; Srikantha, H.; Lobo, A.L. Performance Evaluation of two Batch Operations using Electrochemical Coagulation followed by Sequential Batch Reactor in treating Coffee wastewater. *Int. J. Chem. Tech. Res.* **2014**, *6*, 339–346. Available online: https://www.researchgate.net/publication/286442411_Performance_Evaluation_of_two_Batch_Operations_using_Electrochemical_Coagulation_followed_by_Sequential_Batch_Reactor_in_treating_Coffee_wastewater (accessed on 9 November 2021).
153. Asha, G.; Kumar, B.M. Coffee Pulping Wastewater Treatment by Electrochemical Treatment followed Anaerobic Sequencing Batch Reactor. *Int. J. Sci. Eng. Res.* **2015**, *6*, 1447–1456. Available online: https://www.semanticscholar.org/paper/Coffee-Pulping-Wastewater-Treatment-by-Treatment-Kumar/2e595d676258898e41e943e80015865a86ca8175 (accessed on 13 November 2021).
154. Esfandyari, Y.; Mahdavi, Y.; Seyedsalehi, M.; Hoseini, M.; Safari, G.H.; Ghozikali, M.G.; Kamani, H.; Jaafari, J. Degradation and biodegradability improvement of the olive mill wastewater by peroxi-electrocoagulation/electrooxidation-electroflotation process with bipolar aluminum electrodes. *Environ. Sci. Pollut. Res.* **2015**, *22*, 6288–6297. [CrossRef]
155. Sahu, O.; Rao, D.G.; Gopal, R.; Tiwari, A.; Pal, D. Treatment of wastewater from sugarcane process industry by electrochemical and chemical process: Aluminum (metal and salt). *J. Water Process Eng.* **2017**, *17*, 50–62. [CrossRef]

156. Nasrullah, M.; Singh, L.; Mohamad, Z.; Norsita, S.; Krishnan, S.; Wahida, N.; Zularisam, A.W. Treatment of palm oil mill effluent by electrocoagulation with presence of hydrogen peroxide as oxidizing agent and polialuminum chloride as coagulant-aid. *Water Resour. Ind.* **2017**, *17*, 7–10. [CrossRef]
157. Jaafarzadeh, N.; Ghanbari, F.; Ahmadi, M.; Omidinasab, M. Efficient integrated processes for pulp and paper wastewater treatment and phytotoxicity reduction: Permanganate, electro-Fenton and Co3O4/UV/peroxymonosulfate. *Chem. Eng. J.* **2017**, *308*, 142–150. [CrossRef]
158. Asaithambi, P.; Aziz, A.R.A.; Sajjadi, B.; Daud, W.M.A.W. Sono assisted electrocoagulation process for the removal of pollutant from pulp and paper industry effluent. *Environ. Sci. Pollut. Res.* **2017**, *24*, 5168–5178. [CrossRef]
159. Hmidi, K.; Ksentini, I.; Mansour, L.B. Treatment of olive-pomace oil refinery wastewater using combined coagulation-electroflotation process. *J. Water Chem. Technol.* **2017**, *39*, 275–280. [CrossRef]
160. Ates, H.; Dizge, N.; Yatmaz, H.C. Combined process of electrocoagulation and photocatalytic degradation for the treatment of olive washing wastewater. *Water Sci. Technol.* **2017**, *75*, 141–154. [CrossRef] [PubMed]
161. Taquez, H.N.I.; Pavas, E.G.; Blatchley, E.R.; García, M.A.G.; Gómez, I.D. Integrated electrocoagulation-electrooxidation process for the treatment of soluble coffee effluent: Optimization of COD degradation and operation time analysis. *J. Environ. Manag.* **2017**, *200*, 530–538. [CrossRef]
162. Ozay, Y.; Ünsar, E.K.; Isık, Z.; Yılmaz, F.; Dizge, N.; Perendeci, N.A.; Mazmanci, M.A.; Yalvac, M. Optimization of electrocoagulation process and combination of anaerobic digestion for the treatment of pistachio processing wastewater. *J. Clean. Prod.* **2018**, *196*, 42–50. [CrossRef]
163. Sahu, O.; Rao, D.G.; Thangavel, A.; Ponnappan, S. Treatment of sugar industry wastewater using a combination of thermal and electrocoagulation processes. *Int. J. Sustain. Eng.* **2018**, *11*, 16–25. [CrossRef]
164. Davarnejad, R.; Sabzehei, M.; Parvizi, F.; Heidari, S.; Rashidi, A. Study on Soybean Oil Plant Wastewater Treatment Using the Electro-Fenton Technique. *Chem. Eng. Technol.* **2019**, *42*, 2717–2725. [CrossRef]
165. Mujeli, M.; Hussain, S.A.; Ismail, M.H.; Biak, D.R.A.; Jami, M.S. Screening of electrocoagulation process parameters for treated palm oil mill effluent using minimum-runs resolution IV design. *Int. J. Environ. Sci. Technol.* **2019**, *16*, 811–820. [CrossRef]
166. Abdullah, H.M.; El-Shatoury, S.A.; El-Shahawy, A.A.; Ghorab, S.A.; Nasr, M.; Trujillo, M.E. An integrated bioaugmentation/electrocoagulation concept for olive mill wastewater management and the reuse in irrigation of biofuel plants: A pilot study. *Environ. Sci. Pollut. Res.* **2019**, *26*, 15803–15815. [CrossRef]
167. Sahu, O. Suitability of chemical and electrocoagulation process on sugar industry wastewater treatment. *Int. J. Energy Water Resour.* **2019**, *3*, 117–125. [CrossRef]
168. Elkacmi, R.; Boudouch, O.; Hasib, A.; Bouzaid, M.; Bennajah, M. Photovoltaic electrocoagulation treatment of olive mill wastewater using an external-loop airlift reactor. *Sustain. Chem. Pharm.* **2020**, *17*, 100274. [CrossRef]
169. Khani, M.R.; Mahdizadeh, H.; Kannan, K.; Kalankesh, L.R.; Kamarehei, B.; Baneshi, M.M.; Shahamat, Y.D. Olive mill wastewater (OMW) Treatment by hybrid processes of electrocoagulation/catalytic ozonation and biodegradation. *Environ. Eng. Manag. J.* **2020**, *19*, 1401–1410.
170. Gondudey, S.; Chaudhari, P.K. Treatment of Sugar Industry Effluent Through SBR Followed by Electrocoagulation. *Sugar Technol.* **2020**, *22*, 303–310. [CrossRef]
171. Sia, Y.Y.; Tan, I.A.W.; Abdullah, M.O. Palm Oil Mill Effluent Treatment Using Electrocoagulation-Adsorption Hybrid Process. *Mater. Sci. Forum* **2020**, *997*, 139–149. [CrossRef]
172. Bargaoui, M.; Jellali, S.; Azzaz, A.A.; Jeguirim, M.; Akrout, H. Optimization of hybrid treatment of olive mill wastewaters through impregnation onto raw cypress sawdust and electrocoagulation. *Environ. Sci. Pollut. Res.* **2021**, *28*, 24470–24485. [CrossRef] [PubMed]
173. Shahamat, Y.D.; Hamidi, F.; Mohammadi, H.; Ghahrchi, M. Optimisation of COD removal from the olive oil mill wastewater by combined electrocoagulation and peroxone process: Modelling and determination of kinetic coefficients. *Int. J. Environ. Anal. Chem.* **2021**, 1–14. [CrossRef]
174. Hanafi, F.; Belaoufi, A.; Mountadar, M.; Assobhei, O. Augmentation of biodegradability of olive mill wastewater by electrochemical pre-treatment: Effect on phytotoxicity and operating cost. *J. Hazard. Mater.* **2011**, *190*, 94–99. [CrossRef]
175. Hanafi, F.; Assobhei, O.; Mountadar, M. Detoxification and discoloration of Moroccan olive mill wastewater by electrocoagulation. *J. Hazard. Mater.* **2010**, *174*, 807–812. [CrossRef]
176. Sridhar, R.; Sivakumarb, V.; Immanuel, V.P.; Maran, J.P. Treatment of pulp and paper industry bleaching effluent by electrocoagulant process. *J. Hazard. Mater.* **2011**, *186*, 1495–1502. [CrossRef]
177. Gonder, Z.B.; Balcioglu, G.; Vergili, I.; Kaya, Y. Electrochemical treatment of carwash wastewater using Fe and Al electrode: Techno-economic analysis and sludge characterization. *J. Environ. Manag.* **2017**, *200*, 380–390. [CrossRef]