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Polarity Effect of Stainless-Steel and Copper Electrode Materials for the Purification of Slaughterhouse Wastewater

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Abstract: Although electrochemical methods are one of the most efficient approaches for treating wastewater, the type of wastewater to be treated, the type of electrode material employed, and the polarity direction all significantly affect how well these systems work. The prospective application of the proposed materials for the purification of slaughterhouse effluent has not been sufficiently explored in earlier studies, despite the fact that the materials (copper and stainless-steel) are reasonably inexpensive and easily accessible, especially in low-income countries. It is also unfortunate that previous research has not taken into account the potential effect of polarity direction in stainless-steel and copper electrode materials used for the purification of slaughterhouse effluent. This study investigated the potential effect of polarity direction for the purification of slaughterhouse wastewater using stainless-steel and copper electrode materials. Two electrode polarities were used in the study; stainless-steel (anode) to copper (cathode) and copper (anode) to stainless-steel (cathode). The potential effect of the contact time on the pollutants' removal was also taken into account. Generally, the copper-to-stainless-steel polarity showed a relatively high removal efficiency compared to the stainless-steel-to-copper electrode polarity. For instance, under 20 min of contact time, the removal efficiencies of copper (anode) to stainless-steel (cathode) were higher than that of stainless-steel (anode) to copper (cathode) in 11 out of 14 investigated water quality parameters. From 40 min contact time, the copper (anode) to stainless-steel (cathode) performed higher than that of stainless-steel (anode) to copper (cathode) in 8 out of 14 investigated water quality parameters. Moreover, from 60 min contact time, the copper (anode) to stainless-steel (cathode) performed higher than that of stainless-steel (anode) to copper (cathode) in 11 out of 14 investigated water quality parameters. Based on the findings, it is clear that, in order to obtain desired performance, contact time and polarity direction should be carefully considered when developing electrochemical wastewater treatment systems.

Keywords: electrochemical wastewater treatment; copper and stainless-steel; livestock slaughterhouse; water quality; the removal efficiency

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1. Introduction

The demand for cattle meat products has grown as a result of the world's high population. Unfortunately, meat processing is also linked to excessive freshwater use, which leads to enormous amounts of wastewater production [1]. The trend is also anticipated to intensify over time as a result of the ongoing population growth [2]. Due to their complex composition of pollutants, which includes pathogens, high levels of organic matter, fats, proteins, and fibers, the effluents produced by livestock slaughterhouses are widely acknowledged as being harmful [3].

More precisely, the effluent from livestock slaughterhouses is highly enriched in total organic carbon (TOC), total phosphorus (TP), biochemical oxygen demand (BOD), and total suspended solids (TSS) [4]. In order to safeguard both human health and the environment, such highly polluted effluent must be thoroughly treated before being discharged or used in any other applications. The wastewater from livestock slaughterhouses can be treated using a variety of technologies, including biological [5], physical [6], and chemical methods [7]. Each kind of treatment does, however, have benefits and drawbacks.

For instance, physical treatment processes such as membrane filtration systems have been widely recognized as among the relatively efficient treatment systems in terms of pollutants removal [8,9]; however, they are also well-known in terms of pressure demand and high reject rates leading to relatively huge volumes of sludge that has to be handled separately [10]. The phenomenon makes the treatment approach relatively expensive as well as being associated with feasibility issues for large-scale treatments. However, the use of chemical-based treatments raises the possibility of producing byproducts that are harmful to human health and the environment in general [11].

Additionally, both anaerobic and aerobic biological treatment methods depend on bacteria and are very flexible to a wide range of wastewater compositions and properties [12]. These treatment systems, however, are noted for their slow operations, enormous physical areas, and significant sludge formation. Electrochemical (EC) technologies present a robust, compact, user-friendly, and remarkably adaptable option for dealing with variations in wastewater composition [13]. However, it must be noted that even when handling wastewater with similar characteristics, different electrode materials do not perform the same [14].

The EC treatment methods have been widely used to treat various types of wastewater in the field of wastewater management, including poultry slaughterhouses [15], phenolic wastewater [16], textile dye wastewater [17], Cyanide Wastewater [18], tannery wastewater [19], coal tar wastewater [20], and sugar factory wastewater [21]. General demand for electrochemical wastewater treatment techniques has been rising quickly.

The treatment of wastewater using electrochemical methods can be accomplished in a variety of ways, such as direct oxidation and reduction reactions, using reactive chemical species generated during the process, or chemicals released during the process that facilitate the physical removal of the pollutants. An EC treatment system typically comprises at least two electrodes (one for the anode and one for the cathode), as well as an electrolyte-filled intermediate space. An electrode that permits a regular current (positive charge) to flow into the device from the external circuit is referred to as an anode. The electrode that permits a conventional current to exit the device is known as a cathode [22]. The extensively used electrode materials in the field of wastewater treatment include iron [23], titanium [24], graphite [25], and aluminum [26]. Electronic conductivity and the ability to interact with water molecules are the fundamental characteristics of an electrode material [27].

Two key processes take place when electricity is applied to an EC treatment system, namely, the oxidation process in the anode, which causes the material to be electrochemically damaged, and the passivation process in the cathode. Nevertheless, by electrically dissolving metal electrodes, the therapy procedure generates some coagulants in situ. The metal ion is created during the process at the anode, while hydrogen gas is created at the cathode. Although the hydrogen gas is in charge of floating the water-borne particles, the generated metal hydroxide ions are in charge of the adsorption and trapping of pollutants [22].

However, as was already mentioned, the effectiveness of electrochemical methods depends greatly on the materials used for the electrodes, the polarity direction, and the characteristics of the wastewater that needs to be treated. This means that the same electrode materials can produce noticeably different results when different polarities are used to purify wastewater with varying characteristics. Unfortunately, information on the effectiveness of these systems for the treatment of livestock wastewater using copper and stainless-steel electrode materials with different polarities is still scant and was not included in earlier studies.

The electrode polarity is all about the electrical factors that govern how the current flows in relation to the electrode [28]. The electrodes can have either straight polarity or reverse polarity as their polarity state. Reverse polarity is when the workpiece electrode is linked to the anode (+) and the tool electrode to the cathode (−), whereas straight polarity is when the microtool is attached to the cathode (−) [29]. The tool electrode is utilized as the cathode and the workpiece is used as the anode to produce a high material removal rate from the workpiece. Changing the polarity can improve the performance of particular electrode/work material combinations depending on the application. In general, positive polarity improves wear conditions while negative polarity improves machining speed for graphite electrodes [30]. For instance, in a study by Chow et al. [31], which looked at the potential impact of polarity reversal on the functionality of the electrochemical method using iron electrodes under a variety of water chemistry conditions and at a range of reversal frequencies, it was found that the faradaic efficiency in polarity reversal was consistently lower than that in the electrocoagulation systems operated with a direct current. Additionally, it was shown that the faradaic effectiveness dropped with time as the current reversal frequency rose, reaching a minimum of 10% when the polarity reversal interval was 0.5 min. Additionally, Markus' research [32], examined how polarity reversal in electrolytic cells works in relation to a number of variables, such as polarity reversal time, electrolyte composition, and electrode material. More specifically, polarity reversal times ranging from 1 s to 10 min were used in various water matrices in small bench-size electrolytic systems using iron, aluminum, and boron-doped diamond (BDD) electrodes. It was discovered that using a 30 s polarity reversal period reduced the sacrificial metal dissolution in electrocoagulation using iron electrodes by 60% as compared to not doing so. It was discovered that the reversible electrochemical side reactions involving iron species that occur after each polarity change are what were responsible for this pattern of decreased metal dissolving efficiency. Aluminum electrodes, in contrast, did not show this reduction in efficiency; nonetheless, after polarity reversal, the electrodes repassivated, perhaps as a result of the pH boundary layer becoming neutralized.

Taking into account the aforementioned information, this study uses stainless-steel and copper electrode materials to examine the potential impact of polarity direction on the purification of slaughterhouse effluent. In the investigation, two electrode polarities were examined, namely, stainless-steel (anode) to copper (cathode), and copper (anode) to stainless-steel (cathode). The potential impact of the contact time on the elimination of the contaminants was also considered.

2. Materials and Methods

2.1. Case Study and Characteristics of Raw Wastewater Used in the Study

The Vingunguti cattle slaughterhouse, which is 16.4 km from the city center and is situated at 6°50′9.89″ S latitude and 39°14′24.26″ E longitude in Dar es Salaam, Tanzania, provided the raw wastewater samples used in this investigation. Grab samples of the raw wastewater were taken in 5 L plastic bottles, stored at 4 °C, and then subjected to analysis and treatment. Before use, deionized water was used to thoroughly rinse the plastic bottles. It is also crucial to emphasize that the samples were taken at the end of each experiment.

Pre-slaughter handling, stunning, and slaughtering are the three main processes that make up a slaughterhouse (Figure 1).

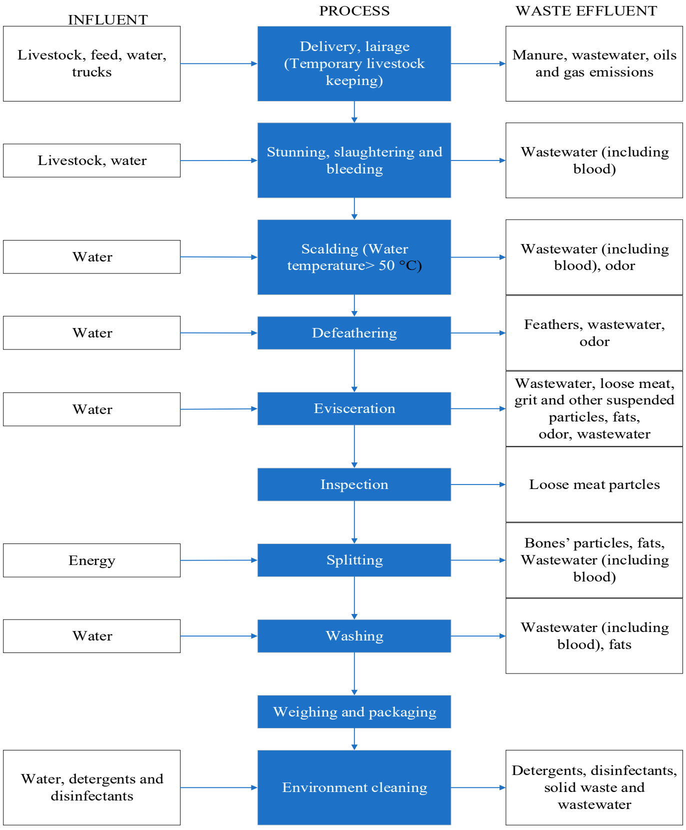


Figure 1. The general process flowchart of the activities involved in the animal slaughterhouse.

Total suspended solids (TSS), phosphates, ammonia, COD, total iron, aluminum, BOD, manganese, nickel, chromium, and total organic carbon were among the 14 water quality metrics examined in this study (TOC). Table 1 summarizes the characteristics of the raw wastewater and lists the recommended drinking water quality standards for pH, turbidity, color, total iron, and chromium from the World Health Organization (WHO), aluminum from Canada, TOC from the United States Environmental Protection Agency (US EPA), and ammonia from the European Union (EU).

Table 1. The characteristics of the livestock slaughterhouse wastewater before treatment.

Indicator	Min	Max	AM	Med	SD	Guideline	Unit
pH	5.5	7.4	6.7	6.9	0.6	6.5–8.5	-
Turbidity	62.6	647	226.7	116	214.4	5	NTU
Color	165.0	452	295.6	278	103.8	5	mg/L Pt scale
TSS	1068.0	6204	3999.8	4212	2025.7	-	mg/L
Phosphates	2.7	6.0	4.7	4.8	1.2	-	mg/L
Ammonia	4.9	12.5	7.9	6.4	2.9	0.5	mg/L
COD	4606.0	9815	7226.6	8002	1968.8	-	mg/L
Total iron	6.9	12.3	9.5	9.2	1.8	3	mg/L
Aluminum	5.3	9.2	7.5	8.2	1.5	0.2	mg/L
BOD	1270.0	8542.0	4290.2	4428.0	2789.5	-	mg/L
Manganese	0.1	0.5	0.3	0.3	0.1	-	mg/L
Nickel	4.0	8.6	6.5	6.2	1.7	0.02	mg/L
Chromium	0.4	2.3	1.0	0.6	0.7	0.05	mg/L
TOC	174.0	1850.0	966.2	898.0	558.6	2	mg/L

2.2. Experimental Setup and Design

The electrochemical experiments used a total of 2 L of wastewater for each session. An electrochemical reactor made of polypropylene measuring 17 × 15 × 13 cm^3 included the electrodes (anode and cathode). Direct current (DC) was applied to both electrodes in a potentiostatic mode to aid the electrochemical reaction. The DC power supply of Xinhua Electrical Weld Company, Loudi City, China, typically has a range of 0 to 50 V for voltage and 0 to 10 A/m^2 for current density. The anode electrode in this study was made of stainless-steel, and the cathode electrode was built of copper, both measuring 12.4 × 13.6 × 0.4 cm^3. The general technical configurations and settings are outlined in Table 2 and Figure 2.

Table 2. The electrochemical setup's technical specifications.

System Parameter	Value	Unit
Raw wastewater temperature	15–20	°C
Potential-voltage	24	V
Average current density	5.5	A
Average power consumption	132	W
Hydraulic retention time (contact time)	20, 40, 60	min

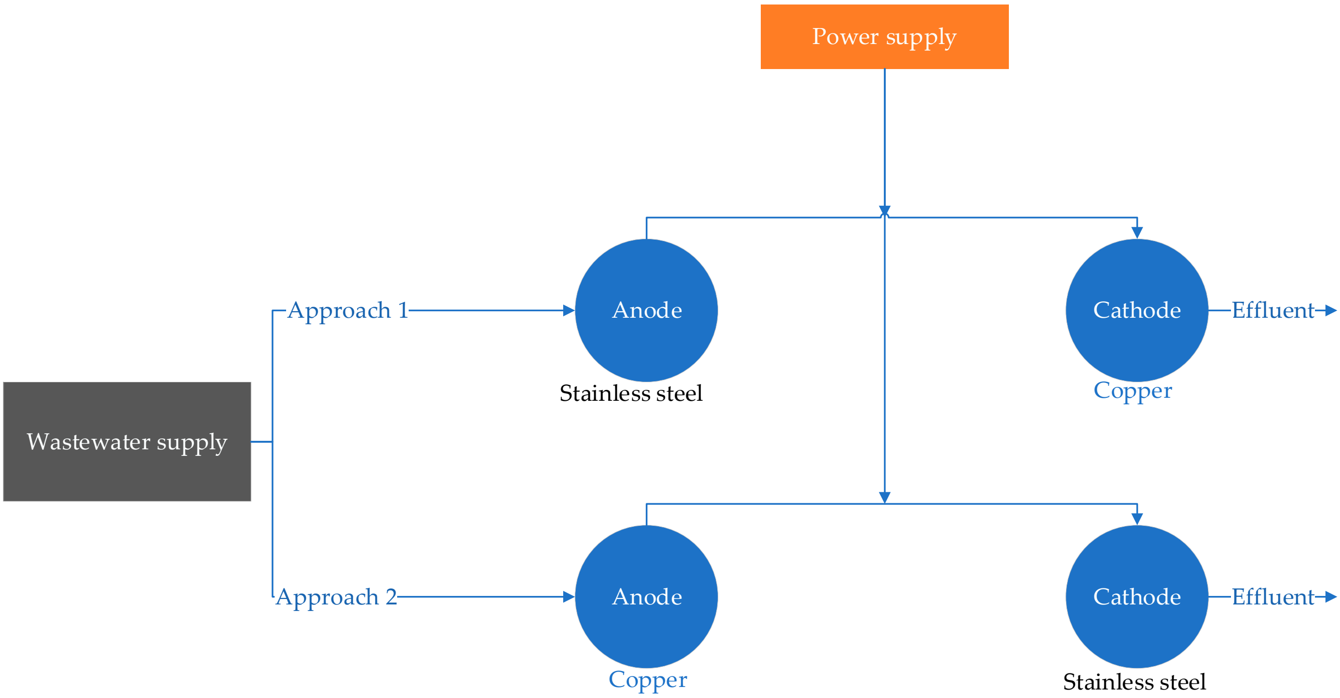


Figure 2. Experimental setup.

2.3. Analytical Methods

Every sample was examined on the same day as the sample collection. Standard practices, reagents, and test kits were primarily used to do this. The provided average concentration is the outcome of six (6) experiments, which is particularly important to note. To be more precise, the chemical parameters were analyzed using a spectrophotometer (Hach DR3900, HACH/LANGE, Berlin, Germany) and colorimeter (Hach DR900) supplied by Hach Company (Hach Company, 2007). A Hach TSS portable hand-held turbidity meter (Hach Company, Loveland, CO, USA), which has a range capacity of 0.001–400 g/L, was used to measure both the TSS and turbidity in the samples. The lab pH meter (Hach Company, HACH/LANGE, Berlin, Germany) was used for the pH measurements, and an ultraviolet-visible (UV-V) spectrophotometer (Mettler Toledo, Greifensee, Switzerland) was used for the color measurements of the samples. A 4500-Nor APHA from the American Public Health Association, Washington, DC, USA, was used for the analysis of phosphates. Atomic absorption spectrometry was used to identify the potentially harmful elements (chromium (Cr), nickel (Ni), and manganese (Mn)) in the water samples that were the subject of this study (Analytik Jena, Upland, CA, USA). A TOC analyzer was used to measure TOC (Hach Company, Lindbergh Drive Loveland, Loveland, CO, USA).

2.4. Statistical Methods

The minimum and maximum concentration values were automatically calculated from the dataset using the built-in capabilities of Microsoft Excel 2019. Additionally, from the data series of each of the examined water quality metrics, other statistical parameters, such as the arithmetic mean, median, standard deviation, and percent removal efficiencies were computed.

2.4.1. Analysis of the Relationships among the Studied Parameters

To assess the strength of the association between the chosen parameters, a correlation analysis was performed using the derived correlation matrices for some of the relevant physicochemical characteristics. A high correlation, from the point of view of interpretation, shows that two or more variables are strongly related to one another; while a low correlation indicates that the variables under study are hardly related. The correlation coefficients that were used in this study fall into the following categories, namely, 0 to 0.29 is considered to be a weak relationship, 0.3 to 0.49 is considered to be moderate, 0.5 to 0.69 is considered to be a strong relationship, and 0.7 to 1 is considered to be a very strong relationship.

2.4.2. Data Distribution Analysis

Investigating the nature of the data distribution across the examined water quality metrics was also crucial. To assess the skewness of the data distribution and determine whether there were any potentially anomalous findings (outliers) in the datasets, box and whisker plots were created.

2.4.3. Variance Analysis Using a *t*-Test

A *t*-Test was employed to compare the means of the two groups. It is frequently employed in hypothesis testing to establish whether a procedure or treatment actually affects the population of interest or whether two groups differ from one another. A high t-score, also known as a t-value, denotes that the groups are distinct, whereas a low t-score denotes similarity. Degrees of freedom, or the values in a study that can fluctuate, are crucial for determining the significance and veracity of the null hypothesis. The sample set's accessible data records determine how many of these values can be calculated.

2.4.4. Variance Analysis Using Tukey's Honestly Significant Difference

Tukey's test identifies the unique means that deviate significantly from a group of means. When comparing more than two means, Tukey's test, a multiple comparison test, should be used (for two means, utilize a *t*-Test). A pairwise comparison of all means is used to produce Tukey's test (Equation (1)) [33].

$$HSD = q\sqrt{\frac{MS}{n}} \quad (1)$$

whereby; n is the number of samples in each group, q is derived from the data range distribution, and MS is the mean square value computed in the ANOVA.

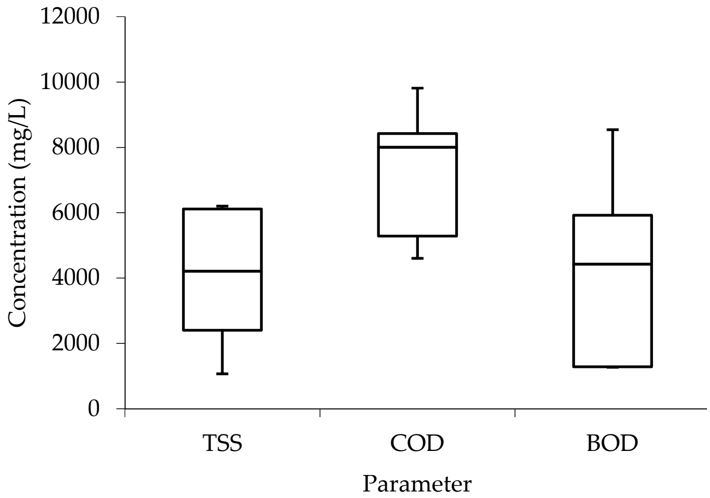
2.4.5. Variance Analysis Using Scheffé's Multiple Comparison Tests

In an analysis of variance, the Scheffé test was applied to examine multiple comparisons among a set of means. This test examines a set of means in order to assess how they differ from one another. After an ANOVA test is finished, the Scheffé test is used to compare two datasets inadvertently.

3. Results

3.1. Data Distribution Analysis in the Raw Wastewater

Figure 3 depicts how the median lines in the ammonia boxplot are closer to the center, indicating that the raw wastewater's data distribution was symmetric or normal (equally distributed). The median lines can be seen to be closer to the upper quartile in the COD, BOD, and aluminum boxplots, indicating that the distribution of the data is "negatively skewed". This indicates that the frequency of low concentration values was higher in the data distribution than the frequency of high concentration values. The median lines of the boxplots for ammonia, total iron, manganese, nickel, and chromium are closer to the lower quartiles, illustrating that the frequency of high concentration values is higher in the water quality data than the low concentration values, a phenomenon known as "positive skewness".



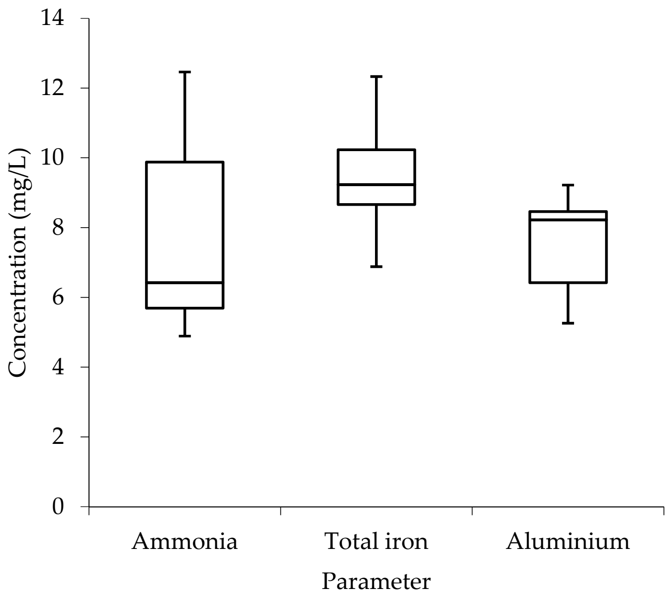


Figure 3. *Cont.*

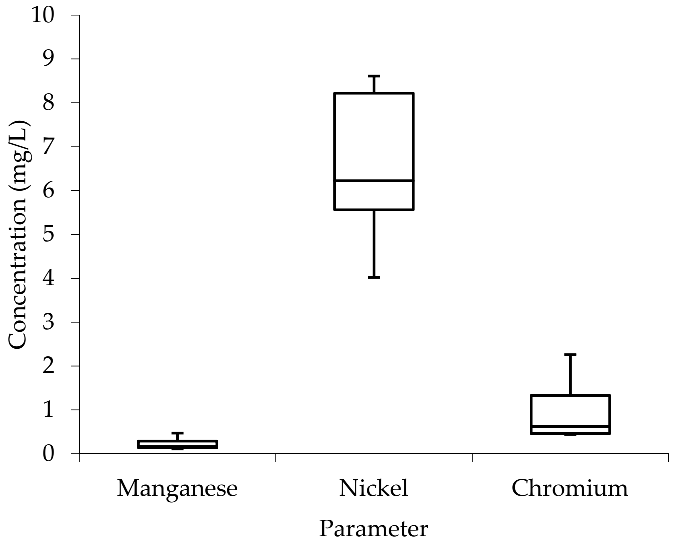


Figure 3. Data distribution in the raw wastewater.

3.2. Correlation Analysis in the Raw Wastewater

Additionally, correlation matrices based on five chosen water quality characteristics were created (turbidity, color, TSS, COD, and BOD). In general, there was a "moderate" to "very strong" correlation between the measures examined (Table 3). With a correlation index of 0.94, it is possible to see a strong association between COD and color. Given that dissolved organic molecules provide color in water and that excessive levels of COD concentrations are most likely caused by dissolved organic compounds, there is a "very high" association between COD and color. It should be emphasized that one of the main contaminants in wastewater from cattle slaughterhouses is blood. Additionally, a correlation rating of 0.87 indicates a "very high" correlation between hue and turbidity. The strong relationship between color and turbidity can be explained by the fact that the more intensely colored water absorbs light, which raises the turbidity levels since scattered light also has a significant impact on turbidity levels.

Table 3. Correlation among turbidity, color, TSS, COD, and BOD in the raw wastewater.

	Turbidity	**Color**	**TSS**	**COD**	**BOD**
Turbidity	1				
Color	0.87	1			
TSS	0.59	0.67	1		
COD	0.79	0.94	0.49	1	
BOD	0.82	0.74	0.84	0.49	1

3.3. Treated Effluent Characterization

According to Table 4, 92.3 NTU turbidity was attained under 20 min of retention time following the electrochemical treatment process using the stainless-steel-to-copper electrode polarity; while approximately 92 NTU was retrieved from the copper-to-stainless-steel. Mathematically, the average concentration attained from the stainless-steel-to-copper electrode polarity is equivalent to roughly 2.5 times less turbidity than the turbidity concentration in the raw wastewater. In the literature, the electrochemical methods are considered to be among the most effective methods for turbidity removal from wastewater; for instance, in the study conducted by [34], a significant reduction in turbidity was observed. Whereby, the anode and cathode materials employed were graphite and stainless-steel, respectively.

Table 4. Average concentrations from the treated effluent with 20 min of contact time.

Indicator	Polarity	
	Stainless-Steel-to-Copper	Copper-to-Stainless-Steel
pH	6.338	5.844
Turbidity	92.286	92.005
Color	141	152
TSS	1014.5	998.9
Phosphates	3.675	3.224
Ammonia	5.167	4.997
COD	3339.833	3002.445
Total iron	7.534	5.646
Aluminum	4.94	4.55
BOD5	2330	2460
Manganese	0.16	0.146
Nickel	4.996	3.889
Chromium	0.686	0.442
TOC	586.8	606.5

On the other hand, the average color value of the 141 mg/L Pt scale recorded from the study is two times lower than the average concentration in raw wastewater (Table 4). In general, all other water quality metrics had an average concentration that was between 1.3 and 3.9 times lower in the effluent treated by the EC system under 20 min of contact time than in the raw wastewater.

According to Table 5, after 40 min of contact time with the wastewater, 53.4 NTU, or around 4.2 times less turbidity than the average concentration in raw wastewater, was obtained from the treated effluent using the stainless-steel-to-copper electrode combination. The combination of copper and stainless-steel electrodes produced a turbidity average concentration of about 49.8 NTU. The average concentration from color was 84 mg/L Pt scale under the stainless-steel-to-copper electrode combination, which is around 3.5 times less than the average concentration in the raw wastewater. The average color concentration produced by the copper-to-stainless-steel electrode combination was 69 mg/L Pt scale. The average concentrations of all other water quality measures in the effluent treated by the EC system under 40 min of contact time were, on average, 1.9 to 9.8 times lower than they were in the raw wastewater.

Table 5. Average concentrations from the treated effluent with 40 min of contact time.

Indicator	Polarity	
	Stainless-Steel-to-Copper	Copper-to-Stainless-Steel
pH	6.338	6.668
Turbidity	53.429	49.808
Color	84	69
TSS	410	422
Phosphates	2.253	2.864
Ammonia	3.83	2.62
COD	2368.333	1978.408
Total iron	5.046	4.69
Aluminum	3.042	3.552
BOD5	1393	1166
Manganese	0.114	0.106
Nickel	3.114	4.68
Chromium	0.536	0.896
TOC	312.2	194.8

According to Table 6, after 60 min of contact time with the wastewater, 25.7 NTU, or around 4.2 times less turbidity than the average concentration in raw wastewater, was obtained from the treated effluent using the stainless-steel-to-copper electrode combination.

The average turbidity concentration from the copper-to-stainless-steel electrode combination was 15.5 NTU. The average concentration, calculated from color, was 41.3 mg/L Pt scale, which is roughly 7.2 times lower than the average concentration in the raw wastewater. A 15.5 mg/L Pt scale of color was achieved from the copper-to-stainless-steel electrode combination. The average concentrations of all other water quality measures in the effluent treated by the EC system during the first 60 min of contact time were, on average, 2.6 to 14 times lower than those in the raw wastewater.

Table 6. Average concentrations from the treated effluent with 60 min of contact time.

Indicator	Polarity	
	Stainless-Steel-to-Copper	**Copper-to-Stainless-Steel**
pH	6.338	6.449
Turbidity	25.683	0
Color	41.333	15.5
TSS	286.667	0
Phosphates	1.362	1.048
Ammonia	2.973	0.68
COD	787.133	26.567
Total iron	2.228	2.405
Aluminum	2.004	1.869
BOD5	463.4	10.393
Manganese	0.087	0.152
Nickel	1.504	0
Chromium	0.344	0.05
TOC (mg/L)	140.4	128.6

3.4. Data Distribution Analysis in the Treated Effluent

Figure 4 demonstrates that the medians for turbidity (20- and 60-min retention times), TSS (20-, 40-, and 60-min retention times), as well as a color (20-min retention time), are more akin to the first quartile (Q1). This indicates that the specific parameters had a higher concentration of high values than low values; this is referred to as a positive asymmetrical data distribution.

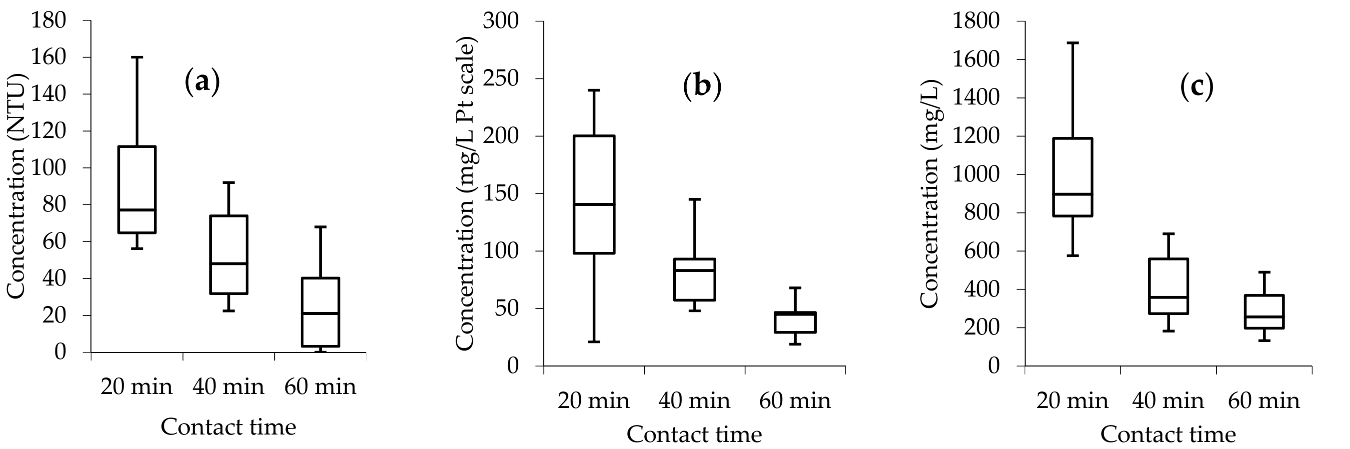


Figure 4. Data distribution for some physicochemical parameters after treatment, (**a**) turbidity, (**b**) color, (**c**) TSS.

The medians for the phosphates (40 and 60 min) are closer to the upper quartiles, indicating that the concentration values in the data series had more low concentration values than high concentration values, which is sometimes referred to as negative skewness. As can be observed from Figure 4, the turbidity (60 min contact time) has a median that is closer to the center, which suggests that the data were evenly distributed.

One of the forms of nitrogen is ammonia, which belongs to the same class of nutrients as phosphorus. Figure 5 demonstrates that the median line for the phosphate's boxplot under 60 min, and the ammonia boxplot under 20, 40, and 60 min, are closer to the higher quartiles, illustrating a "negative skewness" in the data distribution. With a median line that is more closely spaced from the lower quartiles, the phosphates boxplot under 60 min can be seen to be "positively skewed"; though the distribution of data in the phosphates under the 20-min group is equal.

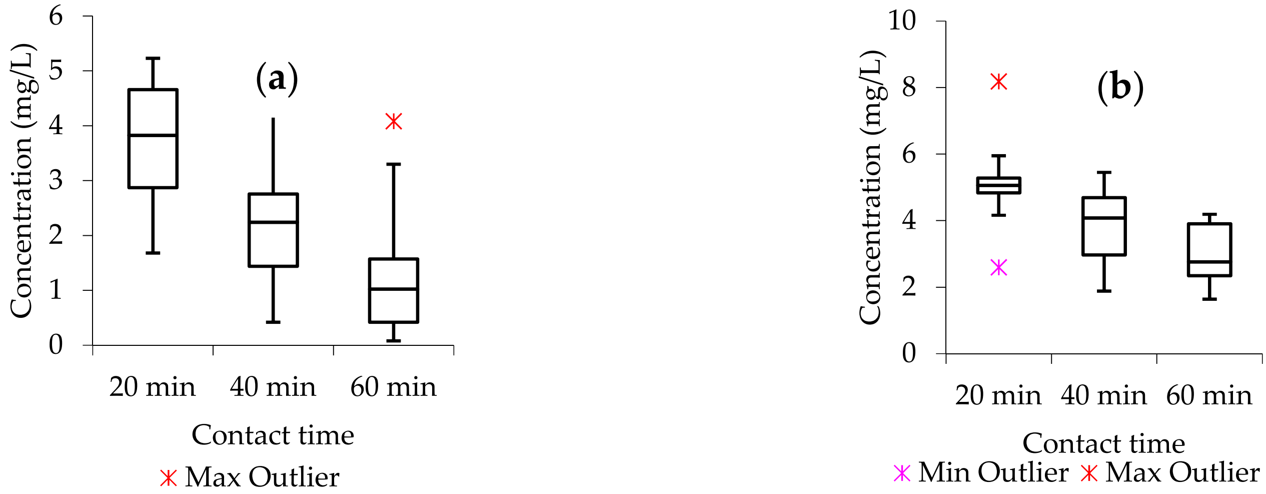


Figure 5. Boxplots for nutrients, (**a**) ammonia, (**b**) phosphates.

The organic matter-dependent indices COD, BOD, and TOC are critical in figuring out the levels of water quality. High pollutant loads are another characteristic of water with a high organic content. Figure 6 demonstrates that the median lines on the boxplots for the treated effluent under 20, 40, and 60 min; BOD under 20; and TOC under 20 and 40 min; are closer to the upper quartiles, illustrating that the frequency of low concentration values was higher than that of high concentration values in the data distribution. The median line in the BOD boxplot for runs under 40 min is closer to the lower quartile, a phenomenon known as "positive skewness". The median line is closer to the center in the TOC boxplot during the first 60 min, indicating that the distribution of the data was equal.

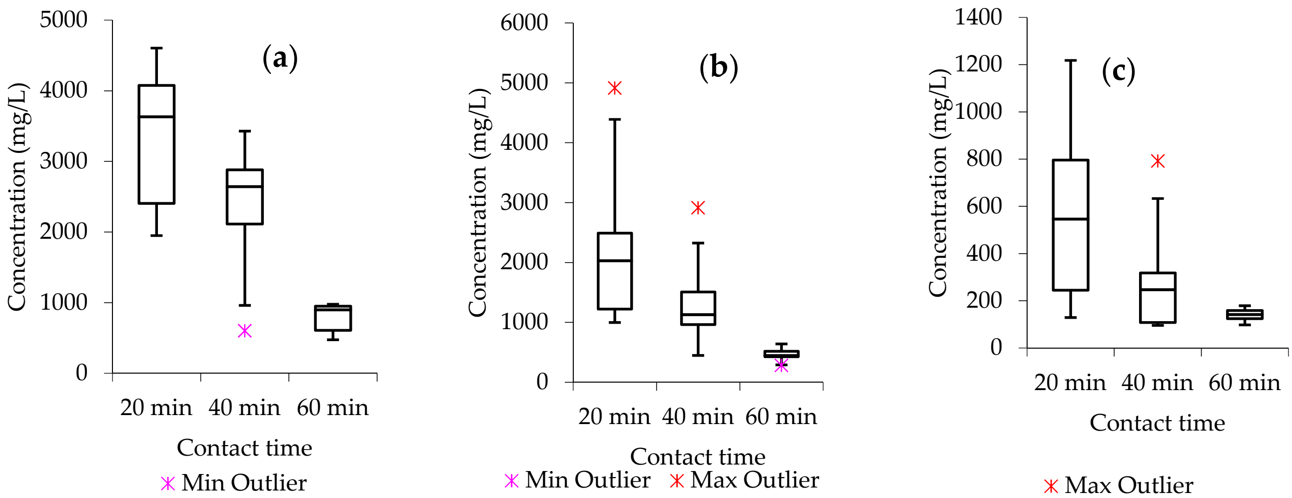


Figure 6. Data distribution for organic-related parameters in the treated effluents, (**a**) COD, (**b**) BOD, (**c**) TOC.

Total iron, aluminum, manganese, nickel, and chromium are all heavy metals that have the potential to be poisonous. Figure 7 demonstrates that the median lines for the total iron boxplot under 20 min, the aluminum boxplot under 60 min, and the manganese boxplot under 20 and 40 min, are closer to the higher quartiles, indicating that the distribution of the data is "negatively skewed". The boxplots for the total iron between 20 and 40 min are closer to the center, indicating an equitable distribution of data. The median lines in the boxplots for aluminum under 20 and 40 min, manganese under 60 min, nickel under 20, 40, and 60 min, and chromium under 20, 40, and 60 min, are closer to the lower quartiles, illustrating what is known as "positive skewness" in the water quality data, which is characterized by a higher frequency of high concentration values than low concentration values.

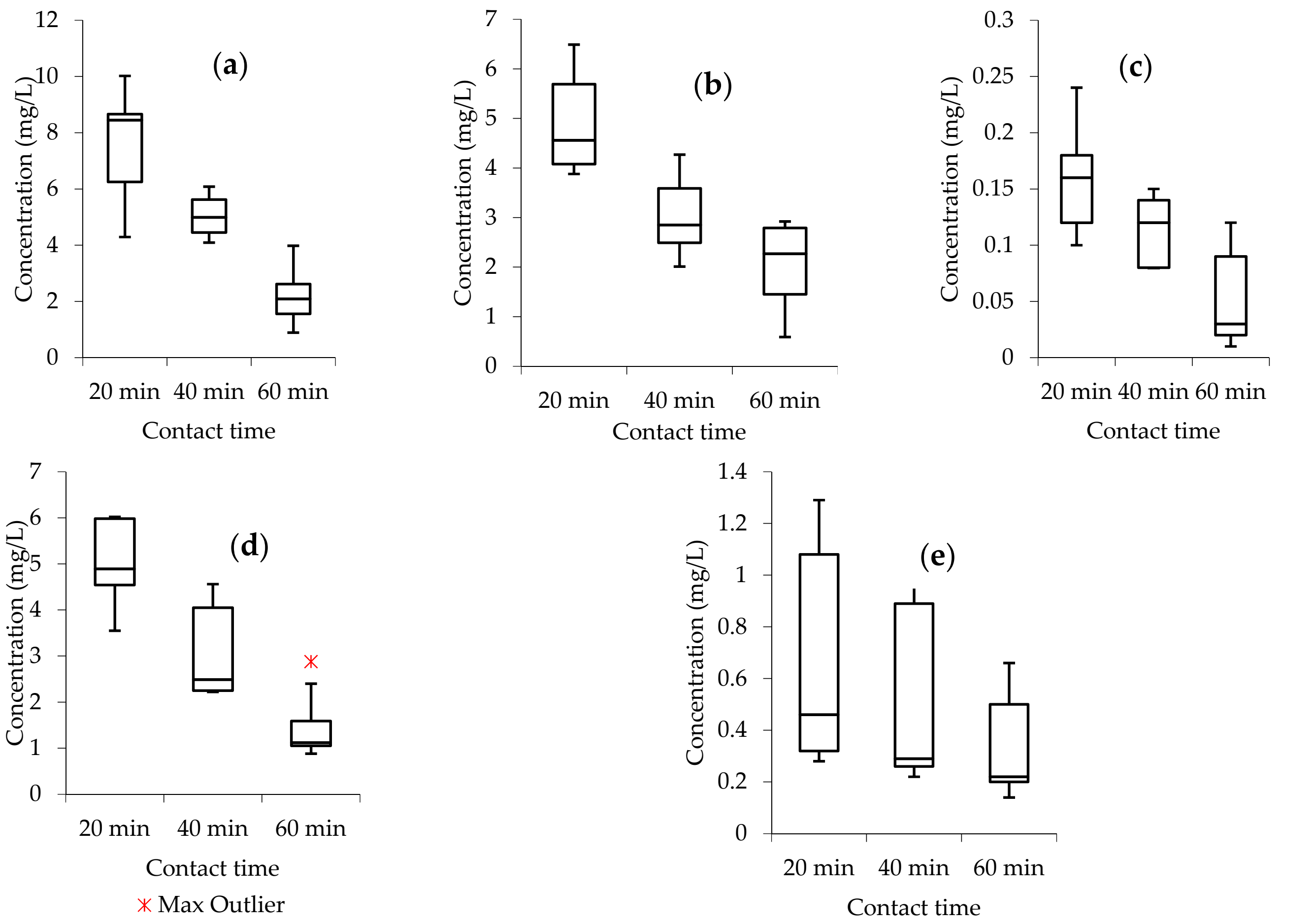


Figure 7. Boxplots for potentially toxic elements, (**a**) total iron, (**b**) aluminum, (**c**) manganese, (**d**) nickel, (**e**) chromium.

3.5. Removal Efficiencies

Figure 8 presents the removal efficiencies from 20 min of contact time. The results show that up to 75.02% removal efficiency of TSS was attained when the wastewater samples were exposed to the treatment systems for less than 20 min of contact time. Turbidity, COD, and chromium levels can all be found to have a relatively higher removal efficiency. Additionally, it can be seen that the two examined electrode polarities have nearly identical removal efficiencies for most of the water quality parameters. It is also worth noting that more environmentally friendly approaches to water treatment can be found using electrochemical techniques. Electricity is the primary reactant in the majority of electrochemical water treatment technologies, which employ electricity to carry out the treatment process [35]. It has been noted in the literature that the selection of the best electrode materials, membranes, operating parameters, such as polarity, as well as control of the electrolyte composition, are the main requirements for effective treatment because the efficiency of electrochemical water treatment methods typically depends on the applied current density, electrode material, and the shape and acidity of the treated electrolyte solution, as well as its composition [36].

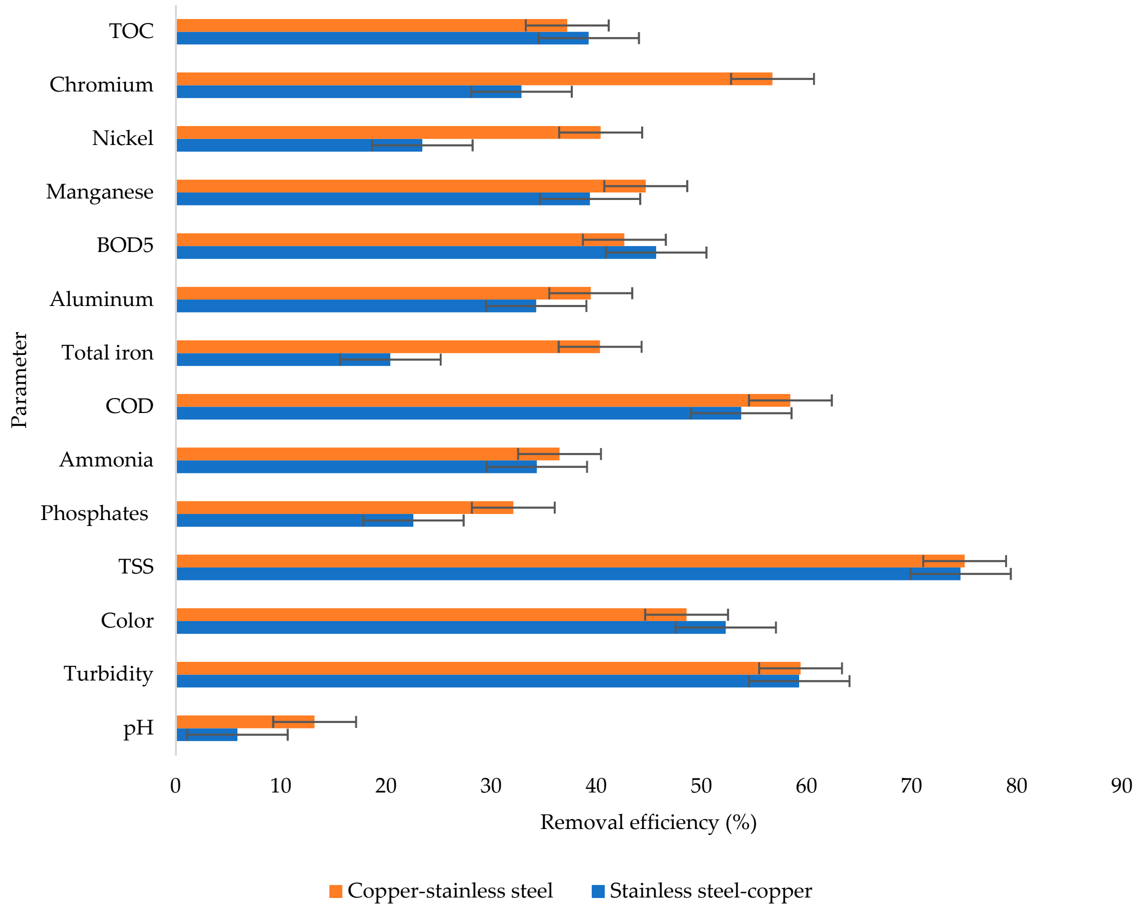


Figure 8. Removal efficiencies from 20-min contact time.

The removal efficiencies after 40 min of contact time are shown in Figure 9. The findings demonstrate that when the wastewater samples were subjected to the treatment systems for less than 40 min of contact time, up to 89.75% removal efficiency of TSS was achieved. All three variables have been determined to have a relatively higher removal efficiency, namely, turbidity, COD, and chromium levels. Furthermore, it is evident that for the majority of the water quality metrics, the removal efficiencies for the two investigated electrode polarities are almost equal.

Figure 10 displays the removal efficiencies following 60 min of contact time. The results show that up to 100% removal efficiency of turbidity was achieved when the wastewater samples were treated by the treatment systems for less than 60 min of contact time. Turbidity, COD, and chromium levels have all been found to have relatively higher removal efficiencies. However, unlike the removal efficiencies from the 20-min and 40-min contact times, the copper to stainless-steel electrode polarity demonstrated relatively high removal efficiencies for the majority of the investigated water quality parameters when the wastewater samples were subjected to the 60-min contact time.

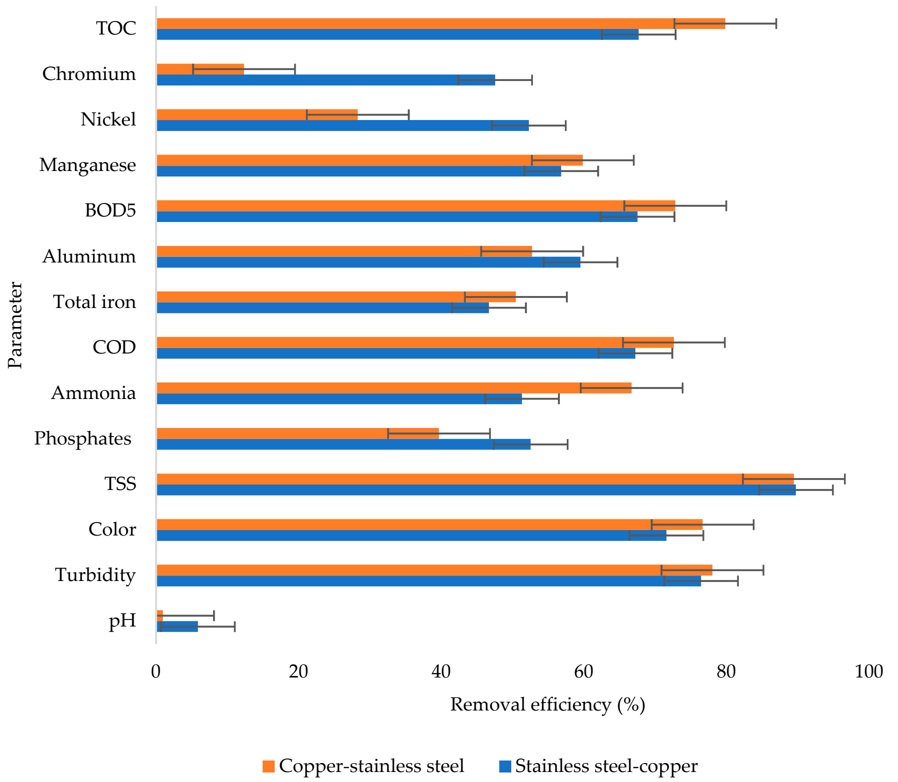


Figure 9. Removal efficiencies from 40-min contact time.

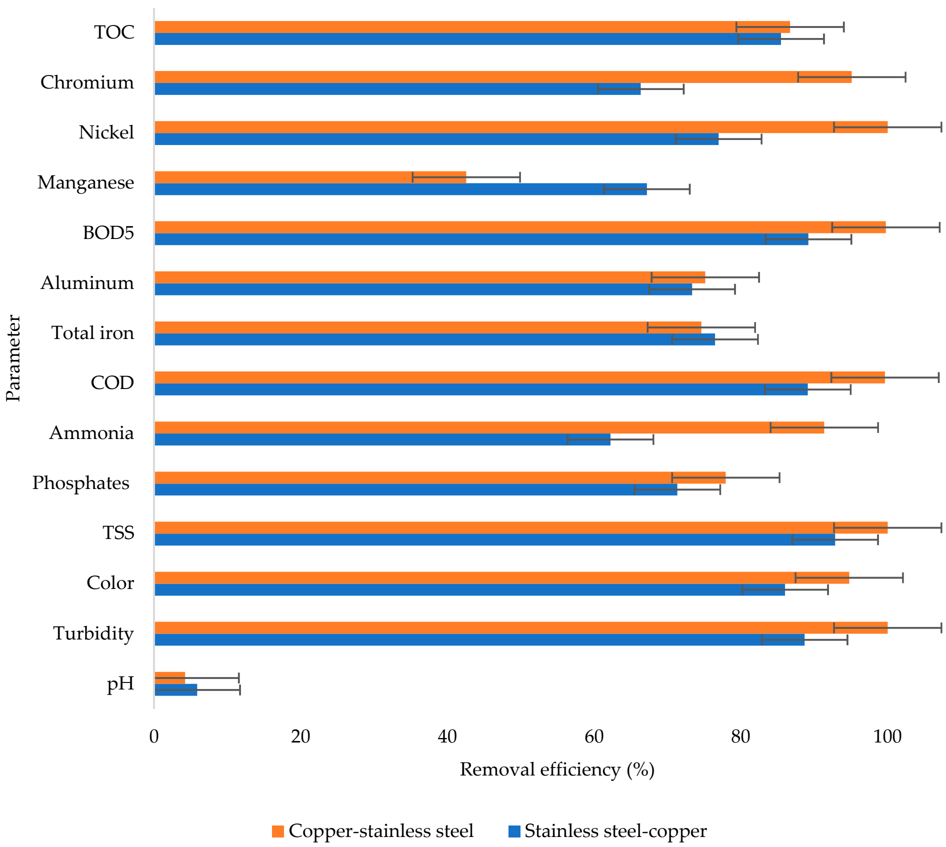


Figure 10. Removal efficiencies from 60-min contact time.

3.6. Percent Compliance Analysis

A summary of the percent compliance of the tested criteria in the untreated effluent and treated wastewater under various contact durations (20, 40, and 60 min) is shown in Table 7. From Table 7 it can be seen that, despite the relatively high removal efficiency observed from both of the investigated polarity directions, only a few water quality parameters complied with the recommended water quality standards; turbidity under copper (anode) to stainless-steel (cathode) and 60 min contact time (100% compliance); total iron under stainless-steel (anode) to copper (cathode) and 60 min contact time (25.7%); total iron under copper (anode) to stainless-steel (cathode) and 60 min contact time (19.8%); as well as nickel under copper (anode) to stainless-steel (cathode) and 60 min contact time (100%). The phenomenon suggests that in order to produce a high-quality recyclable effluent fit for drinking, either more contact time should be applied to the system or the treatment system should be used as a pre-treatment unit before other treatment systems, such as membrane filtration. The negative sign indicates that the parameter concentration in the treated effluent exceeded the prescribed guideline.

Table 7. Percent compliance results from the selected water quality parameters.

		Percent Compliance (%)					
		20 min		**40 min**		**60 min**	
Parameter	**Raw**	**SSA-CC**	**CA-SSC**	**SSA-CC**	**CA-SSC**	**SSA-CC**	**CA-SSC**
Turbidity	−4434.4	−1745.7	−1740.1	−968.6	−896.2	−413.7	100
Color	−5812	−2720	−2940	−1580	−1280	−726.7	−210
Ammonia	−1473.6	−933.3	−899.3	−666	−424	−494.7	−36
Total iron	−215.5	−151.1	−88.2	−68.2	−56.3	25.7	19.8
Aluminum	−3658	−2370	−2175	−1421	−1676	−902	−834.5
Nickel	−32530	−24880	−19345	−15470	−23300	−7420	100
Chromium	−1944	−1272	−784	−972	−1692	−588	0
TOC	−48210	−29240	−30225	−15510	−9640	−6920	−6330

Note: SSA-CC = stainless-steel (anode) to copper (cathode); CA-SSC = copper (anode) to stainless-steel (cathode).

3.7. t-*Test: Two-Samples Assuming Equal Variances*

3.7.1. Analysis of Variance from 20-Min Contact Time Datasets

The results of the *t*-Test analysis for the two polarity orientations under 20 min of contact time are summarized in Table S1. The differences in the concentrations from the examined water quality parameters are not statistically significant because the recovered *p*-value from the *t*-Test analysis is larger than 0.05 (alpha value). To be more precise, the findings show that the concentration differences between the effluents treated by the stainless-steel-to-copper and copper-to-stainless-steel were not great enough to be statistically significant.

3.7.2. Analysis of Variance from 40-Min Contact Time Datasets

In Table S2, the findings of the *t*-Test analysis for the two polarity orientations with less than 40 min of contact time are compiled. It is clear that similar to the 20-min contact duration, the recovered *p*-value from the *t*-Test analysis is greater than 0.05, indicating that the variations in concentrations from the analyzed water quality measures are not statistically significant (alpha value).

3.7.3. Analysis of Variance from 60-Min Contact Time Datasets

Table S3 lists the outcomes of the *t*-Test analysis for the two polarity orientations with less than 60 min of contact time. As a result of the retrieved *p*-value from the *t*-Test analysis being bigger than 0.05, the differences in concentrations from the tested water quality measures are not statistically significant (alpha value). Specifically, the results demonstrate that the concentration differences between the effluents treated by the copper-to-copper and stainless-steel-to-stainless-steel processes were not sufficiently large to be statistically significant. Additionally, it is clear from the mean and variance values that the copper (anode) to stainless-steel (cathode) electrode configuration outperformed the stainless-steel (anode) to copper (cathode) electrode arrangement. To be more precise, a mean value of 13.837 was obtained using a copper (anode) to stainless-steel (cathode) electrode configuration, which is equal to around 11% of the mean value obtained using a copper-to-steel electrode arrangement.

3.8. Tukey's Honestly Significant Difference (HSD) and Scheffé Multiple Comparison Tests from Raw Wastewater and 20-Min Contact Time

As previously highlighted, the Tukey HSD test is a statistical technique used to determine whether a relationship between two sets of data is statistically significant, or whether there is a good chance that a numerical change in one value observed is caused by a change in another value. To put it another way, the Tukey test is a method for evaluating an experimental hypothesis. Moreover, the Tukey test is used to determine whether an interaction between three or more variables is statistically significant; unfortunately, this is not the same as simply adding or multiplying the significance levels of the individual variables. Table 8 provides a summary of the findings from Tukey's honestly significant difference test for differences under 20 min of interaction time. Table 8 shows that a *p*-value that was statistically insignificant was produced when the results from the raw wastewater were compared against the results from the stainless-steel-to-copper electrode configuration. A similar phenomenon can be observed between raw wastewater vs. copper-to-stainless-steel and stainless-steel-to-copper vs. copper-to-stainless-steel electrode arrangements.

Table 8. Results from Tukey's honestly significant difference test under 20-min contact time.

Treatment Pair	Tukey HSD Q Statistic	Tukey HSD *p*-Value	Tukey HSD Inference
Raw wastewater vs. stainless-steel-to-copper	1.6419	0.484796	insignificant
Raw wastewater vs. copper-to-stainless-steel	1.676	0.470762	insignificant
Stainless-steel-to-copper vs. copper-to-stainless-steel	0.0341	0.899995	insignificant

The significant levels of the concentration differences in the raw wastewater and the tested electrode polarities were also further investigated using the Scheffé multiple comparison tests. It is worth noting that, in an analysis of variance (ANOVA) experiment, the Scheffé test is used to compare group means haphazardly rather than in accordance with a predetermined schedule. The advantage of using the Scheffé test is that it allows the experimenter to test whatever comparisons are thought to be intriguing [37]. Table 9 provides a summary of the results from the Scheffé multiple comparison tests under 20 min of contact time. From the table, it can be seen that the *p*-value was statistically insignificant when the results from the raw wastewater were compared against the results from the stainless-steel-to-copper electrode configuration; with a similar phenomenon observed between raw wastewater vs. copper-to-stainless-steel and stainless-steel-to-copper vs. copper-to-stainless-steel electrode arrangements.

Table 9. Results from the Scheffé multiple comparison tests under 20-min contact time.

Treatment Pair	Scheffé TT-Statistic	Scheffé *p*-Value	Scheffé Inference
Raw wastewater vs. stainless-steel-to-copper	1.161	0.515515	insignificant
Raw wastewater vs. copper-to-stainless-steel	1.1851	0.501636	insignificant
Stainless-steel-to-copper vs. copper-to-stainless-steel	0.0241	0.99971	insignificant

3.9. Tukey's Honestly Significant Difference (HSD) and Scheffé Multiple Comparison Tests from Raw Wastewater and 40-Min Contact Time

Additionally, Tukey's honestly significant difference (HSD) and Scheffé multiple comparison tests were run on the results from the raw wastewater and the examined electrode polarities with less than 40 min of contact time. The findings from Tukey's honestly significant difference test under 40 min of contact time are summarized in Table 10. The results from the 40 min of contact time, likewise, show that the concentration differences were not statistically significant, similar to those with 20 min of contact time.

Table 10. Results from Tukey's honestly significant difference test under 40-min contact time.

Treatment Pair	Tukey HSD Q Statistic	Tukey HSD *p*-Value	Tukey HSD Inference
Raw wastewater vs. stainless-steel-to-copper	2.3699	0.22843	insignificant
Raw wastewater vs. copper-to-stainless-steel	2.5112	0.192168	insignificant
Stainless-steel-to-copper vs. copper-to-stainless-steel	0.1413	0.899995	insignificant

The outcomes of the Scheffé multiple comparison tests with less than 20 min of interaction time are summarized in Table 11. The table shows that the *p*-value was statistically insignificant when raw wastewater results were compared to results from the copper-to-copper electrode configuration, and a similar phenomenon was seen when raw wastewater results were compared to copper-to-stainless-steel, and when stainless-steel-to-copper results were compared to copper-to-stainless-steel electrode arrangements.

Table 11. Results from the Scheffé multiple comparison tests under 40-min contact time.

Treatment Pair	Scheffé TT-Statistic	Scheffé *p*-Value	Scheffé Inference
Raw wastewater vs. stainless-steel-to-copper	1.6758	0.258706	insignificant
Raw wastewater vs. copper-to-stainless-steel	1.7757	0.220624	insignificant
Stainless-steel-to-copper vs. copper-to-stainless-steel	0.0999	0.995023	insignificant

3.10. Tukey's Honestly Significant Difference (HSD) and Scheffé Multiple Comparison Tests from Raw Wastewater and 60-Min Contact Time

Furthermore, the results from the untreated wastewater and the investigated electrode polarities with 60 min of contact time were subjected to Tukey's honestly significant difference (HSD) and Scheffé multiple comparison tests. Table 12 presents the results of Tukey's honestly significant difference test after a contact time of 60 min. Contrary to the findings of the 20- and 40-min contact times, the 60-min contact time yielded statistically significant differences between raw wastewater and copper-to-stainless-steel as well as between raw wastewater and stainless-steel-to-copper. The outcomes also show that increasing the contact time greatly increased the investigated treatment system's removal efficiency.

Table 12. Results from Tukey's honestly significant difference under 60-min contact time.

Treatment Pair	Tukey HSD Q Statistic	Tukey HSD *p*-Value	Tukey HSD Inference
Raw wastewater vs. stainless-steel-to-copper	3.4717	0.048795	* $p < 0.05$
Raw wastewater vs. copper-to-stainless-steel	3.4919	0.047259	* $p < 0.05$
Stainless-steel-to-copper vs. copper-to-stainless-steel	0.0201	0.899995	insignificant

* Statistically significant.

However, despite having statistically significant differences when raw wastewater was compared to the effluents from copper-to-stainless-steel as well as stainless-steel-to-copper electrode arrangements under 60 min of contact time (Table 13); the differences were still statistically insignificant when the datasets were subjected to the Scheffé multiple comparison tests. The findings suggest that additional contact would have enhanced the effluent's quality by further reducing the pollutant concentrations in the treated effluent, resulting in concentrations that differed significantly from raw wastewater using Scheffé multiple comparison tests.

Table 13. Results from the Scheffé multiple comparison tests under 60-min contact time.

Treatment Pair	Scheffé TT-Statistic	Scheffé *p*-Value	Scheffé Inference
Raw wastewater vs. stainless-steel-to-copper	2.4549	0.061663	insignificant
Raw wastewater vs. copper-to-stainless-steel	2.4691	0.05984	insignificant
Stainless-steel-to-copper vs. copper-to-stainless-steel	0.0142	0.999899	insignificant

4. Discussion

The analysis of the samples' pre- and post-treatment conditions using the 14 water quality parameters was completed successfully. The list of turbidity data from the raw wastewater showed that the smallest concentration value was 62.6 NTU, the maximum concentration value was 647 NTU, and the average turbidity concentration was 226.72 NTU. The results show that after electrochemical treatment utilizing the stainless-steel to copper electrode polarity, 92.3 NTU turbidity was achieved in less than 20 min of retention time, whereas roughly 92 NTU was retrieved from the copper to stainless-steel electrode polarity. The treated effluent from the stainless-steel-to-copper electrode combination had a turbidity level of 53.4 NTU after 40 min of contact with the wastewater, which is about 4.2 times lower than the typical concentration in raw wastewater. A turbidity average concentration of around 49.8 NTU was obtained from the copper-to-stainless-steel electrode combination. Additionally, the results demonstrated that wastewater samples exposed to the treatment systems for less than 60 min of contact time with the copper-to-stainless-steel electrode combination achieved up to 100% removal efficiency of turbidity. It should be noted that drinking water with high turbidity is not aesthetically pleasing. If the water contains a significant amount of turbidity, disinfecting it with technologies such as chlorination and ultraviolet light can be difficult [38]. This is because microorganisms that impact the disinfection process may use turbidity as a shield or shelter. Some bacteria discovered in water with high turbidity have been linked to a variety of symptoms, including cramps, headaches, and nausea [39]. Because increased turbidity reduces the quantity of light required for the photosynthesis process, it can have a major impact on the development rate of micro-aquatic plants, such as algae, in water bodies [40]. Additionally, because suspended particles have a tendency to absorb more heat, turbidity has the ability to raise the temperature of the water. The World Health Organization (WHO) recommends that the turbidity concentration in drinking water be below 1 NTU and not more than 5 NTU [41].

The average concentration of color in the raw wastewater was 295.6 mg/L Pt scale, with the minimum recorded value being 165 mg/L Pt scale and the maximum recorded value being 452 mg/L Pt scale. The copper-to-stainless-steel electrode combination achieved an average color removal efficiency of 94.76% and the stainless-steel-to-copper electrode combination achieved an average color removal efficiency of 86.02%. A little color in water generally doesn't make it unsafe to drink, but it can be linked to some aesthetic problems that might make it unpleasant to drink [42]. High amounts of color in water bodies can have a substantial impact on algal growth and aquatic plants in general [43]. The phenomenon is related to the fact that light is crucial for the development of aquatic plants, and colored water might prevent light from penetrating properly. That is to say, vividly colored water bodies are not conducive to the general survival of aquatic life. The minimum concentration from TSS was 1068 mg/L, the maximum concentration was 6204 mg/L, and the average concentration was 3999.8 mg/L. The average TSS removal efficiency was 100% when the copper-to-stainless-steel electrode combination was used, and 92.83% when the stainless-steel-to-copper electrode combination was used. High TSS concentrations in drinking water or wastewater have the potential to have a substantial negative impact on both the environment and human health. High TSS concentrations in aquatic bodies have the potential to lower dissolved oxygen levels and raise the water temperature. TSS can have an impact on aquatic life by obstructing fish's gills, which in turn slows down their rate of growth. Additionally, high TSS levels reduce light penetration, which has an impact on algae's capacity to produce food and oxygen.

Additionally, the minimum concentration of phosphates in the raw wastewater was 2.67 mg/L, the maximum concentration was 6.04 mg/L, and the average concentration was 4.748 mg/L. Increased amounts of phosphorous in a body of water causes the excessive growth of algae and other aquatic plants, such as water hyacinth, which is referred to as eutrophication. The average efficiency of phosphate removal was 77.93% for the copper-to-stainless-steel electrode combination and 71.32% for the stainless-steel-to-copper electrode combination. On the other hand, the ammonia levels in the raw wastewater were measured at a minimum value of 4.89 mg/L and a maximum value of 12.46 mg/L, with a measured average value of 7.868 mg/L. Removal efficiencies of ammonia at 91.34% and 71.32% were achieved by using the combination of copper-to-stainless-steel electrodes, and stainless-steel-to-copper electrodes, respectively. Sometimes, relatively high quantities of ammonia in water can result in chloramine production, which gives off an unpleasant taste and odor (which is not aesthetically pleasing). Chlorine and ammonia additions for disinfection can be the cause of chloramine contamination in drinking water. High amounts of ammonia in water bodies cause a number of severe problems for aquatic creatures, such as inadequate toxin excretion, which in turn, causes harmful substances to build up in their internal tissues and blood and, eventually, cause death [44]. However, based on the concentration levels often found in drinking water, there is currently no proof that ammonia would be detrimental to human health.

While the average COD concentration in the raw wastewater was 7226.6 mg/L, after 60 min of contact time, the copper-to-stainless-steel electrode combination and the stainless-steel-to-copper electrode combination achieved removal efficiencies of 99.63% and 89.12%, respectively. More oxidizable organic material is likely to be present in the water if the COD concentration is higher. High COD also results in lower concentrations of dissolved oxygen (DO). Anaerobic conditions in water bodies are caused by a decrease in DO, and these conditions are severely harmful to higher aquatic life forms. The total iron levels in raw wastewater were measured at a minimum concentration of 6.88 mg/L, a maximum concentration of 12.33 mg/L, and an average concentration of 9.466 mg/L. The flavor of the water had a metallic aftertaste that indicates high levels of iron. There is a strong likelihood that items cooked in water with high iron content, including fruits and vegetables, will lose some of their flavor and appearance. Long-term exposure to or ingestion of iron has been linked to a number of health problems, including the risk of developing diabetes, liver cirrhosis, and cancer, as well as heart and central nervous system ailments [45].

An average concentration of 7.516 mg/L in the raw wastewater was recorded for aluminum. However, both investigated treatment approaches achieved relatively high aluminum removal efficiencies. Numerous symptoms, such as arthritic pain, nausea, vomiting, mouth ulcers, skin rashes, skin ulcers, and diarrhea, are linked to increased exposure to, and an intake of, aluminum. However, some have noted that these symptoms are generally minor and quite temporary [46,47]. Aluminum is typically regarded as a non-essential substance in aquatic life because it is not potentially necessary for aquatic life to function. High quantities of aluminum can, however, have certain unfavorable impacts on aquatic life, such as the possibility of interfering with some aquatic species' ability to regulate ions, such as salts, and slowing respiratory processes. The physicochemical parameters (including anthropogenic activities) and mineralogical characteristics of the specific catchment strongly influence the level of concentration at which aluminum can be detected in natural waters [48]. The main sources of aluminum in effluent from cattle slaughterhouses are aluminum materials that have become contaminated due to wear and tear. A similar case was observed from manganese and nickel; whereby, manganese levels in raw wastewater were measured with an average concentration of 0.264 mg/L. Health Canada's research has found that elevated concentration levels of manganese in drinking water can pose a health risk, despite the fact that it is well-recognized that a small quantity of manganese intake is necessary for human health [49]. Additionally, high manganese levels in drinking water can cause aesthetic problems, such as discoloration and an unpleasant taste. Furthermore, high manganese intake in humans can impair memory, attention, and motor skills. Additionally, water with high manganese levels can cause issues for plumbing systems. The nickel levels in the raw wastewater were measured at an average concentration of 6.526 mg/L. Although many creatures consider nickel vital to their diets, it can be poisonous and carcinogenic in high concentrations [50].

Chromium was another parameter investigated in the study; whereby, an average concentration of 1.022 mg/L was observed in the raw wastewater. Normal dietary levels of pure chromium are not thought to be dangerous. Chromium 0 and VI present a challenge because they are regarded as more dangerous and may pose certain health risks when exposed to them over an extended period of time. More specifically, those who consume chromium beyond the maximum allowed concentration (MAC) for an extended period of time may experience allergic dermatitis [51].

BOD measurements showed that the minimum concentration was 1270 mg/L, the maximum was 8542 mg/L, and the average concentration was 4290.2 mg/L. However, after 60 min of contact time, the copper-to-stainless-steel electrode combination and the stainless-steel-to-copper electrode combination achieved removal efficiencies of 99.76% and 89.2%, respectively. Meiramkulova et al. [52] claim that the arrangement of the electrodes, which determines the polarity direction, can have a significant impact on how well electrochemical procedures perform. The rate at which dissolved oxygen in the water depletes increases with BOD, which also lowers the amount of oxygen available to higher forms of aquatic life. The raw wastewater samples had a TOC minimum concentration of 174 mg/L, a maximum concentration of 1850 mg/L, and an average content of 966.2 mg/L. According to some research, hazardous disinfection byproducts that develop during the water treatment process are directly impacted by high TOC levels in the water. It should be noted that byproducts have been linked to bladder cancer in the past.

The copper to stainless-steel electrode polarity generally showed relatively high removal efficiencies for the majority of the investigated water quality parameters when the wastewater samples were subjected to the 60-min contact time, in contrast to the removal efficiencies from the 20-min and 40-min contact times.

5. Conclusions

The potential effect of electrode polarity on the effectiveness of an electrochemical treatment system made up of copper and stainless-steel electrode materials for the purification of wastewater from slaughterhouses was studied. Stainless-steel (anode) to copper (cathode) and copper (anode) to stainless-steel (cathode) electrode polarities were taken into account under three different contact times (20, 40, and 60 min). Up to 9815 mg/L of COD was recorded in the raw wastewater; it is important to remember that high wastewater COD indicates the presence of organic materials that might reduce the amount of dissolved oxygen in the water and have detrimental effects on the environmental and regulatory frameworks. Moreover, according to the findings, up to 75.02% of TSS removal was observed from the wastewater samples exposed to the treatment systems for about 20 min of contact time. A considerably higher removal efficiency was also seen for turbidity, COD, and chromium levels. The removal efficiencies for the majority of the water quality parameters were also found to be almost equal for the two studied electrode polarities under 20 min of contact time. As was previously noted, it was found that the stainless-steel (anode) to copper (cathode) electrode configuration performed somewhat better than the copper (anode) to stainless-steel (cathode). For instance, the copper (anode) to stainless-steel (cathode) electrode design performed better than the stainless-steel (anode) to copper (cathode) electrode arrangement according to the mean and variance values from the *t*-Test analysis. Whereby, the copper (anode) to stainless-steel (cathode) electrode configuration yielded a mean value of 13.837, which is equivalent to almost 11% of the mean value achieved utilizing a copper-to-steel electrode configuration. Furthermore, the results of the Tukey's honestly significant difference (HSD) test revealed that, in contrast to what the 20- and 40-min contact times revealed, the 60-min contact time produced statistically significant differences between raw wastewater and copper to stainless-steel as well as between raw wastewater and stainless-steel to copper. The results also demonstrated that extending the contact time may potentially affect how well contaminants are removed by the treatment system. Accordingly, it can be inferred from the results that when designing electrochemical wastewater treatment systems, contact time and polarity direction should be carefully considered in order to achieve the desired performance. Future comparison analyses based on costs, particularly based on energy usage, for the explored polarity directions would be a fascinating subject. Studies on the potential integration of copper and stainless-steel treatment systems with renewable energy sources, such as photovoltaic solar cells with better energy storage technologies, for complete self-sufficiency in operation, will also be increasingly fascinating.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15032036/s1, Table S1: Results from the *t*-Test: Two-Sample Assuming Equal Variances under 20-min contact time; Table S2: Results from the *t*-Test: Two-Sample Assuming Equal Variances under 40-min contact time; Table S3: Results from the *t*-Test: Two-Sample Assuming Equal Variances under 60-min contact time.

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