Treatment of Public Sewage Wastewater Using Electrocoagulation Process

M. M. H. Khan*, Hira Khalique, and S. Shams

Abstract—**Sewage needs to be treated before it is discharged into the water bodies such as rivers and lakes. Sewage wastewater were analyzed in this study, by electrocoagulation process using an alternating power source with current density of 10 A/m^2 and 20 A/m^2 at treatment time of 10, 20, 40, 60 minutes respectively using copper and zinc electrodes. The effect of electrode material was determined and how chemical oxygen demand (COD), total suspended solids (TSS), Conductivity, pH and turbidity were affected by changing contact time and with changing the current density. We obtained very satisfactory results for the two electrochemical cells such as copper and zinc electrodes. The optimum conditions were determined at treatment time of 20 minutes for a current density of 10 A/m^2 with TSS removal efficiency of 92%, COD removal efficiency of 91.5%, pH of 7.50 , with a low turbidity value of 4.27 turbidity (NTU) and the conductivity of 108 µs for copper electrodes. Whereas, using zinc electrodes, the optimum treatment time was 20 minutes at 10 A/m^2 current density, TSS removal efficiency was of 92%, COD removal efficiency of 85.7%, pH of 7.80 with turbidity removal efficiency of 87.3 % and the conductivity of 117.3 µs. This electrocoagulation process has attracted a great deal of attention in treating various wastewaters because of its versatility and environmental compatibility.**

Index Terms—**Electrocoagulation, sewage water, chemical oxygen demand (COD), total suspended solids (TSS)**

I. Introduction

As the population of Malaysia is rapidly rising, so is the demand for water. It is estimated that four billion people—one half of the world's population will live under conditions of severe water crisis by year 2025 [1]. There is also a threat of an increase in pollution that could adversely affect the environment as well as the human health. Sewage is one of the main point sources of pollutant not only in Malaysia but also on a global scale [2]. The sewage that needs to be treated requires several processes as it not only contains suspended solids (SS), but it also contains biochemical oxygen demand (BOD), as well as chemical oxygen demand (COD). One of the main reasons wastewaters should be treated before being discharged into the surrounding water bodies is to ensure the protection of the environment as the untreated waste may lead to adverse health effect if consumed by the aquatic/marine life or when it comes in direct contact with skin [3]. The sewage can be treated through biological process such as increasing the concentration of BOD through aeration. However, treating wastewater using biological process require higher oxygen by volume for the respiration of microorganisms which is costly process. Other sewage treatment methods which work on conventional procedures may take up large areas of space and would require several workers hence the cost of treatment would shoot up [4]. On the contrary, treatment of sewage through electrocoagulation is one of the most efficient and cost-effective method, especially in the developing countries all over the world. This is when a high cell current is passed through electrodes such as steel, iron, aluminum etc. which have been applied into this study. The high current ranging from 10 A/m^2 to 20A/m^2 has proven to be effective in removing COD, BOD and SS from the wastewater [5]. The research objectives of this study include the characterization of the sewage wastewater properties in terms of COD, total suspended solids (TSS), conductivity, turbidity and pH of the affluence before and after the samples has been treated. Secondly, it is to determine the effects of current density and detention time on the effective removal rate of COD, TSS, turbidity, pH, and conductivity. Lastly, the objective includes to investigate the efficiency of using two different electrodes in treatment process—copper and Zinc electrodes.

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II. Methodology

A. Electrochemical Cell

The electrochemical unit was constructed using a direct current (D.C.) power supply and the electrodes made up of material such as Aluminum, Stainless-Steel Copper and Zinc. For this experiment, Zinc and Copper electrodes were used. According to Nasrullah [6], the experiment should be made of two monopolar electrodes, an anode and a cathode, with similar dimensions of (120 mm × 100 mm × 2 mm) with spacing of 10 mm, 20 mm, 30 mm, and 40 mm (depending on experiment) between them. The total effective electrode is 1.652×10^{-2} m^2. For this experiment, theelectrode spacing was kept constant for each batch treated. The stirrer used is a magnetic stirrer which was turned on and set at 20 rpm to maintain an unchanging composition and prevent the flocs in the solution from forming associations. [7] It also stated that, it is best to wash all electrodes with dilute hydrochloric acid to neutralize any content in the medium before starting of the experiment. Every experiment was performed at the room temperature [8].

B. Electrode Material

For this experiment, according to objective 3 (which is to check the efficiency of using two different electrodes in

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treatment process—copper and Zinc electrodes), two different electrode materials were used. There was a total of four batches of experiments performed with varying detention time and current density. The first two batches were treated using Zinc electrodes and the last two batches were treated using Copper electrodes. The dimensions of the electrodes measure 100mm × 20 mm × 1 mm. Before the experiment began, the electrodes were weighed and washed with distilled water for each sample. These electrodes were placed in the electrochemical cell, at equidistant from one another of 30 mm. This was, however, not accurate for every batch as the electrodes were constantly removed and replaced into new beakers.

C. Experimental Procedure

The experiments were conducted in batch modes where 300 mL of sewage water was collected in the electrochemical cell for each experiment, with two electrodes dipped in the sample. There should be atleast two different alternative high current densities used for example: 10 A/m^2 and 20 A/m^2. In each current density applied there be contact time of 5, 10, 20, 40, and 60 minutes [9]. All the sampling and analysis procedures were adopted from Standard Methods for the Examination of Water and Wastewater. In the beginning, the experiments commenced for the unadjusted raw sample (pH = 5.24). Also it was studied that, after electrolysis, settling of the flocs should be done for at least one hour, then the samples were taken from the liquid phase and analysed for Suspended Solid, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and pH and then compared with the values of parameters of effluent after treatment of sewage water. Finally, the present sludge percentage deposited was recorded [9].

D. Copper Electrode Electrochemical Cell

For this setup, the copper electrodes were attached to the negative terminal and the positive terminal of the power supply using the crocodile wire clips, making up the anode and the cathode. For this experiment there was a total of two different current densities applied, 10 A/m^2 and 20 A/m^2. Current density was calculated by the following equation:

$$Current\ density = \text{Total Current}/\ The\ area\ of\ electrode\ submergedin\ the\ sampl\ liquid\ (m^2) \quad (1)$$

There was a total of eight samples that were treated using this electrochemical cell and the results are recorded. After the samples were treated, COD, TSS, Turbidity, pH and Conductivity of the treated samples were measured, and the results were studied. The detention time used was 10 minutes, 20 minutes, 40 minutes and 60 minutes.

E. Zinc Electrode Electrochemical Cell

For this experiment, a total of 8 samples were treated at a detention time of 10 minutes, 20 minutes, 40 minutes and 60 minutes. There were two different current density of 10 A/m^2 and 20 A/m^2 used for the treatment. For the first sample at 10 minutes with Current density of 10 A/m^2 , a magnetic stirrer was used as a control so that the other samples were compared to the control experiment to check the significance of performing the experiment with and without a magnetic stirrer. The speed of the magnetic stirrer was set to 20 rpm for the first sample.

F. Laboratory Test Analysis

The laboratory analysis includes all the different types of tests that were performed to achieve the three objectives of the experiment as stated in the introduction. There was a total of five different parameters that were analysed before and after that samples had been treated. These parameters include the Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), the pH, Conductivity, and the turbidity of the treated and untreated samples. Standard laboratory methods are used to conduct the experiments.

III. Results and Discussion

A. Raw Wastewater Sample

Collection of samples is an essential part of the project as the sample collected has been treated in the final stage where laboratory experiment was conducted. For the conduction of the experiments in this study, the untreated sewage wastewater was collected from INTI International University and colleges' Sewage Treatment Plant (STP) located at Nilai, Negeri Sembilan, Malaysia. This treatment plant receives effluent from discharges from the various blocks of INTI hostel. A total of eight litres of wastewater had been collected with all the safety measures taken into consideration such as wearing protective gloves and masks. The sample collected was from the equalizer (EQ) tanks. The composition of wastewater was then characterized. A total of 400mL of sample was used and the following parameters as stated were measured. The calculations to measure the TSS also shown in Table I below. The procedure to measure the parameters were broken down in detail in previous sections of methodology. Table II shows the parameter of untreated raw wastewater sample characteristics collected from INTI University's STP below.

TABLE I: Final and Initial Weight of the Filter Paper for Zinc and Copper Electrochemical Cell with Varying Contact Time

Sample (time/minutes)	**Initial Weight (g)**	**Final Weight (g)**	**TSS (mg/L)**
Zinc: Current density: 10 A/m^2			
10	0.0944	0.0949	50
20	0.0944	0.0946	20
40	0.0953	0.0963	100
60	0.0919	0.0928	90
Zinc: Current density: 20 A/m^2			
10	0.0964	0.0965	10
20	0.0957	0.0960	30
40	0.0944	0.0958	140
60	0.0946	0.0961	150
Copper: Current density: 10 A/m^2			
10	0.0960	0.0961	10
20	0.0967	0.0987	20
40	0.0973	0.0975	20

60	0.0970	0.0978	80
Copper: Current density: 20 A/m^2			
10	0.0978	0.0986	80
20	0.0963	0.0969	60
40	0.0958	0.0961	30
60	0.0957	0.0967	100

TABLE II: THE PARAMETER OF UNTREATED RAW WASTEWATER SAMPLE COLLECTED FROM INTI'S STP

Parameter	**Value**
pH	5.24
COD (mg/L)	259 mg/L
Turbidity (NTU)	12.39 NTU
Conductivity	110.9 µm
TSS (Total suspended solids) mg/L)	250/L

Sample Calculation for TSS:

$$TSS\left(\frac{mg}{L}\right)=\frac{Final\ weight - initial\ Weight}{10mL}\times 1000{,}000 \quad (2)$$

B. COD Removal Efficiency

The Fig. 1(a) and Fig. 1(b) shows that for Copper Electrochemical cell, in contrast to Zinc Electrochemical Cell, Copper proved to be better at the removal of COD as the removal efficiency is fairly high (above 90%) for both the current densities applied. This is because copper electrodes are dissolved to produce ions called Cu^{2+} ions. These ions react with the hydroxide ions in water forming copper hydroxides. Copper hydroxides increase the pH of the solution to above 7. Hence, this increase in pH favors the formation of more hydroxide ions. These hydroxide ions are essential in trapping the colloids/pollutants by coagulating them, allowing the formation of larger flocs which are dissipated as sludge, hence leading to a higher COD removal [10]. The optimum current density for maximum removal of COD was achieved at a current density of 20 A/m^2 at 20-minute treatment time with removal efficiency of 98.8%. It can be seen from Fig. 1(b) that the removal efficiency at Current density of 0.02 A/m^2 is higher than 10 A/m^2 hence a higher current would achieve better removal of COD. At treatment time of 40 minutes with 20A/m^2, the COD removal are excellent at a whopping 100% making this the optimum treatment time for Zinc Electrode.

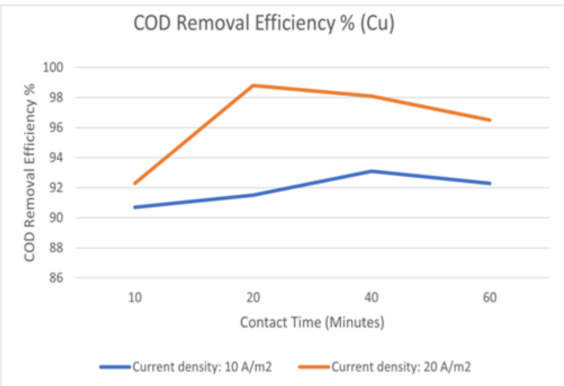

Fig. 1(a). COD removal efficiency—Copper.

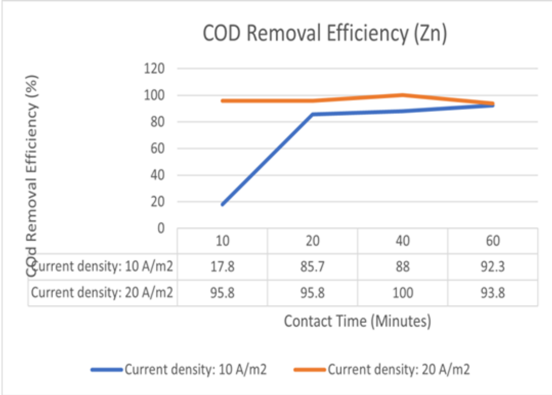

Fig. 1 (b). COD removal efficiency—Zinc electrode.

C. Effect on Conductivity

The graphs in Fig. 2(a) and Fig. 2(b) shows changes in the conductivity of the samples as treatment time is increased at different current densities. The Conductivity of solution treated with a current density of 10A/m^2 are significantly higher than the ones treated with 20 A/m^2. From 10 minutes until 60 minutes, there is a general decrease in conductivity for both the current densities. This is because of the presence of ions and salts in the solution which affects the electrical conductivity. Also, there is precipitation and corrosion of the electrodes by the ions present in the solution which increases the electrical resistance, thereby reducing conductivity [11]. Hence, in the industries, an electrolyte such as NaCl is added to improve the conductivity of the wastewater solution so that the treatment can be efficient and maximum sludge would be removed at lower current densities.

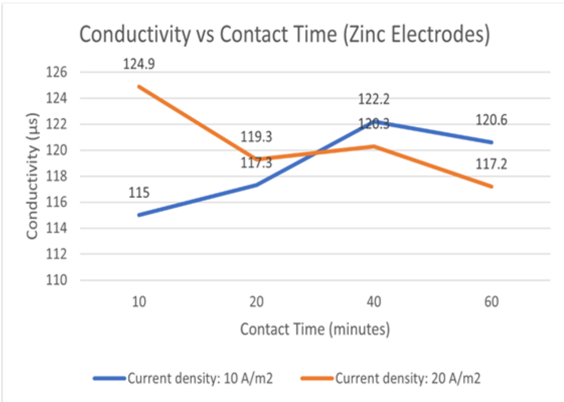

Fig. 2(a). Contact time vs conductivity—Zinc.

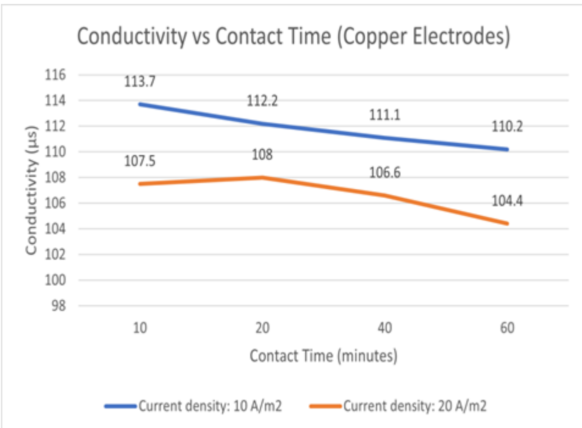

Fig. 2(b). Contact time vs conductivity—Copper.

D. Effect on pH

pH is one of the important parameters that influences the electrocoagulation process. For Zinc as shown in Fig. 3(a), as treatment proceeded, the pH became more neutral. For current density of 10 A/m^2, the pH remains neutral throughout the experiment from 7.7 at 10 minutes to 7.81 at 60 minutes, whereas raw wastewater pH was recorded to be at pH 5.24 . This is because there is an increase in formation of coagulant species which are the metal hydroxides and metal cations. These species are dominant at neutral pH hence increasing the process of coagulation [12]. The removal efficiency of the parameters under study were higher at neutral pH of contact time of 20 minutes compared to more alkaline pH at contact time of 60 minutes. It can be noted that the optimum pH of the treated wastewater was achieved at which efficient treatment of wastewater is achieved. For copper electrodes as shown in Fig. 3(b), the pH of the treated wastewater remained neutral for both the current densities. The pH changed of 10 A/m^2 decreased from 7.8 at a treatment time of 10 minutes, to 7.59 at 60 minutes. On the contrary the pH of the samples treated at 20 A/m^2 increased from 7.59 at 10 minutes to 7.85 by 60 minutes. This is because the acidic pH of the wastewater which is when the sample had a higher concentration of H^+ ions was neutralised by the hydroxide ions produced during electrocoagulation. At higher treatment time of 60 minutes, the concentration of hydroxide ion is slightly higher than H^+ ions, hence the pH was 7.85.

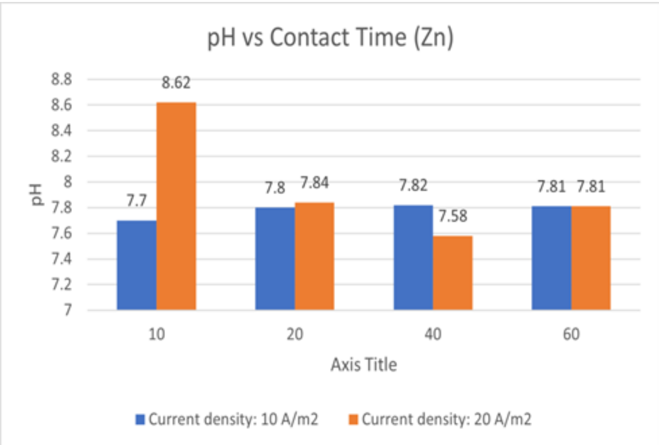

Fig. 3(a). Contact time vs pH—Copper cell.

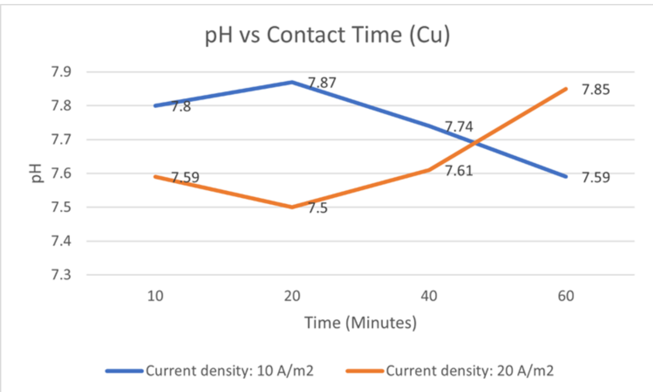

Fig. 3(b). Contact time Vs P_H—Copper cell.

E. Effect on Turbidity

As shown in Fig. 4(a) below, in case of Zinc cell, for both the current density, the residual turbidity is observed to decrease with increasing contact time. The lowest residual turbidity is 0.94 NTU at 10 A/m^2 and 0.48 NTU at 20 A/m^2 with a contact time of 20 minutes and 60 minutes respectively. Further increase in contact time resultant in a sharp decrease in turbidity from 12.34 NTU to 4.97 NTU until 0.48 NTU at 60 minutes for 20 A/m^2 . At 10 A/m^2, beyond 20 minutes, the turbidity values have increased from 0.94 NTU at 20 minutes to 5.14 NTU at 60 minutes. These results shown are consistent with the research done by Bukhari, 2019 where he observed that beyond 20-minute treatment time, the turbidity values decreased until a contact time of 50 minutes [6]. This result achieved is consistent with the study done with a turbidity removal efficiency of 93.97% within 20 minutes of treatment time at a low current density of 8-64 A/m^2 [13].

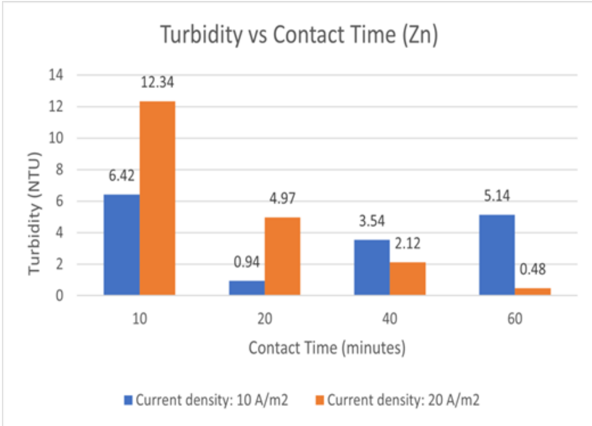

Fig. 4 (a). Turbidity vs contact time—Zinc cell.

As shown in Fig. 4(b) below, for copper, Turbidity concentration is relatively low for contact time of 20 minutes for both the current densities applied. The turbidity value decreases sharply from 7.38 NTU at a contact time of 10 minutes to 2.43 NTU at a contact time of 20 minutes. It then increases again to 5.38 NTU at 40 minutes and 6.14 NTU at 60 minutes. For the current density of 20 A/m^2 the turbidity value is lowest at 10minute treatment time, at 1.33 NTU and then it increases up to 7.76 NTU at 40 minutes before decreasing back to 3.98 NTU at 60 minutes. Higher turbidity values are because of the presence of ions in the solutions that are formed during the oxidation of the electrodes during electrolysis which affects the clarity of the treated water.

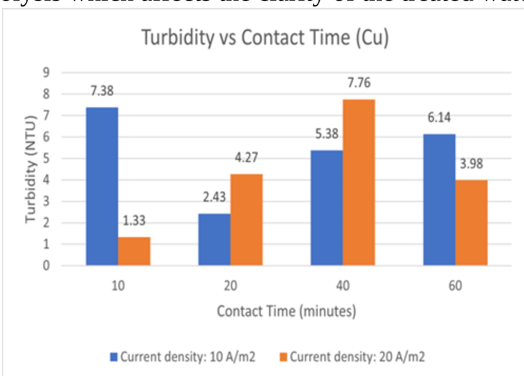

Fig. 4 (b). Turbidity vs contact time—Copper cell.

F. Effect on TSS

As can be seen from graph in Fig. 5(a) for copper electrode, the total removal efficiency of TSS is generally high for contact time of 10 minutes and 40 minutes. The removal efficiency is higher for lower current density. At 10 minutes the removal efficiency is 96% at 10 A/m^2 and 68% at 20 A/m^2. As the contact time increases, the removal efficiency is still high however it decreases slightly to 92% at 20 minutes at 10 A/m^2 and 76% at 20 A/m^2. The removal efficiency swiftly decreases to 68% and 60% at 10 A/m^2 and 20 A/m^2 respectively, at contact time of 60 minutes. Fig. 5(b) below shows how removal efficiency for Zinc electrode is lowest at contact time of 40 minutes and 60 minutes for both the current density. However, the TSS removal efficiency is highest for both the current density at a contact time of 10 minutes and 20 minutes [14]. And with the highest removal efficiency achieved by 10 minutes of contact time using current density of 20 A/m^2.

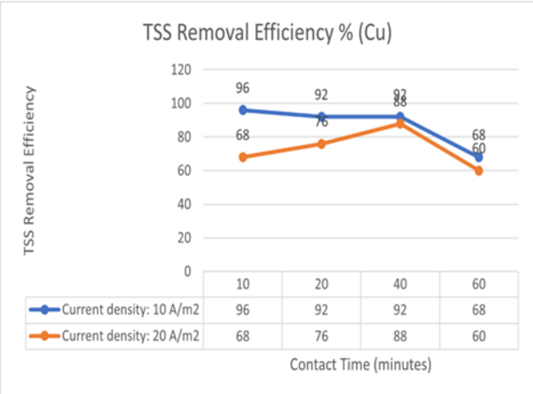

Fig. 5 (a). TSS Removal efficiency—Copper cell

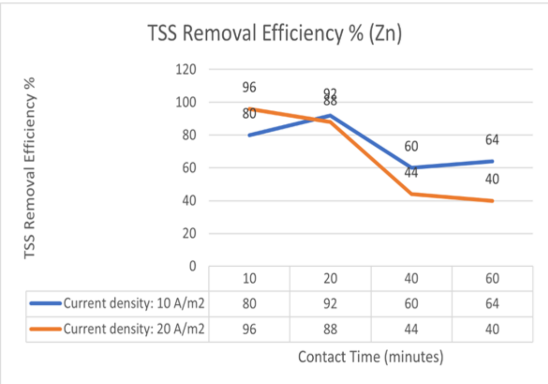

Fig. 5 (b). TSS Removal efficiency—Zinc cell.

G. Discussions

Generally, throughout the treatment process, there was production of sludge which increased in quantity as the treatment time was increased as well as current density for both zinc and copper electrodes. It was observed that removal efficiency of zinc electrodes at a current density of 10 A/m^2 was high at a treatment time of 20 minutes. This is when the turbidity value was as low as 0.94 NTU, and the COD removal efficiency was 87.3% with TSS removal efficiency of 92% at a pH of 7.80 with conductivity value of 117.3 µs. When current density was increased to 20 A/m^2, the amount of sludge produced also increased and the removal efficiency of the parameter under observation were also increased. At a contact time of 10 minutes, the turbidity value was recorded as 12.34 NTU with 95.8% removal efficiency and TSS removal efficiency of 96% at a pH of 8.62 with conductivity of 124.9 µs. The following observation was also made throughout the treatment of the samples of zinc electrochemical cell:

1) There was a visible layer of oil/grease that was formed at 40 minute and 60 minute treatment times for both the current density tested. This shows that electrocoagulation can also be effective in separating the oil and grease layer from untreated raw sample.
2) At lower treatment time of 10 and 20 minutes, no oil layer was observed for current density of 10 A/m^2
3) At higher current of 20 A/m^2, there was oil layer observed for all the samples treated from contact time of 10 minutes to 60 minutes.
4) For samples which were treated for longer periods of time, there was settlement of white flocs at the bottom of the beaker which was sludge. This sludge was white in colour because of the presence of Zn^{2+} ion that was produced into the wastewater sample during the treatment which is white in colour. The layer of oil and white flocs caused an increase in the amount value of turbidity that was observed and presented in figures in the previous sections.

For the treatment done using copper electrodes, it was observed that optimum treatment time was 20 minutes at a current density of 10 A/m^2 with TSS removal efficiency of 92%, COD removal efficiency of 91.5%, pH of 7.50 with a low turbidity value of 4.27 NTU and conductivity of 108 µs. The following observation were made during the eight experiments conducted:

1) At 10 A/m^2 more flocs settled at the bottom as treatment time increased indicating a larger generation of sludge hence shows how the total dissolved solids have been coagulated and converted into sludge.
2) As the treatment was increased, the colour of the sludge turned bluish because of the production of Cu^{2+} ions
3) There was a layer of oil/grease suspended over the samples treated at 20 minutes and more at both the current density and the water turned more cloudier because of an increase in the presence of micro floc.

IV. Conclusion

In conclusion, electrocoagulation is a very effective technique in treating wastewater safely using copper and zinc electrodes. The optimum condition for copper electrode was achieved at treatment time of 20 minutes at 10 A/m^2 current density with TSS removal efficiency of 92%, COD removal efficiency of 91.5%, pH of 7.50 with a low turbidity value of 4.27 NTU and conductivity of 108 µs. Alternatively for zinc electrodes, optimum condition was also achieved at treatment time of 20 minutes for 10 A/m^2 current density TSS removal efficiency of 92%, COD removal efficiency of 85.7%, pH of 7.50 with turbidity removal efficiency of 87.3 % and conductivity of 117.3 µs. The effluent pH was also neutral after the treatment was done hence no further correction of pH was required. This method of treatment is feasible as it is cost effective to treat wastewater at relative low current density which consumes minimum power. The COD removal is fairly good and is comparable to oxidation pond biological treatment where residence time ranges from three to six days whereas electrocoagulation can complete it within a few minutes, depending on the volume of wastewater. Other conventional methods such as using biological oxidation ponds also generates large amounts of foul smell and sludge which is difficult to dispose. Electrocoagulation generates the right amount of coagulant for the treatment and no additional chemical coagulants are required for the treatment.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The research described here is main author's original work and either has not been published before nor currently being considered for publication elsewhere. All authors have been actively involved in this research work leading to the paper, and will take public responsibility for its content.

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