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Electrocoagulation Treatment of UMK Fishpond Wastewater: Impact of Various Parameters on Heavy Metal Ion Removal

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Heavy metal ions in water can significantly threaten aquatic life, human health, and the environment. These ions can accumulate in densely populated fishponds. This study investigates using electrocoagulation to remove heavy metal ions from fishpond water, testing various electrode materials and configurations. The configurations tested include monopolar electrodes in parallel and series connections, and bipolar electrodes in series connections. The electrode materials used were aluminium, stainless steel, and mild steel. The research identifies the most effective materials and configurations for removing heavy metal ions (Cd, Pb, and Zn) from fishpond water within 30 minutes using electrocoagulation. The findings indicate that the optimal setup is configuration 3, with bipolar electrodes in series connections. Aluminium electrodes proved most effective for removing Cd and Pb, achieving removal rates of 45.5% and 48.6%, respectively, after 30 minutes. For Zn removal, mild steel electrodes were the most effective, removing up to 60.9% of Zn in the same timeframe. In summary, the best electrode configuration for electrocoagulation is bipolar electrodes in series connections, with aluminium being the best material for Cd and Pb removal, and mild steel for Zn removal.

Keywords: Electrocoagulation; wastewater; heavy metals; mild steel electrode

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In recent years, fish farming has gained popularity as an alternative to traditional fishing due to its higher yields. Fishponds, used for breeding fish for consumption or display, can be either dug into the ground or constructed as large basins. Artificially constructed fishponds often accumulate high concentrations of heavy metals from fish waste and food. Unlike natural ponds, fish farming ponds lack ecosystems that balance heavy metal ion concentrations, leading to elevated levels of heavy metals in the water and sediments. This can potentially contaminate farmed fish. Untreated pond water can also pollute nearby natural water bodies, causing unpleasant odors.

Electrocoagulation is a potential technique for treating industrial wastewater due to its versatility and environmental compatibility, removing heavy metals from aqueous environments [1]. Electrocoagulation is an effective method for treating various types of wastewater, including municipal and industrial [2, 3]. It uses electrode materials and electrical currents to destabilize and aggregate particles, ions, and colloids, forming floc that can be removed, leaving clean water. This process is particularly effective at removing heavy metals, converting them into stable, non-toxic sludge and floc that are easy to dispose of. Additionally, it generates H_2 gas, which helps remove tiny particles of heavy metals. Previous research works shows that electrocoagulation aluminum (Al) electrodes effectively removes four heavy metals (Cu, Ni, Zn, Cr) in artificial metal plating wastewater, with greater efficiency for Cr removal [4].

However, electrocoagulation has some drawbacks, such as electrode passivation, increased electricity usage due to decreased wastewater conductivity, and potential secondary contaminants when treating complex wastewater [5]. Research by Arslan H and colleagues [6] investigated factors affecting electrocoagulation in removing malachite green dye from synthetic wastewater. They found optimal parameters to be: 200 mg/L dye, 150 mg/L electrolyte, 100 rpm stirring, 8 mA/cm² current density, pH 4.5, 1 cm electrode spacing, and 20 minutes of electrolysis.

To achieve successful electrocoagulation, it is essential to maintain a pH range of 3 to 7.5, an electric current between 0.03 and 0.09 A, an electrolyte concentration of 1 to 3 g/L, an electrode distance of 1 to 2 cm, and an electrolysis duration of 20 to 60 minutes [7]. To avoid electrode passivation, the anode and cathode were periodically alternated. The effectiveness of electrocoagulation is also influenced by the arrangement and materials of the electrodes. While there are limited studies

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on using different electrode polarities for treating mixed pollutants, most literature focuses on single metal treatment. Some studies examine the impact of other pollutants on the removal of a primary target pollutant. In this study, different polarity electrode arrangements were used in all experiments. The objective was to identify factors affecting heavy metal removal rates and to gain a better understanding of the process. Measurements were taken every ten minutes over a thirty-minute period to monitor the removal of heavy metal ions.

EXPERIMENTAL

Chemicals and Materials

Fishponds often contain high levels of heavy metal ions due to fish waste and uneaten food. Therefore, water from the Jeli Fishpond at Universiti Malaysia Kelantan (UMK) Campus Jeli was chosen for this study to reduce heavy metal ions using the electrocoagulation process. Aluminium (AL), stainless steel (SL), and mild steel (ML) were selected as electrode materials to determine which is most effective at removing heavy metals. Each material produces unique electrochemical reactions during electrocoagulation due to their distinct overpotentials when exposed to solvent breakdown [8].

This study will test all three electrode materials to find the most efficient one for reducing heavy metal ions in fishpond water. The electrodes will be arranged in three configurations: monopolar electrodes in parallel, monopolar electrodes in series, and bipolar electrodes in series. Each arrangement creates different electrical potentials, and the goal is to identify which setup is most effective for heavy metal ion reduction.

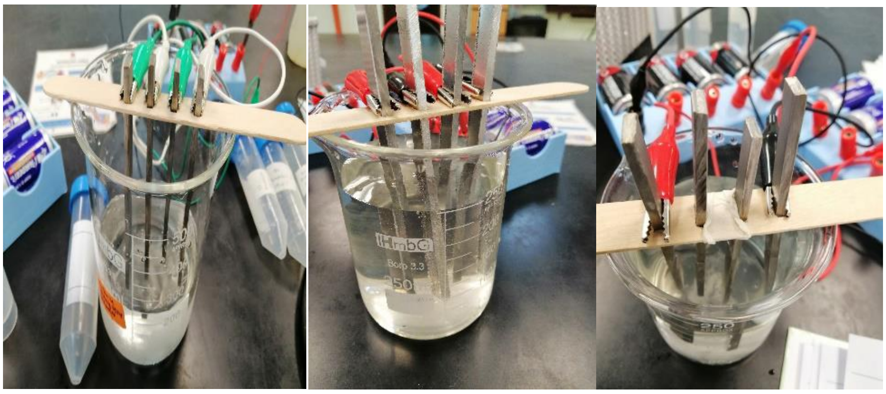
Sample Preparation

A three-litre water sample was taken from the Jeli Fishpond on a sunny day. This sample was divided into twelve 250-millilitre parts. Three parts served as controls, and the remaining nine were distributed among the three electrode arrangements. Before starting electrocoagulation, each sample was filtered to remove large contaminants. On the same day, an in-situ analysis using the YSI Multiparameter (Xylem) device measured water quality parameters: temperature, TDS, pH, DO, and salinity.

Process Study

Effect of Electrode Arrangement Electrocoagulation was tested using three electrode arrangements, a) Monopolar electrodes in parallel connections, b) Monopolar electrodes in series connections and c) Bipolar electrodes in series connections as shown in **Figure 1**.

The electrocoagulation process was conducted for thirty minutes, based on prior research indicating this as the optimal electrolysis time. After the process, all samples except the control were filtered to remove the formed flocculant and then analyzed using atomic absorption spectroscopy (AAS) (PerkinElmer) to determine the final heavy metal levels. Aluminium (AL), stainless steel (SS), and mild steel (MS) were used as electrode materials in all three arrangements. Each electrode measured 120 mm by 10 mm by 3 mm according to the electrode's availability in the lab. The reduction rates of heavy metals were measured to evaluate the effects of different electrode materials. The electrocoagulation process was carried out for thirty minutes for each arrangement, with the electrode material being the constant variable. The distance between electrodes was maintained at one centimeter throughout the experiment.



(a) **(b)** **(c)**

Figure 1. Different Electrode Arrangements in Electrocoagulation Process: a) Monopolar Electrodes in Parallel Connections b) Monopolar Electrodes in Series Connections c) Bipolar Electrodes in Series Connections.

Table 1: Fishpond Water In-situ characteristics.

Parameter	Reading
Temperature (℃)	24.4
TDS (mg/L)	11.27
DO (DO mg/L)	8.28
Salinity (sal)	0.01
pH	7.73

Heavy Metal Removal Rate Analysis

AAS was used to analyze the initial levels of cadmium (Cd), lead (Pb), and zinc (Zn) in the water samples before starting electrocoagulation. During the 30-minute process, 50 ml samples were collected every 10 minutes and analyzed by AAS to determine heavy metal levels [9].

Characterization Methods

The physicochemical characteristics of the fishpond water sample, including temperature, pH, DO, and TDS, were analyzed before and after the electrocoagulation process. The sample was filtered to remove large debris before the process and flocculant using a 0.45-micron syringe filter after the process. The values were compared to assess changes.

Preservation of Sample

After electrocoagulation, the sample was preserved by adding 0.15% HNO_3 and chilling it before AAS analysis to prevent any changes in the water's chemical composition.

Dilution of Water Sample

The water sample for AAS preparation was diluted twice with 5% hydrochloric acid, first by a factor of 10-1 and then by a factor of 10-2. For the study, 15 ml of the water sample were extracted from a larger stock sample of 50 ml. The analysis sample was diluted by mixing 1.5 ml of the water sample with 13.5 ml of 5% hydrochloric acid to ensure the AAS could detect the heavy metals of interest.

RESULTS AND DISCUSSION

Fishpond Water In-situ Analysis

Table 1 shows the result of the in-situ analysis of the fishpond water.

The in-situ analysis yielded a temperature of 24.4 °C, which is slightly less than the average ambient water temperature for a fishpond in Malaysia, which is 24.8 °C. As it is currently rainy season along the East Coast of Malaysia, this is most likely the result of the persistent rain that has been falling in the area. The rainy season, on the other hand, will not affect the removal efficiency of the heavy metal ions in the water sample. The rainy season will, however, affect the initial level of the heavy metal ions. This is because rainwater carries pollutants from the air into the water and allows any pollutants present on land to flow into the water. According to Table 1, the level of dissolved oxygen measured in the fishpond's water was 8.28 mg/L, which is within the acceptable range of DO levels for fisheries. This reading indicates that the water quality is adequate for use in fishponds. Any DO range less than 5 mg/L will put aquatic life under stress, which can be detrimental to fish farming. The in-situ water analysis in the fishpond yielded a pH reading of 7.73, representing a neutral pH value that falls within the acceptable pH range.

Effect of Electrodes Arrangement on Removal of Heavy Metals

According to the initial reading's results for the levels of heavy metal ions, the levels of Cd, Pb, and Zn in the water of the UMK fishpond are still within the acceptable range for water bodies. These results are in accordance with the Class III water body standards found in the INWQS table in **Table 1**. **Table 2** indicates that the electrocoagulation process can remove Cd, Pb, and Zn from the water sample.

Based on **Table 2**, we can see that out of the three arrangements, A1, monopolar electrodes in parallel connection; A2, monopolar electrodes in series connection; and A3, bipolar electrodes in series connection, A1 is the one that is least effective in removing Cd, Pb, and Zn from the water sample. Result also shows that for lead and zinc, the heavy metals removals using electrode material A1 are lowest. This may be caused by the cathode not reducing fast enough to produce the coagulating agent that will bind with the heavy metal ions and form flocs that can be removed by filtration.

Table 2: Heavy metal removal.

Sample	Heavy Metal Removal (%)		
	Cd	Pb	Zn
SSA1	0.00	3.23	3.13
SSA2	0.00	5.51	4.87
SSA3	9.09	6.54	7.47
MSA1	18.18	33.64	32.76
MSA2	18.18	32.71	37.93
MSA3	45.45	45.79	60.92
ALA1	45.45	41.12	25.29
ALA2	45.45	48.60	29.89
ALA3	45.45	45.79	50.00

SS – stainless steel electrode, MS – mild steel electrode and AL -aluminium

Since this arrangement uses a parallel connection, another possible explanation for the low efficiency with which heavy metal ions are removed at A1 is that the resistance to the current increases due to this arrangement. When comparing the effectiveness of removing Cd, Pb, and Zn from the water sample, Arrangement 2 (A2) performed marginally better than Arrangement 1 (A1). Even though both arrangements used monopolar electrodes for the electrocoagulation process, this is most likely the result of the series connection used in one of the arrangements. A direct path is taken by the current as it travels from the power supply to the electrodes through series connections. In contrast, parallel connections direct the current flow through various wires before it reaches the electrodes. Using a series connection would result in a quicker flow of current; Arrangement 2 could perform marginally better than Arrangement 1 when removing Cd, Pb, and Zn.

Cd, Pb, and Zn ions can be most effectively removed from the water sample with A3, which is the recommended option for the arrangement of electrodes. According to table 1, the removal rate is highest using electrode material A3, which is used in the electrocoagulation process. This is the case for all of the electrode materials. This can be seen more clearly by looking at arrangement 3 for mild steel electrodes for Zn, which shows a reduction in the level of Zn from its initial value of 0.174 mg/L to 0.068 mg/L (60.92% removals rate).

Utilising arrangement 3 and making the electrode out of mild steel demonstrates a reduction of 60.92% in the amount of Zn. Heavy metal ions were eliminated by utilizing a bipolar electrode in Arrangement 3. Because each flat side of the bipolar electrodes is subjected to both a negative and a positive charge, the bipolar electrodes will undergo simultaneous oxidation and reduction processes. This phenomenon contributes to increased efficiency with which heavy metal ions can be extracted from a water sample. This is because the ions have a greater potential to bind more quickly with the coagulating agent that forms, leading to the formation of flocs that can then be extracted. This is accordance to the previous research using iron electrodes in alternating current, the removal of zinc was 96.7%, higher compared to stainless steel electrodes [10].

According to the research presented above, the most effective way to eliminate heavy metal ions is to use arrangement number three, also known as A3. Even though the electrocoagulation process was only carried out for thirty minutes, this arrangement could still remove 60.92% of the original heavy metal level at its highest point.

From Table 2, we can see that SS electrode material performed the worst in removing Cd, Pb, and Zn from the water sample. These results are in accordance with previous study by Mansoorian et al. [10] which found out that removal of zinc using stainless steel electrodes is lower that iron electrode for direct current approach. The most that SS electrodes were able to remove are 9.1% for Cd, 6.5% for Pb, and 7.5% of Zn by using arrangement 3. Removal of Pb and Zn using SS electrodes with A1 and A2 was the worst since instead of reducing, the level increased. For Pb removal, it increased instead by 25.2% when using A1 and increased by 35.5% when using A2. For Zn removal, SS electrodes with A1 cause an increase of 47.12%, and by using A2, Zn level increased instead by 2.9%. The increased level for Pb and Zn when using SS electrodes could be attributed to the fact that Pb exists in SS as impurities, and Zn was added to SS to aid it in resisting corrosion and other minor physical mishandling. When SS undergoes reduction and oxidation during electrocoagulation, the Pb and Zn in the material are also released into the water sample. With A1 and A2 being monopolar electrodes, the Pb and Zn were added more into the water sample than the removal. Hence, using A3, some form of reduction can be seen in the level of Pb and Zn in the water sample.

MS electrodes perform better than SS electrodes for the removal of Cd and Pb, and it perform most efficiently for the removal of Zn. 60.9% of Zn level was removed from the water sample using MS electrodes with A3, with the initial reading of 0.174 mg/L; it went down to 0.068 mg/L. MS electrodes are made up of mostly iron with the addition of a small amount of carbon, usually less than 0.2% of carbon. The redox reaction of MS electrodes allows for greater removal of Cd, Pb, and Zn compared to SS due to the high formation of ferric hydroxide, which acts as the coagulation agent that binds the ions together to form floc.

Al electrodes have the highest efficiency in removing Cd and Pb, based on Table 2. Al has a high redox reaction rate which will produce aluminium coagulants, such as aluminium sulphate and aluminium chloride, during the electrocoagulation process. The agent could easily bind with Cd and Pb during the process to form flocs that removed it from the water sample. Removal of Pb using Al electrodes reaches the lowest level of 0.055 mg/L using arrangement A2 from the initial reading of 0.107 mg/L. There was a 48.6% removal of Pb by using Al electrodes. Based on the analysis above, we can see that MS and Al electrodes are the optimum electrode material for removing Cd, Pb, and Zn in the electrocoagulation process. MS electrodes are best used when Zn are the primary contaminants that wish to be removed from the wastewater. In contrast, Al electrodes are best used when Cd and Pb are the primary contaminants that wish to be removed from the wastewater.

From the tabulated data, it shows that Arrangement 3, which uses bipolar electrodes in a series connection, as the most effective setup for removing Cd, Pb, and Zn from the wastewater.

CONCLUSION

This research demonstrates that the electrocoagulation method is highly effective for treating wastewater, particularly in removing heavy metals. The materials and configurations used make it suitable for application in wastewater treatment plants, aligning with Sustainable Development Goal 6 (Clean Water and Sanitation). Although the study was conducted on a limited scale and treated relatively small volumes of water compared to typical treatment plant capacities, scaling up the process is feasible. The experiment identified Arrangement 3, which uses bipolar electrodes in a series connection, as the most effective setup for removing Cd, Pb, and Zn from wastewater. However, there are some limitations to consider. Electrode passivation can occur, meaning that switching the polarity might reduce the process's efficiency over time. Additionally, alternating the polarity of electrodes can increase energy consumption. Despite these limitations, using different polarity electrodes can still be beneficial in certain scenarios, particularly for reducing electrode fouling and improving overall treatment efficiency. It is important to carefully consider these factors when designing and operating an electrocoagulation system. The choice of electrode material should be based on the primary pollutants to be removed. MS electrodes are most effective for removing Zn, while Al electrodes are optimal for removing Cd and Pb. In summary, Al and MS electrodes are the best materials for efficiently removing heavy metals through electrocoagulation. However, the optimal material depends on the specific pollutants targeted for removal. Further research is needed to deepen the understanding of these findings. The power supply voltage required to carry out the electrocoagulation process could be the subject of additional research. This meant that by making the power supply voltage the independent variable, we would be able to determine the ideal voltage that would maximize the effectiveness of the electrocoagulation process by making use of the variables investigated in this article as the variable that remained constant.

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