Comparison of Chemical and Electrocoagulation Methods in Treating Wastewater

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Abstract: In the process of wastewater treatment, chemical flocculation is the method we usually choose, and it has developed early and has rich experience. In recent years, electrocoagulation has become an emerging method. They both provide a reliable method for treating water turbidity, the cloudiness or haziness of a fluid typically invisible to the naked eye, and generally, they enable up to 90% reduction in suspended solids and organic loads. Firstly, we will introduce the mechanisms of the two methods and compare the two principles. The main difference between the two methods can be attributed to the way the coagulant is applied to the treated solution. Organic or inorganic substances are directly added and then dissolve in the water to provide counter electric charges in chemical coagulation, whereas electrocoagulation uses ions produced by the metal electrode during electrolysis process for neutralization. Secondly, methods for measuring chemical oxygen demand (the main pollutants in wastewater) will be introduced. Once again, we will compare the differences between chemical coagulation and electrocoagulation methods in terms of economy, efficiency, stability, and other aspects in specific cases from three aspects: inorganic, organic, and heavy metals. Finally, we will summarize the current application fields of the two technologies and put forward possible research directions in the future.

Keywords: chemical coagulation; electrocoagulation; wastewater treatment; industrial applications.

1 Introduction

Coagulation-Flocculation process is a widely used method for water treatment, due to characteristics of simple and effective. It can be used for pretreatment, posttreatment, or even as the main treatment of wastewater including wastewater from slaughter house, printworks and gelatin factory. According to the record, Egyptians were using aluminum sulfate for water treatment through the process as early as 1500 BC [1].

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Chemical coagulation (CC) is a physical and chemical reaction occurring between the alkalinity of the water and the coagulant added to the water, which results in the formation of insoluble flocs [2]. Coagulants are used for CC process. Substance including PAC, ferric alum can be used as coagulant. CC is widely used in treatment of wastewater of various conditions including pharmaceutical effluents, cyanobacterial blooms and gelatin production plant wastewater. However, there are some challenges in application of chemical coagulation in wastewater treatment. Many of the chemical coagulants are toxic. For example, addition of aluminum sulphate as coagulant may lead to memory loss, neurological diseases and even risk of Alzheimer's disease. Additionally, some polymeric coagulants can be toxic to human and animals. In addition, COD level may increase due to addition of some natural coagulants.

Electrocoagulation (EC) is a method using a direct current source on anode and cathode that is submerged in a wastewater sample [3]. Iron and aluminum electrodes are the most widely used metals as for EC cells because they are available, non-toxic and reliable. However, electrocoagulation also has some problems. Regular replacement of sacrificial anode used in EC is necessary since the anode dissolves into two solution during the process. Additionally, in some areas where electricity is not abundant, the operating cost of EC can be expensive [4].

Because both CC and EC have disadvantages, we want to compare them in applications in different industries to better understand how to make the right choic. Although others may have done researches about similar topics, the difference is we compare in a more comprehensive way. The cases we studied involve wastewater treatment of inorganic substances, organic substances, and heavy metal. For each we chose a representative industry, which is agricultural, gelatin plant, and mining industry, separately. Our research on the treatment of wastewater containing different types of pollutants can help us provide advise with higher level of universality.

2 Methods

To provide a systematic and comprehensive review on the comparison of chemical and electrocoaglation in treating different industrial wastewater, we searched for relevant literature on PubMed, LitSense, and Environmental Health Perspectives. The search terms we used include "chemical coagulation" "electrocoagulation" "coagulation" "coagulant" "flocculation" "wastewater treatment" "industrial application" "heavy metal" "organic" and "inorganic". We read abstracts and introductions of the articles we found and select the ones we need for reference. Finally, 14 articles were chosen as our references.

3 Mechanisms of coagulation

3.1 Chemical coagulation

The process of coagulation-flocculation includes 3 main steps (Figure 1): coagulation, flocculation and sedimentation. In wastewater, there are colloids which are suspended particles that cannot reach the weight to settle down. The particles are negatively charged which cause responsive forces between each other. Coagulation first neutralizes the charges of particles by coagulants. Organic or inorganic substances, which serve as the coagulant, are added and then

dissolve in the water to provide counter electric charges. Next, flocculation enables neutralized particles to stick together and form larger flocs. The larger flocs would become less soluble and settle down in the step of sedimentation. And then treated water can be transferred for further treatment.

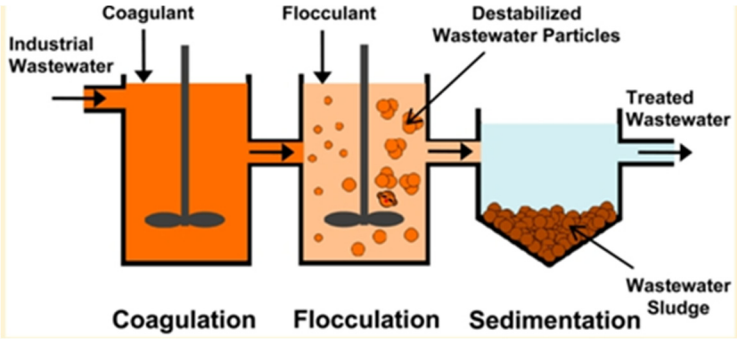

Figure 1. Coagualtion-floccualtion process. (Chee Yang Teh et al., 2016) [5]

3.2 Electrocoagulation

The basic electrocoagulation unit (Figure 2) typically consists of an electrolytic cell with an anode and cathode metal electrodes connected to an external direct current power source and immersed in the solution to be treated [6]. A resistance box to regulate the current density and a multimeter to read the current values are also needed. When electricity is on, oxidation occur at the anode, and reduction occur at the cathode. Iron and aluminum electrodes are the most widely used metals as “sacrificial electrodes" for EC cells. The sacrificial anode lowers the dissolution potential of the anode and minimizes the passivation of the cathode, and can continuously produce ions in the water. The released iron, aluminum, or other metal ions then neutralize the negative charges of the suspended particles, making them bigger and stick together, and therefore less soluble and easier to be separated from liquid. When DC (direct current) is passed through the cell, the anode dissociates to give metal cations and serves as the coagulant in an EC cell [6]. The anodic reactions for iron electrode, for example, include the following [6]:

$$Fe\ (s) \rightarrow Fe^{n+}(aq) + ne^{-1} \quad (1)$$

$$4Fe^{2+}(aq) + 10H_2O + O_2(aq) \rightarrow 4Fe(OH)_3(s) + 8H^+ \quad (2)$$

$$Fe^{2+}(aq) + 2OH^- \rightarrow Fe(OH)_2(s) \quad (3)$$

Side reactions occur in the EC cell, including the evolution of hydrogen bubbles at the cathode along with OH^- ions. The equation is expressed as [6]:

$$2e^- + 2H_2O \rightarrow H_2O + 2OH^- \quad (4)$$

Besides, evolution of oxygen at the anode might take place [6]:

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (5)$$

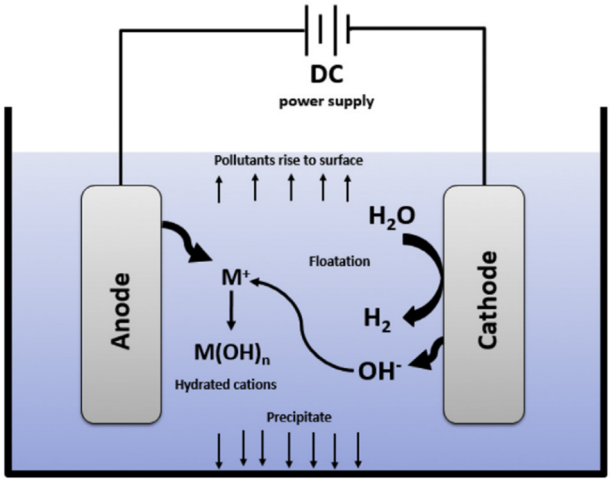

Figure 2. A schematic representation of a basic EC cell. (Dina T. Moussa et al., 2017)

Basically, CC and EC follow the same mechanism: destabilizing suspended particles by neutralizing the repulsive forces to make them clump into bigger particles and become less soluble [6]. The main difference between the two methods can be attributed to the way the coagulant is applied to the solution. Chemicals directly works as coagulants to neutralize charges, whereas electrocoagulation uses ions, usually iron or aluminum cations, produced by the metal electrode during electrolysis process for neutralization.

3.3 Advantages & Disadvantages

Due to different working processes, both chemical and electrocoagulation have their inherent advantages and disadvantages (Table 1).

Chemical coagulation is favored for its easy operation, relatively simple design, and low energy consumption [6]. However, CC is an additive procedure, adding chemicals to remove pollutants, so it requires extensive jar testing to ensure extreme precision of the dosages of coagulants, and often, continuous adjustment to the dosage is needed according to the varying composition of wastewater and coagulants/flocculants that are used. This will make the process incredibly complex and time-consuming. Also, CC will result in toxicity in water and health hazard which prevents the reuse of treated wastewater where metal concentration can be high. Another concern is the high sludge generation, which is a secondary pollution to the environment and requires extra costs on a separate treating process.

Electrocoagulation can remove pollutants and even some of the smallest particles more efficiently than chemical coagulation because the floc formed from EC can be larger and therefore easier to be separated than that formed by chemical coagulants [6]. What's more important is that it generates much less sludge through the treatment process and doesn't require addional chemicals as coagulants, so EC will not cause secondary pollution like CC [6]. However, sacrificial anode during electrolysis needs frequent replacement because it will dissolve into the solution, which may increase operational complexity and raise cost [6]. Another problem, cathode passivation will also reduce the efficiency of EC [6]. Additionally, electricity in some areas are scarce, making it expensive to operate an EC unit [6].

Table1: Advantages & disadvantages of the two techniques

	Advantages	Disadvantages
Chemical Coagulation	easy operation simple design low energy consumption	additive procedure, extensive jar testing toxicity and health hazard high sludge generation
Electrocoagulation	remove very small particles bigger floc no secondary pollution	annode dissolution cathode passivation electricity scarcity

4 Case studies

Before the formal treatment of waste water, people must first measure the water pollution indicators to determine the extent of water pollution. COD (chemical oxeygen demand), BOD (biology oxeygen demand), SS (suspended substance) and pH value are important indexes to measure the degree of water pollution.

4.1 Methods for measuring COD

COD is a measure of the quantity of oxygen necessary to oxidize completely all the organic matter in a sample to CO_2 and H_2O (Figure 3) [7].

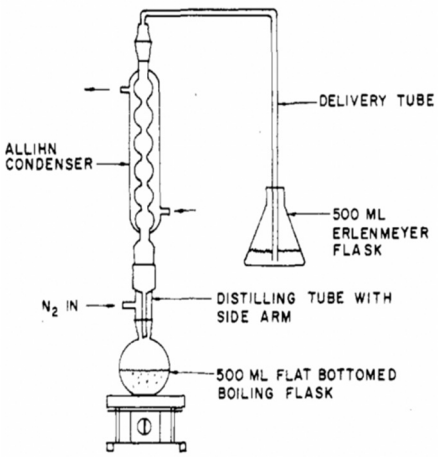

Figure 3. Experimental apparatus for measuring COD index. (Baumann, F. J. et al., 1974)

Lonic equation:

$$Cr_2O_7^{2-}+16H^{+}+3C\rightarrow 4Cr^{3+}+8H_2O+3CO_2 \quad (6)$$

$$Cr_2O_7^{2-}+14H^{+}+6F^{2}\rightarrow 6Fe^{3+}+2Cr^{3+}+7H_2O \quad (7)$$

Principle Overview:

In a strongly acidic solution, a certain amount of potassium dichromate oxidizes the reducing substance in the water sample, using silver salt as catalyst, boiling reflux for 2h. And the excess potassium dichromate is used as an indicator with ferrous ammonium sulfate solution and dripped back. The amount of ammonium ferrous sulfate consumed is converted to the amount of oxygen consumed.

The calculation formula of COD concentration:

$$\rho CODcr=C(V0-V1)\times 8\times 1000/V \quad (8)$$

C—The concentration of ammonium ferrous sulfate standard solution, mol/L;

V—Water sample volume, mL;

V0—The amount of ammonium ferrous sulfate standard solution when titrating blank, mL;

V1—The amount of ammonium ferrous sulfate standard solution for titrating water samples, mL

4.2 Agriculture

Excessive discharge of phosphorus into water is the significant factor of eutrophication. Agricultural wastewater contains a huge amount of phosphorus, which may be directly discharged into the sewer, causing a enormous burden on the municipal sewage network.

Figure 4. Harm caused by water eutrophication (baidu et al., 2022)

The images above (Figure 4) are what happened in reality. In April of this year, millions of gallons of wastewater flowed into Tampa Bay, causing a red tide and the collective death of 600 tons of fish in the United States. The occurrence of this incident is closely related to the leakage of agricultural wastewater four months ago. This brings many challenges to urban development and environmental protection [7].

Table 2: Analysis report of agricultural wastewater samples

Index	COD(mg/L)	NH3-N(mg/L)	TN(mg/L)	TP(mg/L)	pH
content	50000-70000	300-500	800-1200	200-400	5.0-5.6

The above table (Table 2) extracts agricultural wastewater and conducts water sample composition analysis. According to the water sample analysis report, the nitrogen and phosphorus content in agricultural wastewater is very high. The large amount of phosphates contained in agricultural wastewater has caused pollution to water bodies. Consequently, in the treatment process of agricultural wastewater, we will focus on treating the nitrogen and phosphorus elements in the wastewater.[8]

Chemical precipitation phosphorus removal is the earliest and most widespread phosphorus removal method. Chemical phosphorus removal is achieved by adding chemical agents to convert phosphorus in wastewater into insoluble phosphate precipitates, which are then transferred to sludge through solid-liquid separation to achieve phosphorus removal. This method mainly achieves the formation of the most stable and insoluble phosphate by adjusting the pH and controlling the concentration of phosphate and phosphate.

Based on the principle of chemical flocculation, we propose a treatment scheme.

Step 1, test the phosphorus content in 1 liter of water;

Step 2, adjust the pH value of the phosphorus wastewater to 6-9;

In step 3, ferric chloride is hydrolyzed corresponding to the phosphorus content of 1 liter of water in step 1;

In step 4, the ferric chloride hydrolyzed in step 3 is fully mixed with the phosphorus wastewater obtained in step 1 to form iron hydroxyl compounds and produce phosphate colloid;

Step 5, add polyaluminum chloride, adsorption, bridging and rolling, and precipitate the colloids formed by phosphate and iron in the wastewater. [8-9]

Metal hydroxides and complexes formed in the reaction can be used in mixed form. The coagulant is combined with the pollutants in the wastewater, by coagulation and sedimentation removal of pollutants.

Formula:

$$\text{Anode: } Fe-2e^-=Fe^{2+} \quad (9)$$

$$Fe^{2+}+2OH^-=Fe(OH)_2 \quad (10)$$

$$Fe(OH)_2+O_2+2H_2O=Fe(OH)_3 \quad (11)$$

$$\text{Cathode: } 2H_2O+4e^-+O_2=4OH^- \quad (12)$$

Chemical Coagulation has developed earlier. Consequently, it has already accumulated many experiences. Moreover, it is not too hard to operate, stable and reliabe. However, this method requires strictly control of the dose of the flocculants and has risks to cause secodary pollution.

Electrocoagulation treatment technology has high environmental compatibility, high energy efficiency and controllability, and has a good application prospect in agricultural wastewater treatment. On the other hand, the cost of the machines are quite high. In addition, the machines needed the replacement of the batteries and electrodes periodically. In conclusion, the decision

on which method to use to treat agricultural wastewater or a combination of the two methods depends on the specific situation.

4.3 Gelatin

A gelatin manufacture corporation in Qing Hai province in China presented their attitudes and measurements towards the wastewater produced. With an annual production over 4500 tons of gelatin, 1.5 million tons of contaminated solutions are emitted per day.

The sludges have the following features: 1) Sewage mainly contains animal fat and protein in bone particles, which is the main substance that constitutes COD in sewage; 2) Sewage contains a large amount of lime residue and bone residue; 3) The sewage has a large oil content and mostly exists in emulsion oil, and emulsion oil is difficult to completely remove through oil trap and precipitation. It is difficult for the biochemical system to degrade the oil, and if it is not separated, it will increase the difficulty of subsequent biochemical treatment. The water quality and quantity of sewage discharge fluctuate greatly. Thus the sewage plant has set up an air flotation process before entering the biochemical pool, which removes most of the grease through air flotation and reduces the impact of grease on the biochemical system; Gelatin sewage calcium content is extremely high, if the physical and chemical method to remove most of it, it is not realistic, so the biochemical system adopts activated sludge method combined with biofilm method (IBAF process), through activated sludge combined to adsorb most of the calcium, so the activated sludge ash content is high, the activity is relatively poor; IBAF, on the other hand, has a high volumetric load, which guarantees the overall removal rate of wastewater treatment.

Overall, it is EC that takes up more advantages in terms of effectiveness, considering organic matters (Total Suspended Solids, turbidity, COD). Moreover, EC may experience different test results even under the same PH due to the type of charged groups, coagulant, dosage, residual water matrix and PH. These are all vital factors.

The results are determined in two major ways. The two coagulation methods are first compared in the amount of remaining sedimentation after the experiment. There are three samples, one with no treatment (S1) and the other two with 2 coagulations respectively (S2, S3). As a result, the two treatments significantly outweigh S1's efficiency, while S3 took up the greatest amount of treated comtaminants, reaching 312.5ml/l every 10 minutes, which is twice the amount of S2 [10]. What's more, S3's remaining sediments also accounted for the least amount among the three.

From the semi-quantitative analysis of the sludge samples obtained in the EC process at pH 6 to 8, it was found that the Si/Al ratio was approximately 4.5, a range in which microporous aluminosilicate minerals called zeolites are usually found [10]. There are different types of zeolite in function to Si/Al ratio and their main cations.

It is undenyable that when comparied with chemical coagulation, EC showed a promising and more practical application in industry area since the cintaminents produced are of higher COD concentration and more complex in the ingredients. However, both CC and EC treatments are popular in their own area, having an irreplaceable position (Figure 5-7).

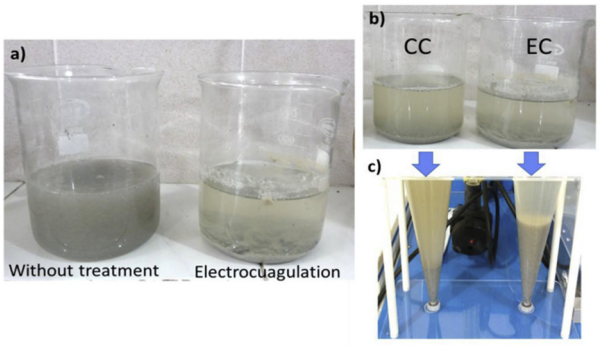

Figure 5. Comparison photographs a) untreated sample and treated by electrocoagulation b) between chemical coagulation (CC) and electrocoagulation (EC) and c) SSdetermination in Imhoff cone. (Arturi et al., 2019)

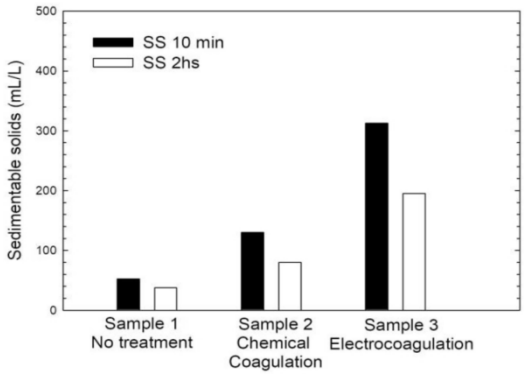

Figure 6. SS in 10 minutes and 2 hours of untreated effluent (sample 1), treated by chemical coagulation (sample 2) and electrocoagulation (sample3). (Arturi et al., 2019)

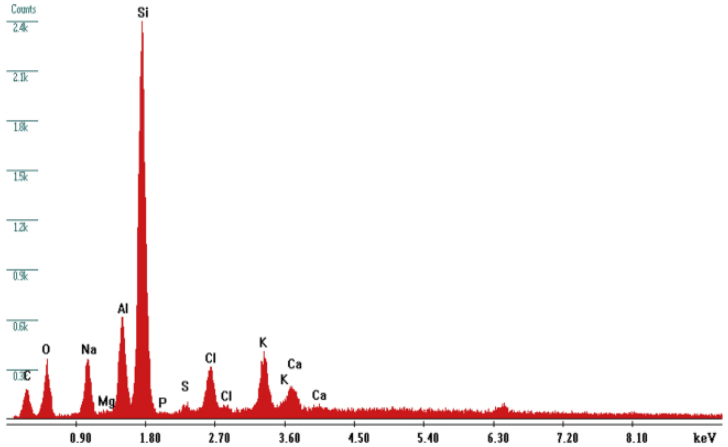

Figure 7. It shows the EDAX analysis performed in precipitates where a predominant peak corresponding to silica is observed. This is consistent with the decrease in the concentration of silicates found in the supernatant after treatment. (Arturi et al., 2019)

4.4 Mining

Metal ions in wastewater, originating from industrial and urban sources, can significantly harm the environment. Industries such as mining, tannery, and electroplating often generates waste water contains highly concentrated heavy metal ions [11]. These ions can poison aquatic life, contaminate groundwater, disrupt ecosystems, and pose health risks to humans. Including the neurological system, liver, lungs, kidneys, stomach, skin, and reproductive systems, even at low exposure levels [12]. Additionally, they can degrade infrastructure through corrosion. Addressing this requires robust regulatory measures and advanced wastewater treatment. Therefore, to solve such problem, serval techniques relate to chemical coagulation and electrocoagulation have been developed for few decays.

Mining effluents can contain a range of toxic metals that are harmful to aquatic and terrestrial ecosystems. Thioteq technology has created a purification process where biologically produced sulfides can be used to treat these effluents by binding with the metals to form metal sulfides, which are less soluble and can be more easily removed [11]. This can greatly reduce the environmental footprint of mining operations. According to the company the reaction can be simplified into the following two reactions to create sulfide as a chemical coagulant in the process.

$$SO_4^{2-} + CH_3COOH + 2\ H^+ \rightarrow HS^- + 2\ HCO^{3-} + 3\ H^+ \ (1) \qquad (13)$$

In the first process sulfuric acid reacts with acetic acid to synthesis sulfide and carbonic acid.

$$Cu^{2+} + S^{2-} \rightarrow CuS\ (2) \qquad (14)$$

Then in the second reaction, sulfide reacts with suspending heavy metal ions to form insoluble residues.

Comparing with conventional method using lime and hydroxides, such technique can significantly reduce the sulphate (< 250 mg/l vs. ~ 1500 mg/l) and metal (ppb- vs. ppm-level) concentrations [11]. In addition, in one of the cases applied in treating waste water from a zinc mine in North America such process was proven to achieve a high recovery rate to reduce the cost of purification up to 94.5% [11].

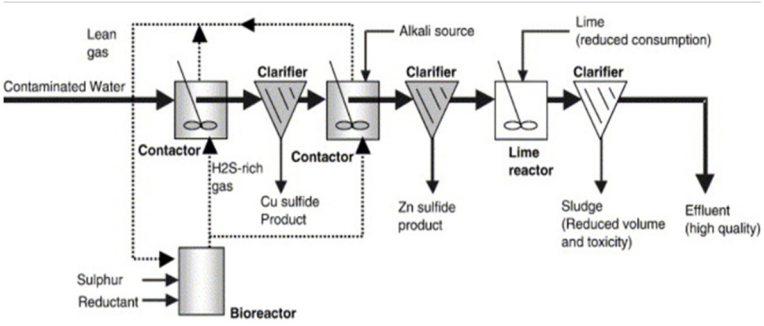

Figure 8. Thioteq process in Zinc mine factory. (Huisman et al., 2006)

The Thioteq process is located prior to the lime plant, as shown in the figure 8. Using a two-phase system, this process extracts different concentrate products such as copper and zinc. For project feasibility, metal concentrations and market prices are critical in determining the best

design. Sometimes it is more cost-effective to extract a single metal. Ultimately, the product from the final clarifier is transported to the lime plant for acid neutralization and, if necessary, iron and aluminum precipitation to reduce residual heavy metal content.

On the other hand, according to the figure, the synthesis of chemical coagulant sulfide required a bioreactor to produce hydrogen sulfide, such chemical gas is very toxic, and exposure can be harmful or even fatal. Even low concentrations can cause irritation to the eyes, nose, or throat.

Biotransformation of elemental sulfur or sulfate to produce a cost-effective sulfide chemical coagulent facilitates the treatment of heavy metal wastewater, solving environmental problems and extracting metals at the same time. However, this process produces harmful hydrogen sulfide gas. Due to high targeted nature, other metal contaminants require subsequent additional treatment with hydroxides.

Another study also focused on treating heavy metal ions in waste water from tannery industries by electrocoagulation (Figure 9). The tannery industry is notorious for generating a large amount of waste water, which is often rich in pollutants such as chromium, sulfur, oils, and solid waste like flesh and hair. Waste water from tanneries is typically highly alkaline and contains a mix of organic and inorganic substances that can be harmful to both the environment and human health if not properly treated.

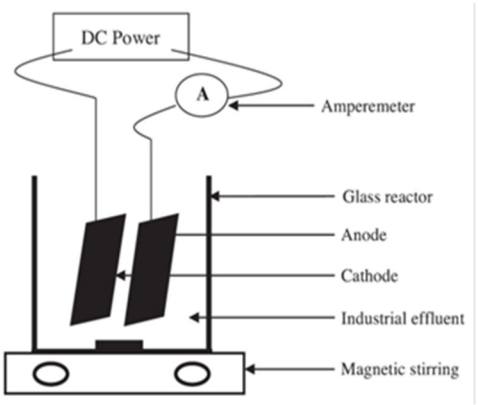

Figure 9. experimental set up for electrocoagulation treating tannery waste water (Ziati et al 598-603)

In this case, experiments were accomplished in the field of electrical coagulation which mainly focused on treating turbidity and chromium content. The experiment was carried out in the following conditions: under the following conditions: 15 V applied potential difference, 45 cm2 electrode surface, 1 cm interelectrode distance, pH 6.1 raw water, and a contact time of 90 min. (Ziati et al 598-603) As shown in Figure 10, a 1000 ml glass reactor was used in the experiment designed for electrochemical reactions. The reactor was installed with two parallel aluminum electrodes. Wastewater for treatment was continuously circulated between these electrodes. On the anode side, the metal is uniformly dissolved into the solution, while hydrogen is separated at the cathode. The experiments were arranged to collect samples at predetermined time intervals. The collected samples are allowed to stabilize for approximately 30 minutes prior to any analysis to ensure accurate results. After stabilization, these samples are scrutinized to assess the efficiency and results of the electrochemical treatment process.

The findings showed that electrical coagulation was extremely effective, achieving a 99% removal rate for turbidity and a 93% rate for chromium elimination under the experimental conditions. [13]

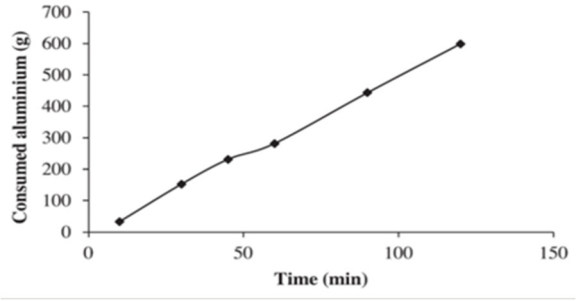

Figure 10. Aluminum electrode consumption trend (Ziati et al 598-603)

$$C_{electrode} = \frac{i*t_{EC}*M_w}{z*F*v} \quad (15)$$

where $C_{electrode}$ is electrode consumption (kg/m^3), M_w is molecular mass of aluminium (26.98 g/mol), z is number of electron transferred (zAl = 3) and F is Faraday's constant (96,487 C/mol). [13]

According to the figure 11 and mathematical formulas outlined in the study (Ziati et al 598-603), the use of aluminum as an electrode material results in an unusually high consumption rate. Specifically, this consumption is 10 to 20 times higher than what Faraday's law typically predicts. This deviation has significant financial implications, adding significantly to the overall cost of the electrochemical process (Table 3~4).

As the equation shows, the cost increase stems from two main factors: the electrical energy required and the cost of the electrode material itself. The use of aluminum electrodes in this case not only consumes more power, but also increases the frequency of electrode replacement. In an industrial setting, these factors can significantly increase operating costs, thus affecting the economic viability of the process.

It is critical for any organization that intends to adopt this electrochemical method to appreciate the potential financial liabilities associated with the use of aluminum electrodes. Whether used for wastewater treatment or other electrochemical applications, the high cost can be a significant barrier to widespread adoption of the technology. It is therefore imperative that a more cost-effective electrode material be found, or that the process be optimized to reduce the rate of aluminum consumption so that it is more in line with Faraday's law and achieves more economical operation.

To overcome the high costs associated with soluble electrodes, one potential solution is the use of insoluble electrodes. This concept was rigorously tested in a study of wastewater treatment in the electroplating industry. In this case, heavy metal contaminants such as nickel, copper and zinc are often encountered, posing a challenge to conventional treatment methods.

This study compares the efficacy of iron and stainless steel as electrode materials in electrochemical treatment processes. Both materials are based on the element iron (Fe) with a molecular weight of 55.85 g/mol. this consistent basic element ensured that any differences

observed in the experimental results could be directly attributed to the solubility characteristics of the two materials rather than differences in their elemental composition.

The experimental design was modeled on a technique previously used for tannery wastewater treatment, thus allowing a more direct comparison and evaluation of the results. The experimental results show that insoluble electrodes such as stainless steel are not only more efficient in removing pollutants, but also more cost-effective in the long run.

Table 3 Removal rate data from stainless steel electrode [14]

Chemicals	Ni		Zn		Cu	
	conc.mg/L	%R	conc.mg/L	%R	conc.mg/L	%R
Initial metal concentration after coagulation	80		20		22.5	
Contact time/min						
15	11.6	85.5	13.6	83	3.65	83.8
30	5.2	93.5	2.04	89.8	2.24	90
45	7.12	91.1	2.38	88.1	3.15	86
60	9.68	87.9	2.88	85.6	3.71	85.3

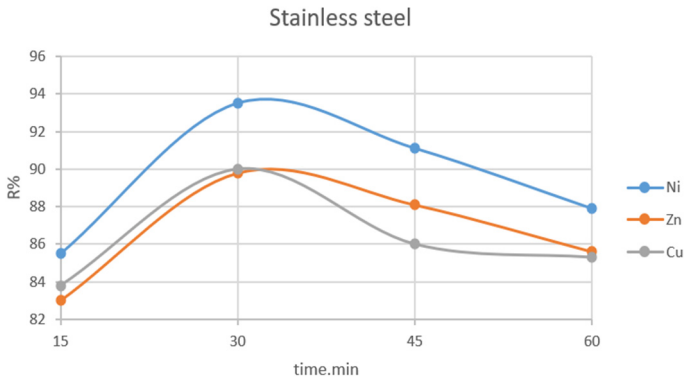

Figure 11. based on the removal rate from stainless steel electrode

Table 4 Removal rate data from iron electrode [14]

Chemicals	Ni		Zn		Cu	
	conc.mg/L	%R	conc.mg/L	%R	conc.mg/L	%R
Initial metal concentration after coagulation	80		20		22.5	
Contact time/min						
15	9.28	88.4	2.46	87.7	2.66	88.2
30	7.52	90.6	2.16	89.2	2.29	89.8
45	8.08	89.9	2.32	88.4	2.5	88.8
60	8.72	89.1	2.38	88.1	2.72	87.9

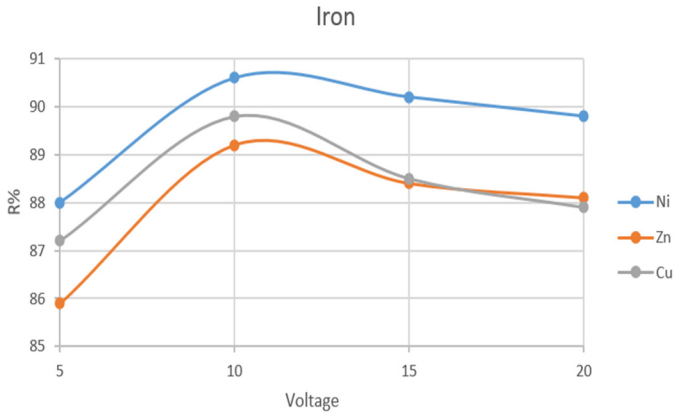

Figure 12. based on the removal rate from iron electrode

These results have a dual significance. First, these results suggest that insoluble electrodes may provide a more efficient mechanism for treating heavily polluted industrial wastewater. Second, these results suggest that the use of such materials can result in significant cost savings, which are critical to the economic viability of wastewater treatment processes, especially in industries such as electroplating that produce highly polluted wastewater. Thus, the use of insoluble electrodes offers a promising avenue for improving the effectiveness and economics of wastewater treatment methods (figure 12).

In the experiment, the combination of electrocoagulation and chemical coagulation was also discussed. Combining electrocoagulation and chemical coagulation in wastewater treatment can offer synergistic benefits, optimizing the removal of contaminants more efficiently than when either method is used alone. Electrocoagulation is excellent for dissolving metal ions and breaking down organic compounds, while chemical coagulation is often more effective at removing finer suspended particles and complex substances.

Table 5 Efficiencies of different chemical coagulant. [14]

	Ni		Zn		Cu	
	conc.mg/L	%R	conc.mg/L	%R	conc.mg/L	%R
Initial Conc	450		75		90	
Chemical Coagulants						
NaOH	76.5	83	19.5	74	11.66	87
Al(OH)3	89.55	80.1	20.63	72.5	19.35	78.5
Al(OH)3+NaOH	78.75	82.5	19.65	73.8	18.27	79.7
CaO	67.5	85	16	78.7	13.79	84.68

However, operational complexities may arise from trying to integrate the two techniques. The efficiency of the combined methods would need to be carefully optimized, considering factors like voltage, current density, and the type and amount of chemical coagulants used, to achieve the desired removal efficiencies (Table 5).

As a result, in the case of heavy metals from electroplating industry when using stainless steel electrodes, optimum removal is achieved in the presence of ferric chloride as a coagulant. [14]

5 Summary

In the current state, both chemical coagulation and electrocoagulation fail to eliminate the use of the other as the only choice of coagulation technology in wastewater treatment. CC and EC demonstrate comparable value for the removal of nitrogen and phosphorus, but a more exact choice still depends on actual situations. EC is more prefered in wastewater treatment of gelatin for its effectiveness of removing organic matters, and CC shows more promising uses in mining industry. Substantial comparisions are needed to cover all kinds of pollutants and industries in order to provide a more comprehensive and informative instruction on choosing between CC and EC. Focus of future research should also include more exhaustive economic estimation of coagulation processes and integration of CC/EC with other technologies so that coagulation can be used to maximum effect in future industrial applications.

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