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Hospital Wastewater Treatment using Electrocoagulation Process in Comparison with Conventional Chemical Coagulation

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Abstract: Wastewater from hospitals is regarded as one of the most hazardous forms of pollution. In addition to dangerous chemicals, pharmaceuticals, and radioactive isotopes, this effluent is polluted with pathogens, including bacteria, viruses, and parasites. It is critical to safeguard water supplies in Iraq which faces several climate-related challenges. As a product, before releasing pollutants into receiving waterways must be treated such as sewage and industrial effluent. Current research aims to investigate utilization of electrocoagulation (EC) for hospital wastewater treatment and compare with conventional coagulation (CC) in terms of removal efficiency and operational costs. In this study, influent wastewater samples were collected to determine the optimal conditions for Total dissolved Oxygen (TDS), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Chloride (Cl), and Turbidity. For EC process, the TDS, BOD, COD, Cl, and Turbidity indicators' removal efficiency percentages obtained their highest levels with varying voltage amounts ranging from (10-25 volts), correspondingly ranging from (62% - 97.1%), (75.6% - 98.9%), (78.2% - 96.6%), (83.7% - 98.1%), and (74.1 - 97.4%). The results proved that the percentage of removal CC efficiency increases with an increase in the amount of Alum for all factors targeted and the optimal alum ratio is 15 g/L. The findings show that the EC process is appropriate for treating hospital wastewater, and that the old method is not beneficial.

Keywords: Hospital wastewater; Conventional Coagulation (CC); Electrocoagulation (EC); Alum, Stirring speed; Electrode distance.

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1. Introduction

Wastewater is produced from a variety of sources, including home, commercial, industrial, and agricultural processes. It contains a range of contaminants that have an impact on the environment's natural state (Meza et al., 2019). Pollution control, infection prevention, chronic illness prevention, environmental preservation, and wastewater reuse are generally the most crucial objectives of wastewater treatment (Dehghani et al., 2014; Bhandari et al., 2023).

The abundance of pathogens found in hospital wastewater highlights the significance of pollution sources. Hospital wastewater has several uses if it is appropriately handled (Djajasasmita et al., 2022). The healthcare facility requires a significant volume of water for delivery. Numerous techniques, including precipitation, ion exchange, adsorption, membrane filtration, photocatalysis, electrochemical, etc., lessen the impacts of hospital wastewater. Direct current electricity is utilized in the conventional coagulation (CC) procedure to eliminate impurities from the solution. In this procedure, an anode composed of suitable materials is electro-oxidized to create the coagulant in situ. After that, the charged ionic species are eliminated by enabling the waste's metal hydroxides or oppositely charged ions to react (Veli et al., 2016; Esfandyari et al., 2019). Due to the need for a straightforward procedure, good sludge settling ability, less sludge production, a larger product flock than chemical treatment, and a reduction in secondary pollution due to the lack of compound chemicals, electrocoagulation (EC) technology has recently gained a lot of traction in the wastewater treatment industry (Gönder et al., 2021; Hassoune et al., 2024). The elimination of impurities like heavy metals is another capability of this technique. For instance, it is employed to eliminate organic substances, bacteria, viruses, cysts, chromium, fats, oils, grease, colloidal and suspended particles, and mono azo acid red and orange color from aquatic environments (He et al., 2024). Numerous wastewater treatment facilities, including dairy (Hoffmann et al., 2023), cyanide removal, biochemical oxygen demand (COD) of olive oil wastewater (Jerie et al., 2024), and detergent removal from industrial wastewater for the automotive sector (Khan et al., 2020), can benefit from electrocoagulation. Higher applied current and a shorter electrode distance in aqueous solutions were shown to improve the elimination of dexamethasone (up to 38.1%) (Khan et al., 2024). According to Khan et al. 2021, genuine dairy wastewater may have up to 98.84% of its COD removed by the electrocoagulation method when it is operated for 60 minutes at 60 V. By using electrocoagulation, a maximum COD removal effectiveness of 82% was observed at a dye concentration of 100 mg/L. The elimination of COD from paperboard mill effluent was investigated with the use of iron and aluminum electrodes. With a current density of 4.41 mA/cm2 and a run period of 10 minutes, the highest COD removal efficiency under ideal working conditions (pH = 5.29 for the Al electrode and pH = 7.21 for the Fe electrode) was 99.93% and 99.92% for the Al and Fe electrode, respectively (Alfatlawi and Alsultani, 2019a; Pariente et al., 2022). Electrocoagulation was used to remove COD and heavy metals from actual industrial effluent. Al and Fe electrodes were able to remove up to 83.94% and 53.83% of COD, respectively (Paulus et al., 2019). It is feasible to dispose of hospital wastewater in networks in towns with wastewater collection systems; in the absence of such systems, hospital wastewater must be completely treated. Hospital wastewater has effluent quality criteria that conventional wastewater treatment facilities cannot achieve. While numerous synthetic wastewater has been treated using electrocoagulation, there hasn't been much research done on using actual wastewater in hospitals. The majority of earlier research has been on how well contaminants are removed from wastewater. Energy consumption has a significant role in the EC process from an economic perspective. The present study's goals are to examine the EC process's potential for treating hospital wastewater and to contrast it with more traditional chemical coagulation methods.

2. Materials and Method

2.1 Characterization of hospital wastewater

Hospital wastewater was collected from the Hospital in Babylon Governorate / Iraq located at 32°17'00" N 44°41'14" E. The hospital generates more than 100 m3 of sewage every day.

Using normal procedures, thirty wastewater samples were collected over six months (Alfatlawi and Alsultani, 2018b ; Ramírez-Coronel et al., 2024). To identify the ideal circumstances, influent wastewater samples were examined in this study. Total dissolved oxygen (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), chloride (Cl), and turbidity were measured. These samples were evaluated in the lab allowing the range of test findings to be discovered and shown in Table (1).

Table 1: Characteristics of Samples Collected from Hospital Wastewater.

No.	*Parameters*	*Quantity Range*	*Unit*
1	TDS	1280-1533	mg/L
2	BOD	108-276	mg/L
3	COD	327-830	mg/L
4	Cl	312-602	mg/L
5	Turbidity	52.6-190	NTU

2.2 Electrocoagulation Experimental Setup

An electrocoagulation (EC) experimental setup, including a power supply used to run a batch operation utilizing 1000 mL of wastewater in an EC cell as shown in Figure 1. The Al electrode with 4cm depth is used in the EC process (Alsultani et al., 2022a). The electrode distance between the anode and cathode varied from 2 to 4 cm, and they were positioned vertically and parallel to one another. Electrical clips were used to connect the electrodes to the copper wires on one end and a direct current (DC) power supply on the other. Subsequently, the anode and cathode immersed in the solution received the predicted current (Alsultani et al., 2022b; Salah Al-Shati et al., 2023). With a multimeter, the current and cell voltage were monitored regularly. A magnetic stirrer was used to continually stir the mixture at a steady pace. Using a pH meter, the wastewater's pH was determined, and sulphuric acid (H2SO4) and sodium hydroxide (NaOH) were added as needed.

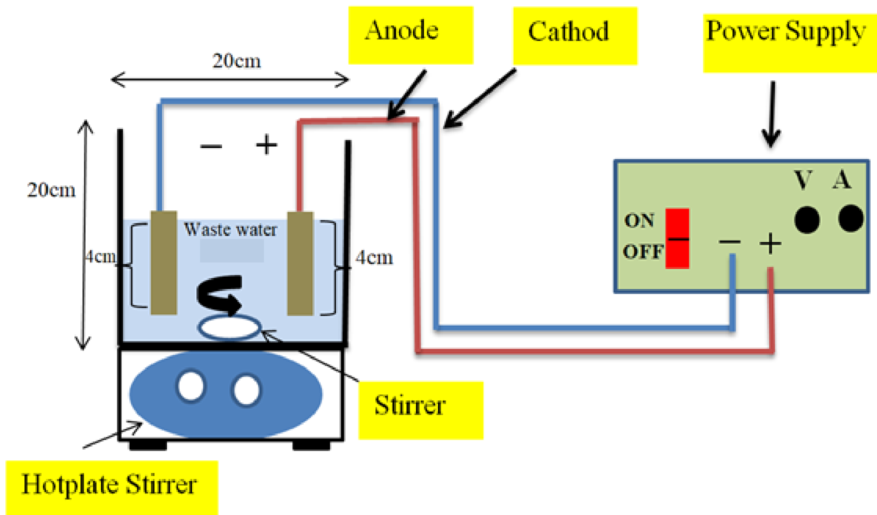

Figure 1: Electrocoagulation test apparatus.

The electrode plates were cleaned physically by washing them with distilled water before every run and owing to their sacrificial nature and also, they were replaced after every two runs. The percent of TDS, BOD, COD, Cl, turbidity removal efficiency, and energy consumption of the EC reactor were investigated under various conditions such as pH, reaction time, voltage, electrode distance, and stirring speed, respectively, and as presented in Table (2).

Table 2: Current Study Variable Parameters.

Parameter	*pH*	*Time (min)*	*Voltage (v)*	*Distance cm)*	*Stirring speed (rpm)*
Value	4	15	10	2	100
	5	30	15	4	150
	6	45	20	6	250
	7	60	25		
	8				
	10				
	12				

2.3 Conventional process

The conventional coagulation method is successfully eliminates dangerous germs and almost any range of turbidity in raw water. The fundamental of this process is neutralizing or interfering with the negative charges of the suspended particles that cause them to repel one another, a process known as coagulation or flocculation helps the particles to aggregate (Alsultani et al., 2023a). This results in the formation of larger particles that settle due to their weight and can be readily removed from the mixture in subsequent treatment steps like filtration. The benefits of alum adding encourages the suspended granules to aggregate and form larger granules that can easily settle under their weight in other treatment processes, by neutralizing or neutralizing the negative charges on the granules that cause their repulsion (Yadav et al., 2024). The conventional reactor is conducted to use same EC reactor without electrodes and the Alum dose can be summarized in Table (3).

Table 3: Conventional Wastewater Treatment Scenarios.

Test No.	*Alum (mg/L)*
1	5
2	10
3	15
4	20
5	25

2.4 Removal Efficiency Analysis

Data processing and analysis were done through the laboratory based on the sample obtained from the selected hospital. The removal percentage of TDS, COD, BOD, and turbidity were determined according to the formula given in Eqs. (1 to 4 for each parameter (Alsultani et al., 2023b), respectively.

$$\text{TDS removal (\%)} = \frac{TDS_0 - TDS_T}{TDS_0} \tag{1}$$

Where, TDS_0 and TDS_T are the total dissolved Oxygen at time $= 0$ (initial) and at t (reaction time, t), respectively.

$$\text{BOD removal (\%)} = \frac{BOD_0 - BOD_T}{BOD_0} \tag{2}$$

Where, BOD_0 and BOD_T are the biochemical oxygen demand at time $= 0$ (initial) and at t (reaction time, t), respectively.

$$\text{COD removal (\%)} = \frac{COD_0 - COD_T}{COD_0} \tag{3}$$

Where, COD_0 and COD_T are the chloride content at time $= 0$ (initial) and at t (reaction time, t), respectively.

$$\text{Cl removal (\%)} = \frac{Cl_0 - Cl_T}{Cl_0} \tag{4}$$

Where, Cl_0 and Cl_T are the Chemical oxygen demand at time $= 0$ (initial) and at t (reaction time, t), respectively.

$$\text{Turbidity removal (\%)} = \frac{C_0 - C_T}{C_0} \tag{5}$$

Where, C_0 and C_t are turbidity registered (in NTU) at time $t = 0$ (initial) and at t (reaction time), respectively.

2.5 Cost Analysis

The expenses associated with operating a wastewater treatment process include electricity, sludge disposal, chemical use, labor, equipment, and maintenance. The primary running expenses in the EC process are power and electrode material. The following formulas were used to determine the total operating costs [28]:

Total operating cost = a Cenergy+ b Celectrode (6)

Cenergy = U I RT / V (7)

Celectrode = Mw I RT / z F V (8)

Where the variables Cenergy, Celectrode, a, b, U, I, RT, V, Mw, z, and F represent the energy intake for each cubic meter of wastewater (kWh/m3), the electrode intake for treating 1 m^3 of wastewater (kg/m^3), the total electricity costs (about 0.075 US$/kWh), the cost of iron or aluminum (2.5 US$/kg), voltage, current intensity, EC electrolysis time, the working volume of hospital wastewater, the molecular weight of aluminum (26.98 g/mol), the amount of electrons moved (3), and the Faraday constant (96500 C/mol), respectively. To make an accurate comparison with conventional coagulation, the price of aluminum sulfate powder, which includes dissolution charges, is 10 US dollars per kilogram. The cost of operations was calculated using the prices that were obtained from the Iraqi market in 2024.

3. Results and dissection

3.1 The Effect of pH Variation

In this test, different pH values were taken, such as 4, 5, 6, 7, 8, 10, and 12, with a treatment time of 15 minutes, a voltage of 20 volts, a distance between the electrodes of 2 cm, and several stirring speed of 150 rpm. From Figure (2), it can be seen that the percentage of removal efficiency increases with an increase in the amount of pH and for all factors targeted during this research (TDS, BOD, COD, Cl, and Turbidity). Also, a clear stability of all the results can be seen when the pH = 7. This stability can be explained by the fact that the ratio of the acidic water has reached the optimum level (Thair et al., 2018; Afan et al., 2024). Thus, it can be appreciated that all indicators have reached a state of equality in the treatment. Therefore, pH 7 will be the approved number for the rest of the tests. It is worth noting that the removal rate varied for each indicator separately. This can be explained by the ability of pH to affect treatment efficiency and for each indicator. Through the comparison made between the removal percentages for all indicators shown in Figure (5), the removal efficiency percentage of the TDS, BOD, COD, Cl, and Turbidity indicators ranged from approximately (56.5% - 82.4%), (51.7% - 94.7%), (47.1% - 88.5%), (56.5% - 86.2%), (36.8 – 86.2%), respectively.

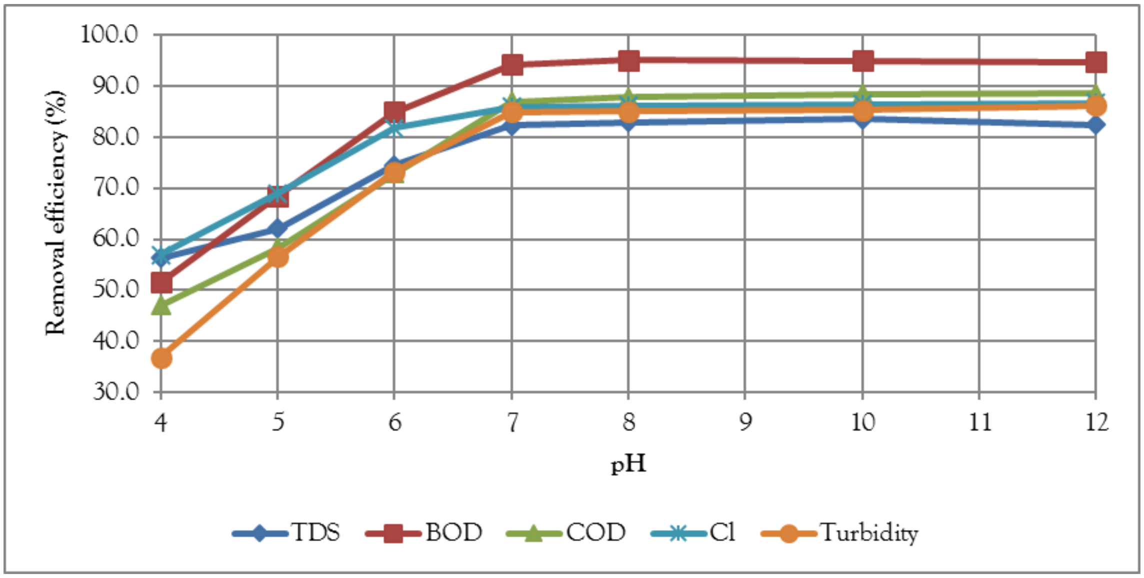

Figure 2: Removal efficiency comparative under pH variation.

3.2 The Effect of Treatment Time Variation

Several treatment times were used in this test: 15 min, 30 min, 45 min, and 60 min. A pH of 7 was used during the treatment period, along with 20 volts, 2 cm between the electrodes, and 150 rpm of stirring speed. Figure (3) shows that for all parameters targeted (TDS, BOD, COD, Cl, and Turbidity), the percentage of removal efficiency increases as treatment duration increases. Additionally, as the treatment duration reaches 45 minutes, a definite stability of all the benefits is evident. The fact that the water treatment ratio has achieved the acceptable level (Amin et al., 2024) helps to explain this stability. As a result, it is clear that all indicators have attained parity in the course of treatment. Consequently, 45 minutes will be the authorized amount of time for the remaining examinations. It is important to remember that the elimination rate differed for every indicator on its own. This can be explained by the fact that each indicator and treatment duration have an impact on each other's effectiveness. The removal efficiency percentage of the TDS, BOD, COD, Cl, and Turbidity indicators ranged from roughly (62.0% - 89.6%), (75.6% - 95.0%), (51% - 94.5%), (38.5% - 91.7%), and (42.4% – 88.7%), respectively, based on the comparison of the removal percentages for all indicators.

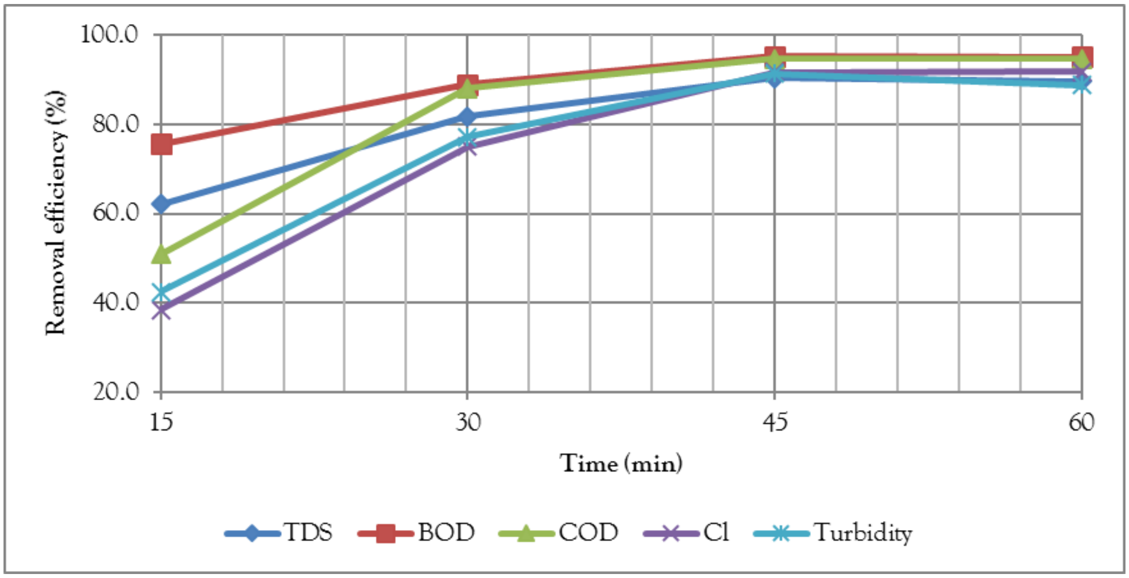

Figure 3: Removal efficiencies comparative under treatment time variation.

3.3 The Effect of Voltage Variation

In this experiment, various voltage levels 10, 15, 20, and 25 volts as well as a pH of 7, 45 minutes of treatment, a distance of 2 cm between the electrodes, and 150 rpm mixing speed were used. As the voltage value increases, Figure (4) illustrates that the percentage of removal efficiency rises for all the parameters examined in this study (TDS, BOD, COD, Cl, and Turbidity). When the voltage hits 20 volts, all of the results also exhibit a noticeable stability. The percentage of the water has reached the ideal treatment level, which explains this stability (Xu et al., 2024). It is therefore evident that all indicators have attained a level of parity in the course of treatment. For the remainder of the testing, 20 volts will be the permitted voltage. It is noteworthy that the rate of removal differed for every indicator on its own. This makes sense given that voltage might have an impact on each indicator's performance and treatment efficacy.

The TDS, BOD, COD, Cl, and Turbidity indicators obtained the maximum removal efficiency percentage when compared to the change in other parameters (pH and treatment time). The ranges of these indicators were roughly 62% - 97.1%, 75.6% - 98.9%, 78.2% - 96.6%, 83.7% - 98.1%, and 74.1 - 97.4%, respectively.

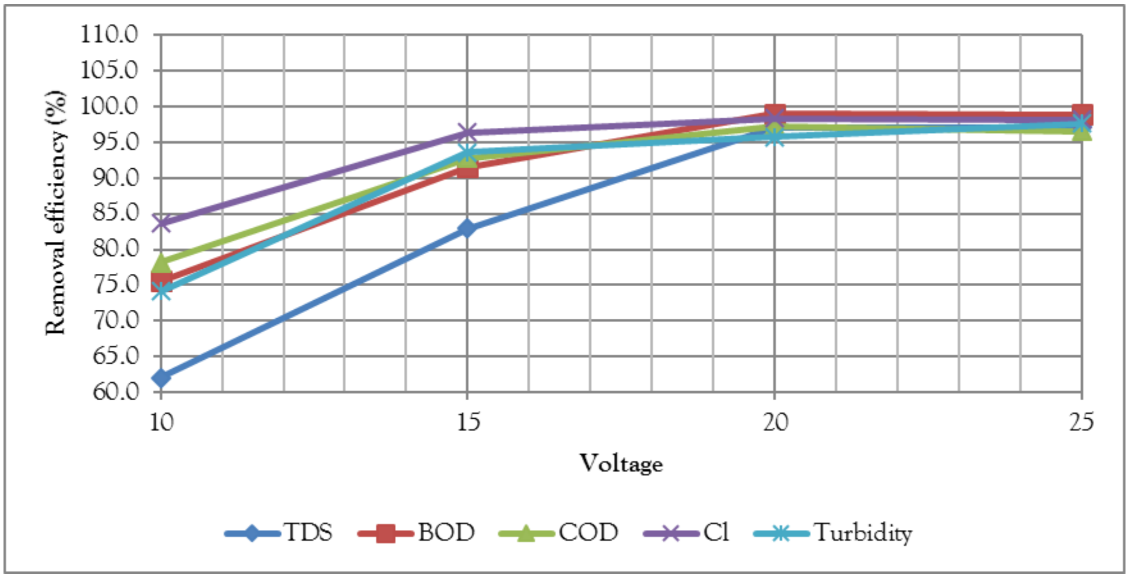

Figure 4: Removal efficiencies comparative under treatment voltage variation.

3.4 The Effect of Electro-rode Distance Variation

In this case, several electrode distances such as 2, 3, and 4 cm, as well as a pH of 7, 45 minutes of treatment, 20 volts of power, and 150 rpm of stirring speed were used. Figure (5) shows that for all the parameters examined in this study (TDS, BOD, COD, Cl, and Turbidity), the percentage of removal efficiency falls as road distance increases. This decline in water treatment effectiveness can be explained by the fact that the positive and negative electrodes and wasted water lose some of their concentration as the treatment electrodes are farther apart (Hasan et al., 2024). For any extra testing, a separation of 2 cm will be the authorized value. It is noteworthy that the rate of removal differed for every indicator on its own. This can be explained by the fact that each indicator's and treatment efficiency's rod spacing can vary. By comparing the removal percentages of each indicator, it was possible to determine that the removal efficiency percentages of TDS, BOD, COD, Cl, and Turbidity ranged from roughly (85.1% - 66.0%), (98.0% - 78.9%), (95.9% - 76.2%), (96.2% - 78.8%), and (96.4 – 67.9%) respectively, for took distances of (2-4) cm.

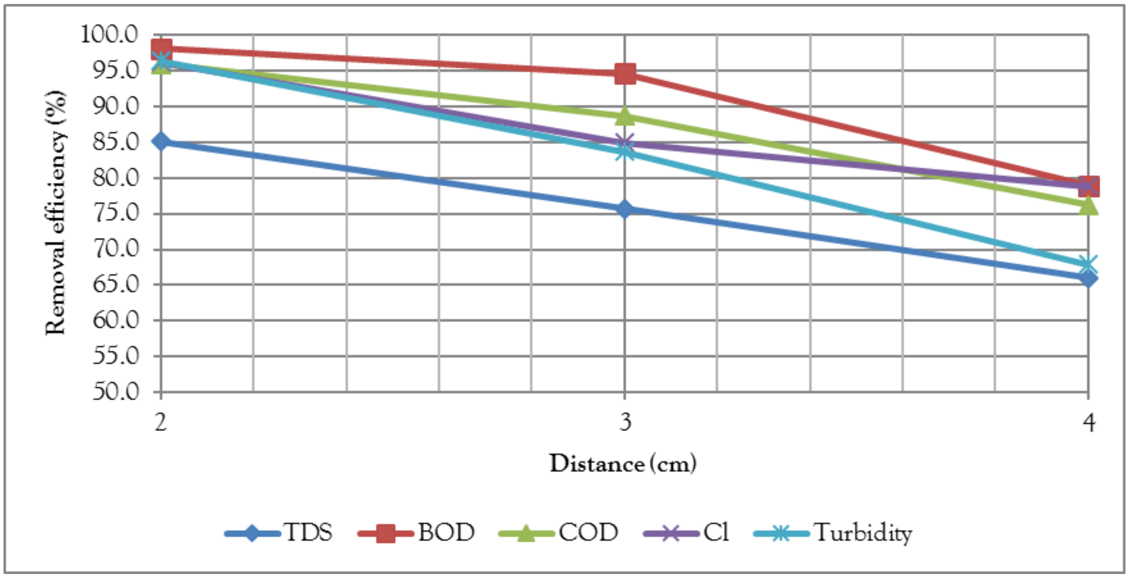

Figure 5: Removal efficiencies comparative under rode distance variation.

3.5 The Effect of Stirring Speed Variation

Various stirring rates, including 100, 150, and 250 rpm, a pH of 7, a 45-minute treatment period, a voltage of 20 volts, and a 2 cm spacing between electrodes were used in this experiment. Figure 6 illustrates how, for all criteria examined in this study (TDS, BOD, COD, Cl, and Turbidity), the percentage of removal efficiency rises with an increase in stirring speed from 100 to 150 rpm and falls with an increase to 250 rpm. The explanation for this decline in water treatment efficiency is that the rising rotation speed causes the treatment electrodes in the treatment vessel to become less concentrated in their efforts to treat the water (Ebba et al., 2022; Salahaldain et al., 2023). Thus, the experiment that will be administered will be permitted to run at 150 rotation cycles per minute. It is important to remember that the elimination rate differed for every indicator on its own. This can be explained by the fact that each indicator's and treatment efficiency's stirring speed can vary [28]. The removal efficiency percentage of the TDS, BOD, COD, Cl, and Turbidity achieved roughly (97.3%), (97.9%), (96.5%), (96.6%), and (95.5%), respectively, for stirring speed of 150 rpm, based on the comparison of the removal percentages for all indicators. At last, the ideal parameters for treating wastewater can be determined to be pH = 7, Time = 45 min, Voltage = 20, electrode spacing = 2 cm, and Stirring speed = 150 rpm.

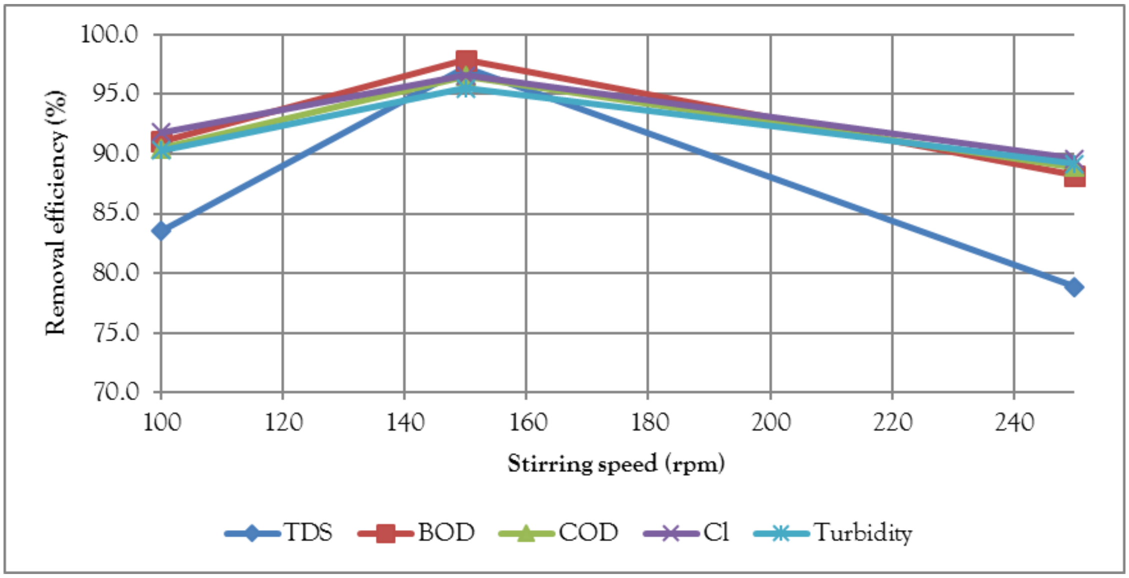

Figure 6: Removal efficiencies comparative under stirring speed variation.

3.6 Conventional Test

Numerous alum ratios, ranging from 5, 10, 15, 20, and 25 gm/L, were used in this experiment to determine the removal effectiveness of waste water. As the amount of alum increases, Figure (7) shows that the percentage of removal efficiency improves for all components that were studied in this research (TDS, BOD, COD, Cl, and Turbidity). When the alum reaches the percent of 15 gm/L, all the data also clearly stabilize. The fact that the acidic water ratio has achieved its ideal level helps to explain this stability. As a consequence, it is clear that all indicators have attained parity in the process of treatment. Anything over that causes the sample to become distorted further and converts into salts (Alfatlawi and Alsultani , 2019; Aydin et al., 2019). Therefore, the ideal amount of alum to use when the experiment's results are in line with earlier investigations is 15 gm/L (Majumder et al., 2021; Alsultani and Khassaf, 2022). The TDS, BOD, COD, Cl, and turbidity indicators' removal effectiveness percentages ranged from roughly (56.6%), (77.5%), (73.3%), (50.6%), and (55.0%), respectively, based on a comparison of the removal percentages for all indicators.

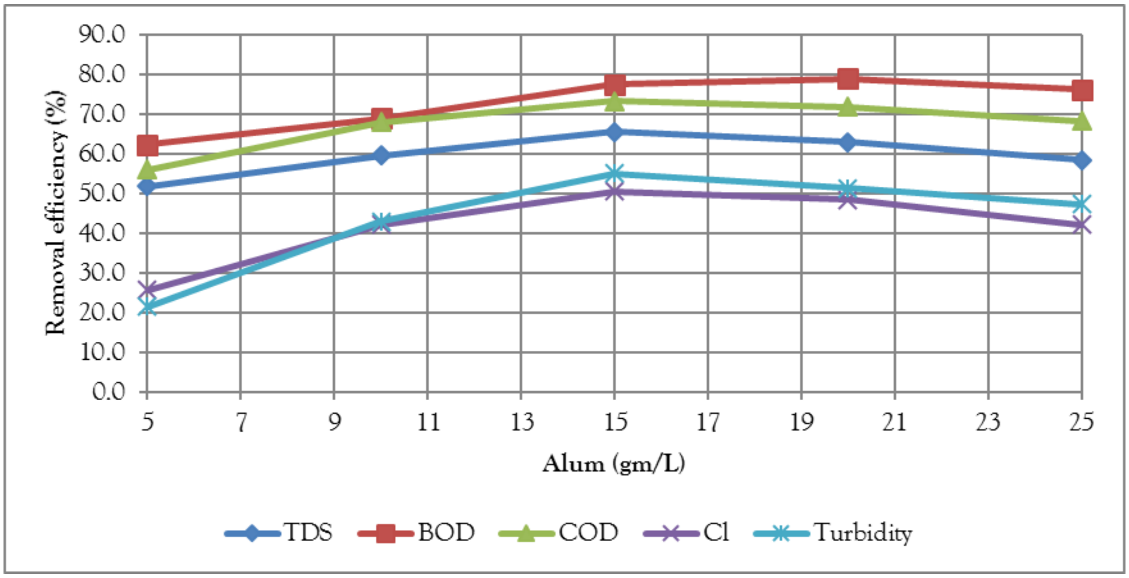

Figure 7: Removal efficiencies comparative under different Alum percent.

3.7 Comparison between EC and CC

Based on the above-mentioned experiments, the comparison will be made is presented in Table 4. The comparison results indicated that the EC method was superior to the CC method in terms of removal efficiency for all parameters that were targeted in this study. The superiority rates for the first method relative to the second method TDS, BOD, COD, Cl, and Turbidity were 48.4%, 26.3%, 31.6%, 90.8%, and 73.5%, respectively. The results obtained show that aluminum hydroxide, which is produced by EC process, has the best rates of contamination removal and is successful in alkaline media as opposed to acidic media, where alum performs better. The explanation for this is that EC process can produce several aluminum hydroxides, which increase precipitation naturally (Alfatiawi et al., 2020; Kumari et al., 2020; Yánes et al., 2021).

Table 4: Comparison between EC and CC.

Treatment Method	TDS removal %	BOD removal %	COD removal %	Cl removal %	Turbidity removal %
EC	97.3	97.9	96.5	96.6	95.5
CC	65.6	77.5	73.3	50.6	55.0
Superiority rates*	48.4	26.3	31.6	90.8	73.5

*Removal efficiency of the EC method relative to the CC method.

3.8 Operational cost outcomes

Table 5 is listed the total operation cost (USD/L) for EC and CC process according to the dose of coagulants. It can be noted that the cost of treating hospital wastewater using the electrocoagulation method is less than the traditional method special in the optimal condition of EC process (15mg/L aluminum dose, 20 v) and CC process (15 mg/L alum dose) where the optimal costs were 0.131 USD/L for EC and 0.162 USD/L for CC. This indicates that there is no benefit in using the traditional method relatively. The extracted operating costs are consistent with previous studies (Rozman et al., 2020; Shajari et al., 2020).

Table 5: Total Operation Cost According to the Dose of Coagulants

EC process			CC process	
Dose (mg/L)	Voltage (v)	Cost (USD/L)	Dose (mg/L)	Cost (USD/L)
3	10	0.115	5	0.146
12	15	0.123	10	0.153
15	20	0.131	15	0.162
20	25	0.145	20	0.171
-	-	-	25	0.183

4. Conclusion

At 20 volts, pH = 7, 150 rpm mixing speed, and 2 cm electrode spacing, all of the EC process's results exhibit a certain stability. It is clear from this that every indicator has attained parity in the process of treatment. Aluminum electrodes are a good option for hospital wastewater removal. In terms of time savings, removal effectiveness, and operational costs, electrocoagulation performs better than conventional coagulation.

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