

Treatment of Groundwater Using a Unique Reactor with Renewable Energy Processing

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Abstract: This study investigates the remediation of groundwater from the Al-Hashimia region in Babylon Governorate, utilising electrocoagulation (EC) technology as a viable and enduring purification method. Researchers examined the physicochemical characteristics of raw groundwater, encompassing total dissolved solids (TDS), electrical conductivity, total hardness (TH), and turbidity. A methodical analysis of the principal operational parameters influencing EC performance was performed, encompassing applied current density, electrode material, reaction time, pH, interelectrode distance, and mixing speed. The tests showed that the removal rates were very high under the best conditions: 91% for TDS, 91% for electrical conductivity, 92% for total hardness, and 92% for turbidity. The best treatment setup had a current of 0.8 A, aluminum-aluminum electrodes, a pH of 7.12, a reaction time of 80 minutes, an interelectrode distance of 1 cm, and a mixing speed of 500 rpm. These results show that electrocoagulation is a useful, reliable, and environmentally friendly method for improving groundwater quality. The treated water met quality standards for a range of uses, including drinking, watering plants, and industrial use. Overall, the study highlights the potential of EC as a cost-effective, adaptable solution for groundwater remediation in regions facing water quality challenges and an increasing demand for safe, sustainable water resources.

Keywords: Removal Efficiency; Operating Parameters; Purification Technique; Electrode Material; Total Dissolved Solids (TDS); Water Resources; EC Performance; Physicochemical Properties.

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1. Introduction

The Groundwater should be managed appropriately to reduce or eliminate toxins and achieve the desired level, thereby promoting sustainability [1]. The significant foreign substance in groundwater is colloidal components, which are pungent, hard, and turbid [8]. Coagulation is a compound treatment utilized before sedimentation in water and wastewater treatment. It

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is a cycle in which tiny pieces come together to make bigger ones. The main problems with this treatment method are that it doesn't work very well, it takes a long time to get out, and it makes you sleep a lot. Also, coagulation requires a lot of synthetic chemicals, such as those used for coagulation, flocculation, pH adjustment, and conductivity control. This makes the cycle too expensive [19]. A lot of new ideas have been looked at, including organic oxidation, chemical oxidation, advanced oxidation, nanofiltration, and adsorption.

Despite this, electrochemical innovations such as electro testimony, electro coagulation (EC), electro buoyancy (EF), electro oxidation (EO), and electro active remediation have received significant attention over the years. People know about them because they are easy to obtain and don't require many synthetic chemicals. Be that as it may, a large portion of the previously mentioned techniques have some significant disadvantages. For instance, natural oxidation is, without a doubt, a modest process, yet the presence of harmful or biorefractory compounds may prevent this method due to effluent pollution with natural compounds. Compound oxidation has low reaction rates and requires transportation and capacity for hazardous reactants. Progressed oxidation measures require high venture costs.

Nano-filtration and adsorption measures are generally inadequate to achieve this, and EO and electrodeposition methods require long treatment response times [13]; [12]; [4]. EC is another effective method for treating wastewater and removing pollutants. It works very well for cleaning wastewater from steam cleaners, pressure washers, material assembly, metal plating, and meat and poultry processors [17]. It also works well for cleaning up wastewater from mining, industrial clothing, municipal sewage, and palm oil effluents [18]. There are different responses at the cathode and anode in the EC framework. The coagulation of particles occurs in situ through several stages: Electrolytic oxidation at the conciliatory cathode (anode) produces coagulants. This weakens the poisons, suspends particles, and breaks up emulsions. The subverted stages then come together to form flocs.

The charged particles are pushed to the edge of the diffused double layer by the particles produced during the oxidation of the conciliatory anode. The charge-balancing of the existing ionic species can be achieved through the electrochemical breakdown of the conciliatory anode. Coagulation occurs when the electrostatic repulsion between molecules is reduced enough by these counter particles for van der Waals attraction to take control.

The floc that forms during coagulation makes a muck cover that holds and supports colloidal species in the water phase. The strong oxides, hydroxides, and oxyhydroxides create the surfaces that allow foreign substances to stick to them [14]; [10]. This examination presents EC measures for groundwater treatment in Al Hashimia district. The objectives of the flow study are to treat the groundwater in Al-Hashimia city, Babylon governorate, Iraq, utilizing the electrocoagulation process and to determine the optimal operational conditions for treatment.

2. Materials and Methods

2.1. Characteristics of Groundwater

Groundwater is collected from the Babylon governorate, Al-Hashimia township area, at a depth of 9 m. The groundwater characteristics are listed in Table 1.

Table 1: Characteristics of groundwater

Properties	Values
pH	7.12
EC (µs/cm)	60200
TDS (mg/l)	37128
Turbidity (NTU)	390
Total Hardness	550
CL (mg/l)	160
SO ₄ (mg/l)	45
Br(mg/l)	6.00
K(mg/l)	30
Na(mg/l)	110
Mg(mg/l)	11
Ca (mg/l)	50

2.2. Experimental Setup and Procedure

The experimental EC setup employed in this study is shown in Figure 1. The reactor was a glass-forming inline batch reactor. Researchers looked at various groundwater parameters, including TDS, electrical conductivity (EC), total hardness (TH), and turbidity. The experiment used a reactor that was 20 cm long, 15 cm wide, and 15 cm deep. The amount of treatment water used each time was 4.5 L. When both the anode and cathode were monopolar, six aluminium plates were connected in parallel to the power supply. The electrode size was 10 × 10 cm², the thickness was 0.1 cm, and the interelectrode gap was 1 cm. The electrodes were 100 cm² in area (10 cm wide and 10 cm long). The array of electrodes was submerged in the groundwater. The anode and cathode groups were connected to the negative and positive poles of a direct current power supply. The electrolyte mixture was stirred on a magnetic stirrer. and the positive pole of a DC power source [20].

A magnetic stirrer was used to mix the electrolyte. When an electric current was applied to the electrodes, anodic and cathodic reactions occurred at the inner electrode surfaces. This study used a DC power supply from China, the YIZHAN, which can output 0–40 V and 0–6 A. The effect of the applied current was examined at different current densities (0.2, 0.4, 0.6, 0.8, 1, and 1.2 A) over a cumulative reaction duration of 100 minutes. Accordingly, the ranges considered in the studies for reaction time (20-100 min), pH (5-11), inter-electrode distance (IED) (0.5-2 cm), and mixing Stirring speed (MS) were 250 and 750 rpm.

To make sure the experimental results were accurate and reliable, the best condition was repeated three times. This was confirmed by repeating the experiments. The YIZHAN programmable power supply maintained a steady output current throughout the experiment. After each run, the electrodes were thoroughly washed with distilled water [20]. The experiments took place in the lab, where the temperature was kept between 26 and 28 degrees Celsius. The pH of the groundwater was changed to the right level by adding concentrated hydrochloric acid and sodium hydroxide.

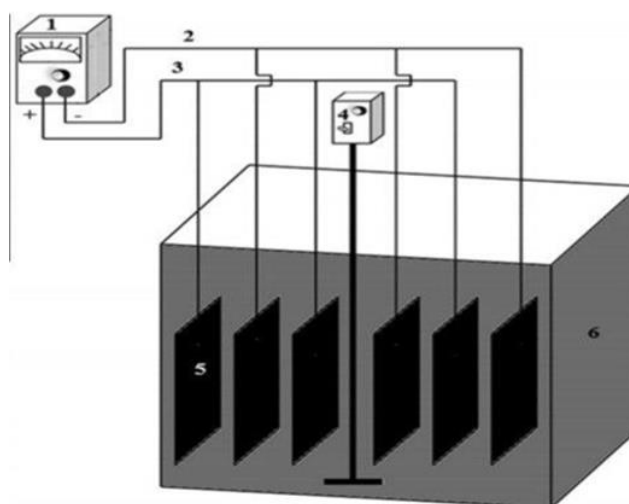


Figure 1: A diagram of the experimental setup: (1) Power supply for DC; (2) Cathode; (3) Anode; (4) Stirrer that works with machines; (5) Electrodes made of aluminium; (6) EC reactor

2.3. Parameter Analysis

Table 2 shows the methods used to measure groundwater pollutants and the devices used before and after treatment. The present study deals with the removal of TDS, electrical conductivity, TH, and turbidity from groundwater.

Table 2: Methods of analysis

Method	Parameters
pH meter -pHM84	pH
TDS meter (TDS-EZ, HM Digital)	TDS
HANNA HI-99301	Electrical conductivity
HACH 2100P	Turbidity
Gravimetric	Total hardness (TH)

Controlling the reactor rate during the EC process. The current study involved experiments to ascertain the percentage removal of total dissolved solids (TDS), electrical conductivity, total hardness (TH), and turbidity at different applied current densities ($I = 0.2, 0.4, 0.6, 0.8, 1.0, \text{ and } 1.2$) and varying reaction times (20, 40, 60, 80, and 100 minutes).

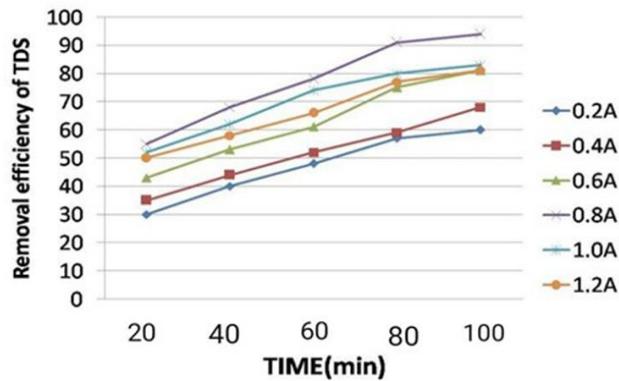


Figure 2: How the current used effects how well TDS is removed

Figures 2, 3, 4, and 5 show how the applied current (I) and reaction time affect removal efficiencies. The EC process works better when the reaction time is longer. The highest removal rates are at $I = 0.8\text{A}$ and $RT = 80$ minutes. The highest removal rates were 91% for TDS, 91% for electrical conductivity, 92% for TH, and 92% for turbidity.

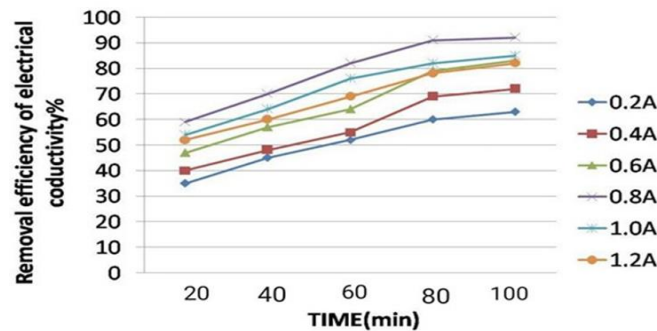


Figure 3: Effect of Current on Conductivity Removal Efficiency

After 80 minutes, there is a small, non-significant increase in removal efficiency, leading to increased energy consumption [16]. So, 0.8 A and 80 minutes were chosen as the optimal working conditions, consistent with previous studies.

2.4. Effect of pH

Previous studies have shown the importance of pH in water treatment using the EC method. The current study examined the influence of pH on the removal of TDS, electrical conductivity, total hardness (TH), and turbidity by varying the initial pH from 5 to 11, under optimal conditions of $Al/Al = 1$, $I = 0.8\text{ A}$, and a reaction duration of 80 minutes.

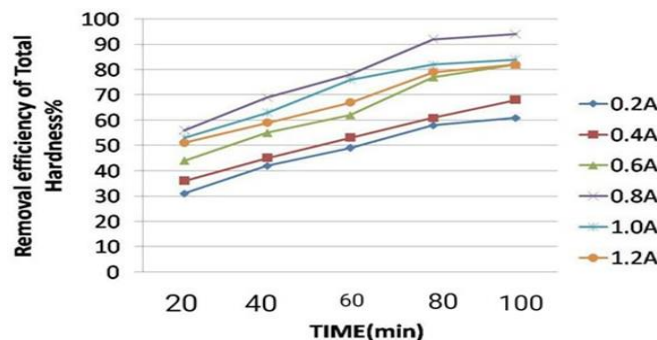


Figure 4: Effect of applied current on total hardness removal efficiency

Figure 6 shows that at pH 8, the removal efficiencies for TDS, electrical conductivity, TH, and Turbidity were only slightly higher at 91%, 93%, 92%, and 90%, respectively.

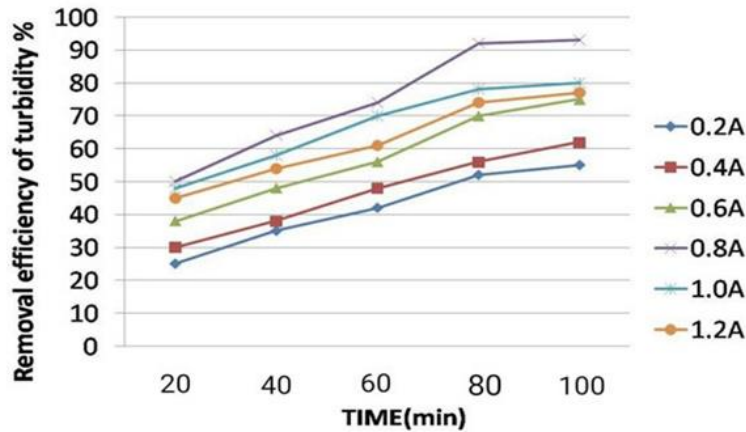


Figure 5: Effect of applied current on turbidity removal efficiency

The increase in pH levels is attributed to the presence of water electrolysis that led to the production of hydrogen and (OH) ions. After that, pH is thought to be stable, which may be because insoluble M(OH)₃ flocs and metal hydroxides form [2].

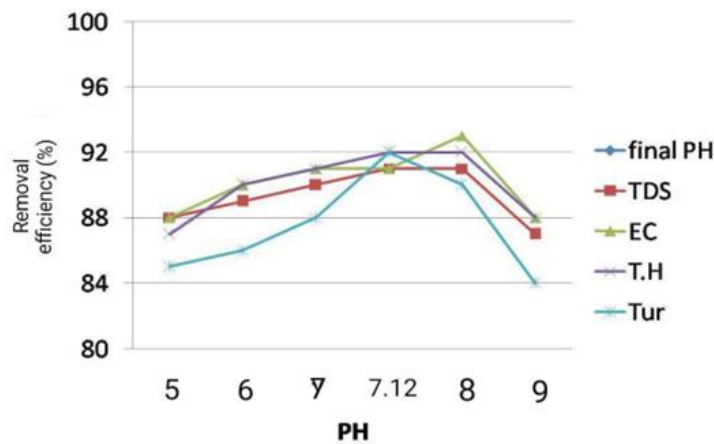


Figure 6: pH effect at optimal conditions

The results indicate diminished solubility of aluminium hydroxide at pH 4 and 5 in the acidic phase, and at pH 9, 10, and 11 in the alkaline phase. The optimal pH level identified in this study is consistent with these results. Normal pH is best for groundwater.

2.5. Effect of Inter-Electrode Distance

Setting up the electrode assembly is very important for getting a good electrode surface area and inter-electrode distance (IED). The resistance between two electrodes goes up when you move them farther apart. This, then, reduces the value of electrical current. But, as expected, when the distance between the electrodes increases, the ions and hydroxide polymers interact less. Literature reviews have demonstrated the influence of IED on removal efficiency in the EC method. The following equation governs the change in voltage drop (ηIR) [11]:

$$\eta IR == I.(d/s * k) \tag{1}$$

I use the specific conductivity in micro-Siemens per meter ($\mu S/m$), the active anode surface area in square meters (m^2), the electric current in Amperes (A), and the distance between the two electrodes in meters (m). If the anodic surface area and

solution conductivity remain constant, the voltage drop increases with increasing inter-electrode distance (IED), as shown in this equation [20].

The current study investigated the influence of IED at distances of 0.5, 1, 1.5, and 2 cm, utilising Al-Al, with an intensity of 0.8A, a duration of 80 minutes, and a pH of 7.12 as the optimal parameters, as depicted in Figure 7. The best results were obtained at a middle distance of 1 cm. The results were 90 to 91% for TDS, 92 to 91% for electrical conductivity, 90 to 91% for TH, and 88 to 92% for turbidity, with the distance changing from 0.5 to 1 cm.

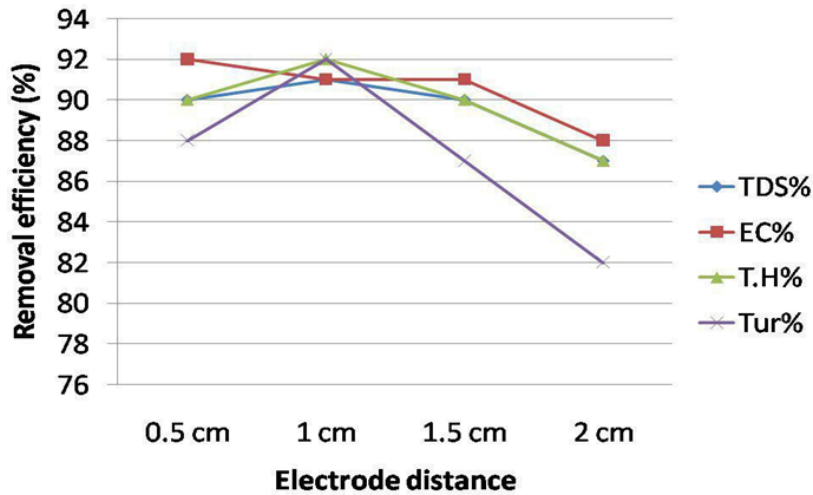


Figure 7: Effect of inter-electrode distance under optimal conditions

On the other hand, increasing the distance from 1.5 to 2 cm reduced the treatment's effectiveness. For TDS, it went from 90% to 87%; for electrical conductivity, from 91% to 88%; for TH, from 90% to 87%; and for turbidity, from 87% to 82%.

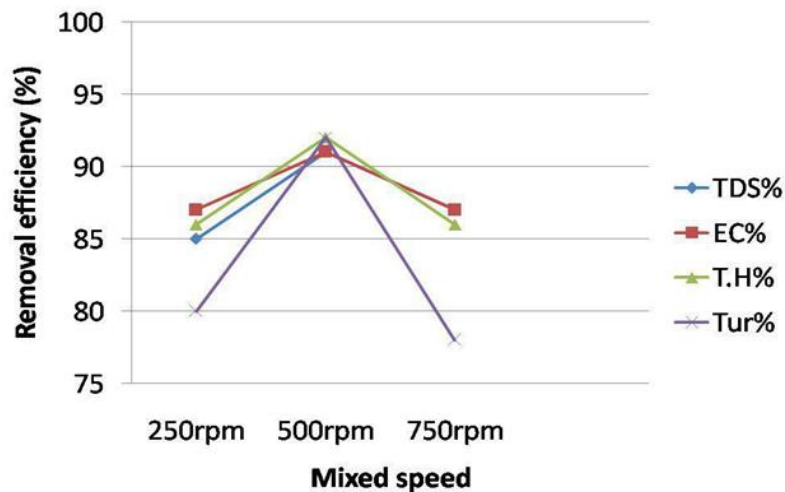


Figure 8: Effect of mixer speed under optimal conditions

Previous studies elucidated the impact of the final inter-electrode distance (IED) on contaminant removal efficacy, indicating that an increased IED resulted in diminished electrode attraction [5]; [9]. This was observed in the iron polymers produced, which disrupted the EC process.

Mixing stirring speed (MS) is an important part of the EC process. As the stirring rate increases, particles come together, become monodispersed, and clump. This makes precipitation and mass transfer easier [7]. When the stirring rate goes up, the opposite happens. If the stirring rate goes too high, the contaminants that form in the reactor will break down into smaller clumps that are hard to separate from the solution. This makes the treatment less effective. To examine the influence of agitation speed on

TDS, electrical conductivity, total hardness, and turbidity removal efficiency via the electrocoagulation process, stirring speeds of 250, 500, and 750 rpm were employed under optimal conditions: Al-Al, I = 0.8 A, RT = 80 min, and pH = 7.12.

The most effective treatment was at 500 rpm, which was higher than 250 rpm. The findings indicate that the efficiency of TDS removal has risen from 85% to 91%, electrical conductivity from 87% to 91%, TH from 86% to 92%, and turbidity from 80% to 92%. When the agitation speed was raised from 500 to 750 rpm, the results were worse. The TDS removal efficiency dropped to 87%, the electrical conductivity to 87%, the TH to 86%, and the Turbidity to 78%, as shown in Figure 8. This means that stirring too quickly can break the flocks [6]; [15]; [3]. Also, the agitator uses more energy the faster it stirs, which increases the cost. So, 500 rpm was chosen as the optimal stirring speed.

3. Conclusion

It is very important to treat groundwater so that homes, farms, and businesses have clean, safe water. Groundwater can contain pollutants, such as high levels of total dissolved solids (TDS), electrical conductivity, total hardness (TH), and turbidity. These factors can significantly affect water quality, making it unsafe to drink. So, researchers need effective ways to purify the water, removing these contaminants and improving its quality. This study assessed the effectiveness of electrocoagulation (EC) using iron electrodes for the extraction of groundwater pollutants from aqueous environments. Electrocoagulation is regarded as an effective and eco-friendly water treatment process, as it reduces the need for chemical additives and generates less sludge than traditional treatment techniques. The study also examined how different operational characteristics affected pollutant removal.

The following parameters were measured: current (I), reaction time (RT), solution pH, inter-electrode distance (IED), and stirrer speed (rpm). By changing these things in a planned way, the best conditions for removing contaminants were found. The EC process worked best when the current was 0.8 A, the reaction time was 80 minutes, the pH was 8, the temperature was 25°C, the distance between the electrodes was 1 cm, and the stirrer speed was 500 rpm. Also, the electrocoagulation technique worked quite well for treating groundwater when a monopole electrical connection with aluminium electrodes was used. In these best-case scenarios, the removal rates were 91% for total dissolved solids, 91% for electrical conductivity, 92% for total hardness, and 92% for turbidity. These high removal rates indicate that the EC procedure is effective at removing key groundwater pollutants. In general, this study's results show that electrocoagulation is a reliable and long-lasting method for improving groundwater quality and treating contaminated water across a range of environmental settings.

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Data Availability Statement: The dataset used in this study concerns the analysis of groundwater treatment using a renewable energy-assisted reactor system. Relevant data supporting the findings of this research can be obtained from the corresponding author upon reasonable request, subject to institutional and ethical considerations.

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Conflicts of Interest Statement: The authors declare that there are no conflicts of interest associated with this work, and all sources of information, citations, and references have been properly acknowledged in accordance with academic standards.

Ethics and Consent Statement: The study was conducted in compliance with established ethical guidelines.

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