Research Article

Investigation on Solar-Powered Electrocoagulation (SPEC) for the Treatment of Domestic Wastewater (DWW)

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Received 11 March 2022; Revised 24 March 2022; Accepted 28 March 2022; Published 7 April 2022

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Solar-powered electrocoagulation (SPEC) was used for the treatment of domestic wastewater by using aluminum electrodes. As a single-unit process for treating household wastewater, the EC is solar-powered. The aim of this research was the removal of chemical oxygen demand (COD), TDS, and turbidity by SPEC. Optimization of various operating parameters such as pH, voltage/current, electrode gap, and pollutant concentration was first performed using direct electrical current. By using batteries and charge controllers with panels, the SPEC reactor has achieved consistent and efficient performance. The effects of COD, turbidity, and TDS exclusion of functioning parameters such as density (8–40 A/m²) and detention time (5–30 min) were examined. The COD reduction was 85%, and removal efficiency of TDS and turbidity was 70.18% and 87.4%. The results have shown the technical feasibility of SPEC design as a potential method for domestic wastewater treatment by electrocoagulation. Further analytical study of sludge was also performed by FTIR and XRD analysis.

1. Introduction

The lack of adequate water supplies and the release of commercial, agriculture, or domestic wastewater in waterbodies emphasize the importance of treating water and wastewater [1, 2]. One of the most severe environmental issues has been urban pollution; numerous domestic and industrial activities create wastewater streams that contain various hazardous pollutants; these pollutants have a very harmful influence on both human beings and the organisms when discharged to the environment [3, 4]. These domestic wastewater are considered as one of the major source of wastewater contamination [5]. It may therefore contribute to serious pollution in water; hence, domestic wastewater is inevitably treated and used again in an environment before it is discarded [6]. The wastewater is disposed of without treatment in the environment which leads to several serious problems like pollution by surface and groundwater [7]. Therefore, the treatment of domestic wastewater becomes very
important not only for the environment but also to fulfill the water requirement for domestic purposes [8, 9]. The treatment methods are commonly categorized as physical, chemical, and biological treatment [10, 11]. Several treatment techniques, namely, coagulation, sedimentation, adsorption, membrane filtration, and reverse osmosis, were the most preferred treatment techniques [12, 13]. Of all these treatment methods, the adsorption technique is considered as one of the most preferable methods for the removal of toxic pollutants from the wastewater [14]. Many industries, namely, the paint industry, textile industry, and paper and pulp industries, are consuming more dyes for their manufacturing process which results in huge quantities of wastewater [15, 16]. Several researchers conducted adsorption studies using biosorbent produced from agro waste, marine seaweeds, and dry leaves [17, 18]. But the characteristics of domestic wastewater are entirely different from industrial wastewater [19]. A low-cost treatment method is preferred for treating domestic wastewater. At present, SPEC has been a quick, successful, and eco-friendly method that has attracted considerable attention. The SPEC method offers many advantages such as flexibility, simple operation and shorter reactive time, no chemicals, and lower sludge rates that sediment quickly [20]. According to Alfredo et al., lower densities and lesser flow levels with higher energy utilization are achieved with the reduction of contaminants. Generally, iron (Fe) or aluminum (Al) electrodes are used in the SPEC process, and good results were found in aluminum depletion efficiency under optimum conditions [21]. SPEC systems have been successfully studied for the treatment of water and wastewater, particularly for COD removal by SPEC with DC supply from the photovoltaic panel directly [22]. This is a promising tool for remote community applications. Low maintenance and reduced PV panel cost in combination with a lightweight and durable design make this a great solution for deposited and tiny wastewater collection. The photovoltaic (PV) systems are run by an electricity supply that is clean and sustainable because of the universality of solar power [23]. PV systems use materials to generate direct electricity from sunlight through photophysical processes. Depending on the technology, PV cells are commonly produced from sunlight [24]. The major objective was to study the application of uninterrupted mode solar-powered EC for the eradication of pollutants from domestic wastewater [25]. Tests were carried out to observe the causes of wastewater operating parameters, such as current density and detention time on deduction in COD, turbidity, and TDS [26]. The present study focused on the optimization of the working circumstances of the SPEC process.

2. Reaction of Aluminum Electrode in Electrocoagulation

Aluminum is commonly used for electrode material in the EC phase. The major reactions are as follows:

\[
\begin{align*}
\text{anode: } & Al(s) \rightarrow Al^{3+} + 3e^- \\
\text{cathode: } & 3H_2O + 3e^- \rightarrow 1.5H_2(g) + 3OH^- \\
\end{align*}
\]

(1)

The generated \( Al^{3+} \) and \( OH^- \) react with each other to form \( Al(OH)_3 \):

\[
Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \\
\]

(2)

Freshly formed amorphous \( Al(OH)_3 \) clean flocs exhibit large shell areas which are favorable for rapid adsorption of soluble organic compounds and for trapping colloidal particles [27]. The hydrogen bubbles are formed by the cathode and it is transferred as an electro floating agent from the aqueous media; due to this process, sedimentation and floatation take place in the effluent [28].

3. Materials and Methods

3.1. Sample Collection and Characterization. In this research, domestic wastewater (DWW) was collected from the interconnected sewer of the canteen and hostel at Bule Hora University, Ethiopia. The samples were collected by the grab sampling method [29]. The collected wastewater was stored, and the water quality characteristics were analyzed. The DWW characteristics are shown by average values and ± variation (Table 1).

3.2. Experimental Setup. The EC reactor used in this study consisted of a 5 L glass beaker with two aluminum electrodes (17 cm × 9 cm × 0.2 cm) having grid powered volume of 1.5 L (Figure 1). The DC power converter or monocrystalline silicon PV panel with a maximum capacity of 40 w was used as a source of power supply. It can be used with or without a charge controller. The dimension of the panel was \((1340 \times 650 \times 30)\ mm\), and the weight was 10 kg. The battery was sealed, and it is rechargeable in combination with panel [30]. In the experimental setup, the PV panel was attached to the electrical DC power supply. The chemical process has occurred for EC supply in the same experimental setup [31]. The experimental setup was placed on the balcony of the college. The charge controller battery system with a capacity of 12 V was used for the entire process. This controller was used to prevent overcharging of the battery. On continuous mode, DWW samples were carried out with EC experiments [32]. A feed tank at predetermined flow rates was used for feeding each sample to the EC units for detention time from 5 to 30 min. Specific densities of 8–40 A/m² are applied for each period of detention [33]. The DWW was collected in a glass beaker after the completion of EC process and retained for 30 minutes in the EC unit. Usual characteristics have been checked for the settled sample.

The flow rate is calculated by

\[
Q = \frac{v}{t},
\]

(3)

where \( Q \) denotes flow rate (L/h), \( t \) indicates detention time (min), and \( v \) is the quantity of effluent treated (L). The electrode was eliminated from the EC unit and cautiously sanitized before and after a run with tap water. The
electrodes are inserted for 20 min into the device and HCL solution. The distilled water washed the unit and electrode.

3.3. Analytical Method. The samples are obtained and examined regularly for their characteristics and the prominent effluent. The digital pH meter (Elico-442) was used to measure the pH. The conductivity was determined by a conductivity meter (Elico-125). The nephelometer was used to quantify the turbidity level (NTU), the COD was determined by the closed reflux method, and TDS was measured by a TDS meter [34]. Table 2 summarizes the time with respect to flow rate.

The removal efficiency was calculated by

\[
\text{removal efficiency} (\%) = \left( \frac{C_o - C}{C_o} \right) \times 100
\]

where \(C_o\) is the initial turbidity (NTU) and \(C\) represent the final turbidities (NTU).

4. Result and Discussion

4.1. Influence of Density and Detention Time. The electrode gap was studied by using DC as a power source; with this process, the following components like initial pH and current and initial organic loading were studied [35]. The optimum significance for every parameter is determined based on removal of organic pollutants and turbidity. The specific EC tests were used to quantify the current density and hydraulic detention period [36]. The results show that the current density and detention period have beneficial effects on the EC process. Figure 2 shows that the detention period of COD was important for 10 min and 15 min, and current density ranged from 26 A/m² to 40 A/m² for hydraulic detention. For the period of hydraulic detention, the removal of the COD was relatively less than 5 min and 10 min because of less Al(OH)₃. Due to the increase in current density, the dissolution capacity was increased. The results of the electrolysis process were highlighted many times during the removal process [37].

Figure 3 shows the 10–30 min hydraulic retention period with different densities of current (12 A/m²–40 A/m²), and the removal of turbidity was significant. The hydraulic retention time of 5 min is relatively less for removing turbidity [38]. The turbidity elimination increased from 5 A/m² to 40 A/m² from 15.71% to 87.14%. If the flow rate increases in the same amount, the turbidity elimination efficiency decreases.

Figure 4 shows that at 70.18%, the detention time was 20 min, and the removal of TDS was observed. Dissolved compounds flow into the water surface with the cathode released hydrogen gas, so the performance of disposal was less than that of other parameters.

The pH increases mostly when pH is in acidic condition, and the pH decreased when EC used aluminum as an electrode. EC therapy refers to wastewater treatment, which prevents the pH in the effluent [39]. Figure 5 illustrates the optimum conditions for the maximum pollutant removal.

4.2. Sludge Analysis. The FTIR dry sludge spectra are displayed in Figure 6. FTIR spectrum sludge vibration reveals the –OH groups at a distance of the peak at 1043.49 cm⁻¹ in precipitation. The C-H starching of alkanes induced peaks of 2387.87 cm⁻¹. The high 775.38 cm⁻¹ spectra indicates the presence of acetamides. All other bends represent the metallic groups attributed to vibration. These functional groups reflect originally proposed organic compounds and the oxide of wastewater.

X-ray diffraction analysis of sludge shown in Figure 7 demonstrates the morphological nature and texture of sludge which shows that sludge contains both crystalline and amorphous compounds. In sludge, due to iron electrode dissolution, broad hump arises with no sharp characteristic diffraction peaks in the range of 10–20°.
Spacing represents the amorphous nature of ferric sludge [40], while the sharp peaks begin from the crystalline fragments. Peaks between 20 and 30° show silicate compounds and peaks at 30° and 50° represented the iron oxides because of electrode metal ions.

5. Conclusion

This work demonstrated that the use of the SPEC method for the treatment of DWW could be possible on a laboratory scale. In this analysis, the EC system with the aluminum electrode is processed with parameters of wastewater. The DC power supply was initially used to optimize electrodes. In combination with battery control and charge control, the PV panel used in the system improved EC’s performance because the power supply did not fluctuate. In the most favorable circumstance, the results proved the maximum turbidity reduction of 87.4%, TDS of 70.18%, and COD of 85%. The pH of the effluent is achieved from 4 to 6.8; therefore, there is no need for further treatment for pH correction. The XRD and FTIR for sludge analysis showed that high sludge metal content is useful for catalysis. Compaction properties allow sludge to be easily disposed of and utilized. Therefore, it showed that the pilot-scale SPEC is practicable for the remediation of DWW on a laboratory scale.

Data Availability

The data used to support the findings of this study are included within the article.
Disclosure

This study was performed as a part of the employment of Samara University, Ethiopia.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors appreciate the support from Samara University, Ethiopia. The authors thank Bule Hora University, Ethiopia, for the technical assistance to complete this experimental work.

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