Optimization of Electrocoagulation for Reducing the Organic Load of Landfill Leachate: A Case Study of the Tehran Kahrizak Landfill

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ABSTRACT

The leachate generated at municipal solid-waste landfills contains complex, recalcitrant, and potentially toxic constituents; therefore, it should be treated before discharge to the environment and groundwater. In this study, leachate samples were collected from the Aradkouh waste management complex (Kahrizak, Tehran, Iran) and treated using an electrocoagulation (EC) process. The effects of initial pH (4, 7, and 9), current density (25.31, 37.97, and 50.63 mA/cm²), reaction time (15–60 min), and inter-electrode distance (1, 2, and 4 cm) were evaluated for the removal of chemical oxygen demand (COD), total dissolved solids (TDS), and total suspended solids (TSS). Experiments were conducted in a plexiglass batch reactor equipped with three aluminum electrodes and powered by a direct-current supply. Under the optimum conditions (pH 9, 50.63 mA/cm², 60 min, and 2 cm), removal efficiencies of COD, TDS, and TSS reached 37.8%, 34.3%, and 40.2%, respectively. In addition, concentrations of Cr, Pb, Zn, and Fe were determined in raw and treated leachate using atomic absorption spectrometry, with corresponding removal efficiencies of 43.75%, 41.43%, 37.50%, and 27.23%. Overall, the results indicate that electrocoagulation can serve as an effective pretreatment option for reducing the pollutant load of highly concentrated landfill leachate.

KEYWORDS

Landfill leachate; Electrocoagulation; Current density; Aluminum electrodes; Heavy metals

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1. Introduction

Municipal landfill leachate is a complex and persistent effluent that typically contains high organic load, suspended solids, and heavy metals; therefore, discharging it without treatment may contaminate surface and groundwater and degrade soil quality, making compliance with environmental discharge standards essential [1]. Although biological, physical, and chemical approaches are used for leachate treatment, purely biological processes often face practical performance limitations; thus, physicochemical processes are commonly recommended, and membrane processes, chemical coagulation, and advanced oxidation have been applied as complementary options to target recalcitrant pollutants [2]. Electrocoagulation (EC) is a physicochemical process in which an electric current applied to metallic electrodes (typically aluminum or iron) generates coagulant species in situ, promoting pollutant removal via charge neutralization, floc formation, and adsorption and thereby reducing turbidity, TSS, a fraction of COD, and meaningful amounts of heavy metals [3,4]. EC performance is strongly dependent on operating conditions-particularly pH, current density, reaction time, electrode material/configuration, and interelectrode distance-whose optimization influences removal efficiency as well as energy consumption, electrode dissolution, and sludge production [5]. Accordingly, this study evaluates feasibility and optimizes aluminum-electrode EC for leachate from the Aradkouh Waste Management Complex (Kahrizak, Tehran) by systematically investigating these parameters to achieve effective COD, TDS, and TSS removal, heavy-metal reduction, and acceptable energy consumption.

2. Methodology

Leachate was collected from Kahrizak Landfill (Tehran, Iran) during winter 1400 to autumn 1401 using grab sampling at the leachate collection channel/outlet (mid-depth: approximately 20-30 cm below the surface). Samples were transferred to the Environmental Laboratory of Kharazmi University, stored at 4 °C, and analyzed as soon as possible. Electrocoagulation tests were performed in a batch plexiglass reactor (11 × 11 cm; effective volume 605 cm³) equipped with three aluminum plate electrodes (15.1 × 7.9 cm; thickness 0.2 cm) in a monopolar configuration (middle anode; side cathodes) and electrode gaps of 1–4 cm. Operating conditions included currents of 2–4 A (25.31–50.63 mA/cm²), initial pH of 4, 7, and 9 (adjusted with H_2SO_4/NaOH), and reaction times of 15–60 min. After each run, samples were settled for 20 min and collected from the reactor mid-depth. COD, TSS, and TDS were measured using APHA 5220-D, 2540-D, and 2540-C, respectively. Heavy metals were analyzed by flame AAS after acid digestion, with QA/QC based on blanks, spiked samples, and replicate measurements (recovery: 90–110%) [6]. Experiments were conducted in duplicate (n = 2), and results were reported as Mean ± SD; electrical energy consumption was calculated from recorded voltage and current.

3. Results and Discussion

Electrocoagulation (EC) performance was strongly influenced by operating conditions, and higher removals were achieved under alkaline pH. Over 60 min of electrolysis, solution pH increased from 7.2 to 8.3, from 7.25 to 8.6, and from 7.3 to 8.9 at current densities of 25.31, 37.97, and 50.63 mA/cm², respectively [7]. Under the optimum operating conditions (pH 9, 50.63 mA/cm², 60 min, and 2 cm), COD, TDS, and TSS removals reached 37.8%, 34.3%, and 40.2%, respectively. The improved performance at alkaline pH was attributed to enhanced formation of $Al(OH)_3$ flocs within pH 8–9, which strengthens pollutant capture and separation, whereas acidic conditions were associated with weaker metal-hydroxide formation and poorer settleability [8]. At pH 9, increasing current density from 25.31 to 37.97 mA/cm² increased COD removal to 34.3% (an increase of 10.6%), while increasing it further to 50.63 mA/cm² provided an additional 3.5% improvement. TDS removal increased with current density and reached 34.3% at 50.63 mA/cm² (60 min). TSS removal increased with both time and current density, reaching 40.2% at 50.63 mA/cm² and 60 min; at the same current density, TSS removal was 23.2% at 15 min and increased by 11% at 60 min. Interelectrode distance showed an optimum at 2 cm; decreasing spacing from 2 to 1 cm reduced COD, TDS, and TSS removals by about 19%, 17%, and 23%, respectively, while increasing spacing from 2 to 4 cm reduced them by about 15%, 14%, and 20.5%, respectively. Heavy-metal removal under the optimum conditions followed the order Cr > Pb > Zn > Fe, with removal efficiencies of 43.75%, 41.43%, 37.50%, and 27.23%, respectively. Corresponding concentrations changed from 2.8 to 1.75 mg/L (Cr), 1.4 to 0.82 mg/L (Pb), 1.6 to 0.9 mg/L (Zn), and 2.35 to 1.71 mg/L (Fe). These outcomes are summarized in Figure 1 (Mean ± SD, n = 2). Energy demand at the optimum conditions (recorded voltage up to 15 V; 400 mL) was estimated as about 150 kWh/m³, with a specific energy of 5.26 kWh per kg COD removed [9]. Aluminum consumption was 3.36 g/L (equivalent to 3,355 g/m³), and dry sludge generation was estimated to be of the same order; because heavy metals were present in the sludge, stabilization/solidification was suggested for sludge management [10]. Overall, EC achieved noticeable reductions in organics/solids and metals, but given the high initial leachate strength, it is best positioned as a pretreatment step prior to downstream polishing.

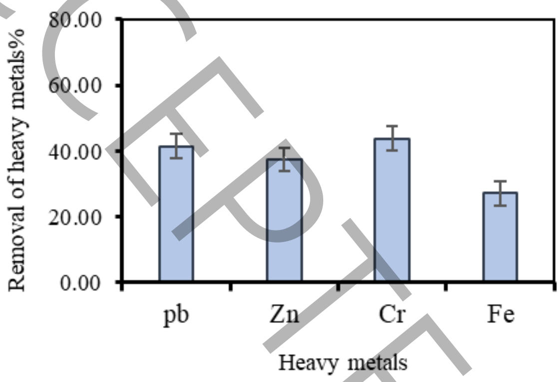

Figure 1. Heavy-metal removal efficiencies after electrocoagulation under the optimum operating conditions (pH 9, 50.63 mA/cm², 60 min). Values are reported as Mean ± SD (n = 2), and error bars indicate ±SD.

4. Conclusion

Electrocoagulation (EC) using aluminum electrodes showed practical potential as a pretreatment for high-strength landfill leachate. The optimum operating conditions were pH 9, current density 50.63 mA/cm², reaction time 60 min, and interelectrode distance 2 cm. Under these conditions, COD, TDS, and TSS removals were 37.8%, 34.3%, and 40.2%, respectively, and heavy-metal reductions were 43.75% (Cr), 41.43% (Pb), 37.50% (Zn), and 27.23% (Fe). Operationally, energy consumption was about 150 kWh/m³, specific energy was 5.26 kWh per kg COD removed, and aluminum consumption was 3.36 g/L. Overall, despite noticeable reductions in organic load, solids, and metals, post-treatment is still required due to the high initial leachate strength; therefore, EC is recommended as an effective pretreatment step prior to downstream polishing processes.

5. References

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