Leachate Treatment by Electrocoagulation

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Abstract

Electrocoagulation (EC) method, which is frequently preferred among the electrochemical treatment types, was performed to treatment of leachate. 5, 10, 15, 20 and 25 minute measurements were made with different current values. In the experimental study with aluminum electrode; COD, pH and conductivity parameters were measured. Measurements were made at the beginning and end of the experiment and these results are interpreted. The efficiency of COD removal of leachate with 50 g COD/L are obtained as 58% for the reaction duration of 25 minutes and 50 mA/cm2. Thus, leachate treatment with electrocoagulation should be preferred as a pre treatment stage.

Keywords: Electrocoagulation, leachate, COD, Aluminum electrodes, Taguchi Method.

1. Introduction

A landfill is an engineered method for solid waste disposal and important to protect the environment. In the landfill physical, chemical and biological processes occur. These processes results in the production of gases and leachate [Worrell and Vesilind, 2012]. Leachate has a complex structure and high pollutant load, and its treatment is quite hard to meet the discharge standards. Leachate contains lots of organic or inorganic pollutants with high concentration and measured as BOD, COD, ammonia, heavy metals. Hence, many treatment methods such as biological, chemical, physical, wetland and AOPs, have been performed to treat leachate [İnanç *et al*., 2000]. In the study was used aluminum electrodes performed EC process. An electrical current is passed through a metal electrode; the anode material undergoes oxidation, while the cathode will be subjected to reduction or reductive deposition of elemental metals. In the case of aluminum, main reactions can be given as [Daneshvar *et al*., 2006]:

Anode $Al_{(s)} \rightarrow Al^{3+} + 3e^-$

Cathode $3\ H_2O + 3e^- \rightarrow \frac{3}{2} H_{2(g)} + 3OH^-$

Al^{3+} and OH^- react with each other to form $Al(OH)_{3(s)}$ according to complex precipitation kinetics.

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

Recently, statistical experimental design techniques, such as response surface methodology and full or partial factorial have frequently been used in various fields of science from chemistry to engineering and from microbiology to agriculture [Yusoff *et al*., 2011; Parks, 2001; Yang *et al*., 2007; Deghles and Kurt, 2016]. The Taguchi technique includes the design of an experiment process that uses orthogonal arrays (OA) that allow for the independent evaluation of factors through a small number of trials. This technique includes data transformation to a signal-to-noise (S/ N) ratio, which is a measure of the variations presented [Gonzalez and Diaz, 2010]. Besides all other statistical experimental design methods, it is possible with Taguchi method that the parameters affecting an experiment can be investigated as controlling and not controlling and that the method can be applied to an experimental design involving a large number of design factors [İrdemez *et al*., 2006]. The main objective of this research was to investigate the optimum operating conditions such as current density (Ampere/m2) and electrolysis time (minute) of leachate by Taguchi method.

2. Materials and Methods

2.1. Experimental setup

In the study, young-aged leachate with 58 kg COD/m^3 was used. Experimental studies were performed in a lab-scale batch mode in a plexiglas reactor. Al electrodes were used both anode and cathode in the study. GW INSTEK GPS 3030 DD was used as DC power supply. The anode and cathode that have the dimensions of 4.5-14 cm, are placed vertically and parallel to each other with inter-electrode distance of 4 cm. The electrodes plates are cleaned manually by washing them in distilled water prior to every run. The volume of effluent taken is 250 mL in electrochemical reactor. The wastewater analyses were done in accordance with The Standard Methods for Examination of Water and Wastewater [APHA, 1998].

2.2. Experimental design based on Taguchi Method

Taguchi method was used to create a set of designed experiments by MINITAB software (Minitab 17.0 trial version). The Taguchi method includes the design of an experiment process that uses orthogonal arrays (OA) to reduce the number of experiments. OA refers to experimental matrix designed by Li, where i is the number of trials of experimental matrix or total degree of freedom and includes a set of experiments where the settings of process parameters are changed. OA allows evaluating the effects of several process parameters to be determined efficiently. The selection of a suitable OA depends on the number of control factors and their levels [Gökkus *et al.*, 2012]. In this study, Taguchi method was applied to determine the optimum condition of EC process. Similarly, the current density, and electrolysis time were selected as control parameters during Taguchi orthogonal arrays experimental design. Each factor that consisted of five levels and L_{25} orthogonal arrays were taken to establish the optimal conditions for aluminum electrodes with minimum number of experiments. The factors and their levels are presented in Table 1.

Table 1. Factors and their values corresponding to their levels to be studied in EC experiments

Factors	Levels				
	1	2	3	4	5
A: Current density (mA/cm^2)	10	20	30	40	50
C: Reaction Time (minutes)	5	10	15	20	25

3. Results and discussion

The collected data were analyzed using Minitab software for the estimation of the effect of each parameter on the optimization criteria. Experimental results, with regard to the model from Taguchi method and demonstrated in Table 2. On the other hand, all levels of variables are situated in Table 1. During this work, COD, and color results are expressed as percentage of removal (%) through the following equation:

$$\text{Removal efficiency (\%)} = \left[\frac{C_i - C_e}{C_i}\right] x100$$

Where; C_i is the initial concentration and C_e is the final concentration of the pollutant (mg/L and ptc). The obtained results are shown in Figure 1 and 2 for aluminum electrodes. The numerical value of the maximum point in each graph clarifies the best value of that particular parameter, situated in Table 2 for each parameter, and indicates the optimum conditions within the range of experimental conditions.

Table 2. Experimental variables, their levels, and results of conducted experiments corresponding to L_{25} experimental plan

Experiment no	Variables and their values		Removal of COD (%)	Removal of color (%)
	A	B		
1	1	1	11	20
2	2	2	23	51
3	3	3	37	77
4	4	4	44	88
5	5	5	58	95
6	1	2	25	45
7	2	3	24	63
8	3	4	57	84
9	4	5	45	93
10	5	1	47	57
11	1	3	28	36
12	2	4	26	65
13	3	5	46	90
14	4	1	33	45
15	5	2	49	74
16	1	4	33	49
17	2	5	28	81
18	3	1	34	41
19	4	2	34	66
20	5	3	55	88
21	1	5	36	53
22	2	1	12	43
23	3	2	35	52
24	4	3	35	88
25	5	4	56	90

Figure 1 and Figure 2 illustrate the effects of performance criteria on COD and color removal efficiency, respectively. The figures illustrate the effects of performance criteria on COD and color removal efficiencies. The experiments performed within the investigated range showed that optimal current density and reaction time values were 50 mA/cm^2 and 25 min, respectively (fifth parametric levels) for the best pollutant removal efficiencies. It is clear Figure 1 and Figure 2 that high current density and long reaction time increase both COD and color removal efficiencies. Analysis of variance (ANOVA) was performed to examine the effective parameters and their confidence levels on the COD and color removal efficiencies. ANOVA is to explore which process parameters importantly affect the process responses. F-test is a tool to see which process parameters effect on the COD removal and color removal efficiency. The larger the F-value, the greater effect on the performance criteria value due to the change of the process parameter [İrdemez *et al.*, 2006]. Table 3 and Table 4 show the result of the ANOVA test for COD and color removal. According to ANOVA analysis, the factors in the tables can be accordance with their significances. In this case, current density > time for the COD removal efficiency, and time > current density for the color removal efficiency. Cost is considered a vital parameter that affects the implementation of any method of wastewater treatment. In this paper, operating costs have been calculated for EC process under optimum conditions. Generally, the operating cost includes material (mainly electrodes) cost, electrical energy cost, as well as labor, maintenance, and other costs. On the other hand, in the study, the operating costs were calculated as energy consumption and electrode material where as consumption quantities per m^3 of treated wastewater.

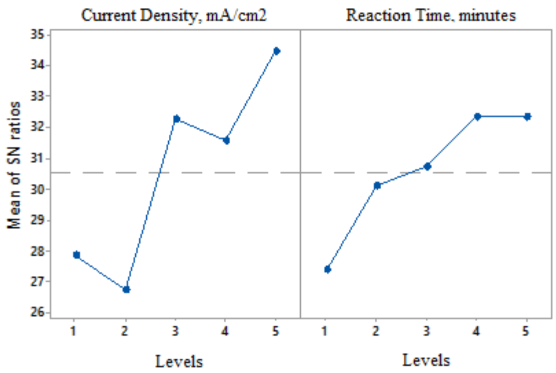

Figure 1. The effect of the parameters on COD removal efficiency On the left side, it shows the current density with different currents (10–50 mA/cm2). On the right side, it explains reaction time with different intervals from 5 to 25 minutes.

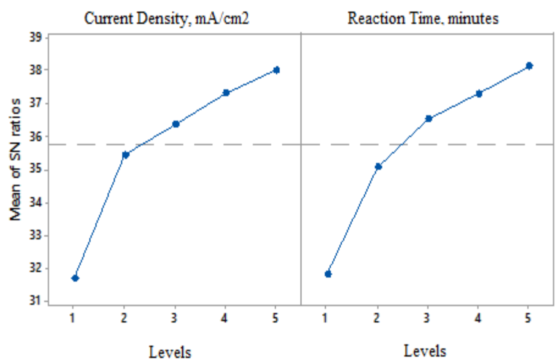

Figure 2. The effect of each parameter on color removal efficiency. On the left side, it shows the current density with different currents (10–50 mA/cm2). On the right side, it explains reaction time with different intervals from 5 to 25 minutes.

Table 3. Results of ANOVA values on COD removal performance with EC.

Sources	DF	SS	MS	F	C%[a]
Current density (mA/cm^2)	4	2972,2	743,04	46,69	72,3
Reaction Time (minutes)	4	881,4	220,34	13,84	21,5
Error	16	254,6	15,91		
Total	24	4108,2			

Notes: SS: sum of squares; DOF: degree of freedom; C%: contribution percentage. aContribution is defined as 100 x (Sum of squares/Total sum of squares).

Table 4. Results of ANOVA values on Color removal performance with EC.

Sources	DF	SS	MS	F	C%[a]
Current density (mA/cm^2)	4	4995,8	1248,94	31,15	45,7
Reaction Time (minutes)	4	5282,6	1320,64	32,94	48,4
Error	16	641,4	40,09		
Total	24	10919,8			

Unit prices, given as Turkish market, 2015, are as follows: electrical energy price 0.1 $/kWh, electrode material price 1.5 $/kg for aluminum. The energy consumptions in the EC process can be calculated as below:

$$\text{Energy consuption} = \frac{V\,I\,t}{W}$$

Where, the energy consumption is kWh/m^3, V is the voltage (Volts), I is the current (Amperes), t is the Reaction time (hour), and W is the volume of the treated wastewater (m^3). Moreover, electrode consumption can be evaluated according to Faraday's law as the following equation:

$$\text{Electrode consuption} = \frac{M\,I\,t}{z\,F\,W}$$

where F is the Faraday's constant (96,485 C/mol), M is the molar mass of electrode type as aluminum (27 g/mol), and z is the number of electron transfer (zAl:3).

4. Conclusion

Taguchi design experiment (L_{25}) was carried out to optimize the effective parameters on the removal efficiency of leachate by electrocoagulation process. The larger-the-better SN ratio was used to analyze the result experiments. In view of our results, the conclusion can be given as follow: First important parameter on COD was current density and its percentage contribution value was 72,3%. The second important parameter on COD was the reaction time with percentage value 21.5%. Moreover, first important parameter on color was reaction time and its percentage value was 48.5%. The second important parameter on color was current density with percentage value 21.5% As said by the results statistical analysis, the set of the best efficiency for COD, and color removal was current density 50 mA/cm^2, and reaction time 25 min. Optimum removal efficiency for aluminum electrode, operating costs for COD, and color removals were obtained as 0.91 USD$/$m^3$leachate.

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