EnvironmentAsia
The international journal published by the Thai Society of Higher Education Institutes on Environment

Available online at www.tshe.org/ea/index.html
EnvironmentAsia 10(1) (2017) 25-33
DOI

Stabilized Old Landfill Leachate Treatment Using Electrocoagulation

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Abstract

Electrocoagulation of leachate samples was performed by using aluminium and iron electrodes. The objective of study was to optimize the parameters such as current density, electrolysis time and pH for maximum removal of chemical oxygen demand by electrocoagulation process from landfill leachate collected from Deonar landfill in Mumbai, India. Landfill leachate was found to have Turbidity (177 NTU), Chemical oxygen demand (2300 mg/l), low BOD/COD ratio (0.10) and Total solids (10910) mg/l respectively. The Chemical Oxygen Demand (COD) of leachate sample was found to be 2300 mg/l and Biochemical Oxygen Demand (BOD) confirming that it was old or stabilized leachate. 47% COD was removed at current density of 466A/m^2 with optimum electrolysis time of 60 mins and pH 8 with aluminium electrode while for iron electrodes, the COD removal efficiency came out to be 56% at current density of 466A/m^2, optimum electrolysis time 90 mins and pH 6.

Keywords: electrocoagulation; iron electrode; aluminium electrode; chemical oxygen demand

1. Introduction

Presently the population of world has reached 7 billion. As the population is increasing, solid waste generation is also following similar trend. Urbanization is a major trend all over the world mainly due to rapid growth in population. More than half the population of the world now lives in urban areas. This may be attributed to the continuous increase in global population (Kumar *et al*., 2016). Municipal landfills are used worldwide for the decomposition of the municipal solid waste. Before 1975 nobody thought about the contamination of the groundwater because of landfill leachate. So the design of landfills was not having any system to control or check the flow of landfill leachate (Yadav and Dikshit, 2016). Today the landfill leachate has taken the attention of research. When refuse decomposed in landfills gets moisture through rainwater or by other mean, then contaminants (like organic matter, heavy metals) get dissolved and flows out of the landfill as called leachate (Wu *et al*., 2004). The composition of refuse has changed over a years due to change of life styles which is now producing more strength landfill leachate. This high strength leachate contaminates the nearby groundwater and surface water. Generation of landfill leachate depends on design and operation of landfills. Characteristics of landfill leachate vary from one to another, and it also changes with space and time on same landfill with fluctuations. It depends mainly in variations in climate, hydrogeology and waste composition (Keenan *et al*., 1984). Landfill engineering focuses on reducing leachate production, collection and treatment prior to discharge (Farquhar, 1989). So there are requirements of effective treatment technologies to treat landfill leachate for stopping the contamination of groundwater and to save the people from diseases living nearby landfills.

Landfill leachate contains both larger fraction of higher molecular weight organic material and heavy metals (Wang *et al*., 2002; Knox *et al*., 1979). Separate treatment either by biological or physico-chemical cannot give high removal efficiencies of pollutants like BOD, COD, heavy metals etc. So the combination of physicochemical and biological treatment is required to remove both organic matter and heavy metals (Ehrig, 1984; Crawford *et al*., 1985). Landfill leachate is classified in young, medium and old depending on its age. Young leachate contains very high COD and BOD around more than 10000 mg/l and 2000 mg/l respectively while old leachate contains very low BOD/COD ratio around 0.1 (Lema *et al*., 1988).

Effective pre-treatment like adsorption, coagulation of leachate is required which can reduce the load on further treatment process with economic feasibility. As coagulation is the pre-treatment process which is applied on many types of wastewater from decades but now, there is new emerging pre-treatment technology of electrocoagulation also which uses electric current which functions as a trigger for the anode electrolysis to generate ions to enhance the formation of metal hydroxide for removing pollutants (Veli *et al*., 2008).

Electrocoagulation is an efficient technique because hydroxides when adsorbed on mineral surfaces form large flocs which are stable and can be easily removed by filtration (Khandegar *et al*., 2013). This method is simple and requires simple instruments which can be easily designed. It also does not involve chemical treatment and hence there is no production of secondary pollutants with minimum sludge generation (Mollah *et al*., 2001). However, in this method, sacrificial anodes need periodic replacement and there can be formation of oxide film on cathode which can provide resistance to current (Ilhan *et al*., 2008; Labanowski *et al*., 2010). The objective of present study was to optimize the parameters such as current density, electrolysis time and pH for maximum removal of chemical oxygen demand by electrocoagulation process from landfill leachate.

Orkun and Kuleyin (2012) investigated that electrocoagulation with the iron anode gives the COD removal efficiency of 65.85%. The optimum values of current density, operation time, conductivity and pH are 30 mA/cm^2, 180 min and pH 6.54 respectively. They also evaluate the performance of electro fenton and observed that COD removal efficiency is 10% more than that of electrocoagulation with optimum dose of 5000 ppm hydrogen per oxide.

Bouhezila *et al*. (2011) studied that after 30 min of treatment of landfill leachate by aluminium electrode with current density 500 A/m^2, the removal efficiency of COD, turbidity, color and total nitrogen becomes more than 70%, 60%, 56% and 24% respectively. But with Fe electrodes the removal efficiency of COD, total nitrogen got reduced upto 68% and 15% respectively. The final pH increased from 8.69 to 9.2.

Li *et al*. (2011) examined the factors affecting the removal efficiencies of COD and BOD$_5$. The results showed that at optimum condition of 4.96 mA/cm^2 current density, 2319 mg/l Cl concentration, 90 min electrolysis time the removal efficiency of COD, BOD$_5$ were 49.8% and 69.7% respectively with the Fe electrodes. It was concluded that electrocoagulation can be applied as pretreatment for leachate.

Top *et al*. (2011) studied electrocoagulation treatment of the membrane concentrate with aluminium plate electrodes. 15.9 mA/cm^2 and 30 min came most favourable current density and time for removing COD, color and phosphorus and their removal efficiencies were 45%, 60% and 94.8% respectively. So these results signifies that electrocoagulation can further treat the nanofiltration concentrate of leachate.

Chiang *et al*. (1995) investigated that electrochemical process is a promising technology for the treatment of low BOD/COD ratio (0.2) leachate. 92% of COD get removed by the operating condition of 15 A/dm^2 and 240 mins with SPR anodes. 7500 mg /l additional chloride also added due to indirect effect of chlorine and hypochlorite on the removal of ammonium. Addition of sulphate also tried to get better results but it failed.

Table 1. Relationship among landfill age, leachate characteristics and treatment technologies

Parameters	Leachate type		
Landfill age (years)	<5 (young)	5-10 (medium)	>10 (old)
pH	<6.5	6.5-7.5	>7.5
COD (mg/l)	>10,000	<10,000	<5,000
COD/TOC	<2.0	2.0-2.7	>2.0
BOD$_5$/COD	>0.5	0.1-0.5	<0.1
VFA (% TOC)	>70	5-30	<5
Biological treatment	Good	Fair	Poor
Chemical oxidation	Fair-Poor	Fair	Fair
Chemical precipitation	Fair-Poor	Fair	Poor
Activated carbon	Fair-Poor	Fair-Poor	Good
Reverse osmosis	Fair	Good	Good
Coagulation-flocculation	Fair-Poor	Good-fair	Good

Source: Amokrane *et al*. (1997)

2. Materials and Methods

2.1 Chemicals

All the chemicals used in this study were of analytical grade. Chemicals such as concentrated sulphuric acid (98%), ferrous ammonium sulphate, potassium dichromate, nitric acid, ferric chloride, glycerol, sodium chloride, ammonium chloride, ammonium hydroxide, calcium chloride, sodium bicarbonate were purchased from Merck chemicals, Mumbai.

2.2 Analytical methods

pH and turbidity of the leachate were measured using a digital pH meter (APX 175 E/C, Control Dynamics, India) and turbidity meter (2100P, Hach, USA) respectively. COD was determined by the standard closed reflux method using a COD reactor (DRB200, Hach, USA). Total organic carbon was measured using a TOC analyzer (TOC-VCSH, Shimadzu, Japan). The BOD_5 of leachate were determined by the modified Winkler's method. Fe, Na, Cd, Ag, Al, Mn and other metals were analysed by the ICP-AES method. Sample was digested with concentrated HNO_3 in a Mars6 microwave digestor (CEM, USA). Easy plus vessels were used to keep samples in the microwave. Time was set to 12 minutes to reach 180ºC and allowed to hold for 15 minutes. And then samples were allowed to cool down. Then solution was filtered and then analysed by the ARCOS ICP-AES (Spectro, Germany) at sophisticated analytical instrument facility, IIT Bombay.

2.3 Experimental study

Electrocoagulation of landfill leachate samples was performed by using aluminium and iron electrodes. Electro coagulator was fabricated from plexiglas having total volume of 735 cm^3 with dimensions of 70 mm × 70 mm × 150 mm stirred at constant stirring speed of 200 rpm by magnetic stirrer. Two electrodes were used one acting as cathode and other as anode with dimensions of 50 mm width, 160 mm height with 2 mm thickness. The electrodes used were of aluminium and iron with purity of 99.2% each. Total effective area of electrodes was 90 cm^2 and electrodes were dipped upto height of 90 mm. The spacing between electrodes was maintained 50 mm. Electrodes were connected to the DC supply of capacity 6 Ampere. Fig.1 shows the diagram of experimental set up. For removing surface grease after every run from electrode, acetone was used. Landfill leachate was collected from Deonar landfill in Mumbai, India.

2.4 Characteristics of landfill leachate

Landfill leachate samples were characterized for various parameters (like pH, COD, BOD, TS, TSS, TDS, alkalinity and turbidity). The COD of leachate sample was found to be 2300 mg/l which it tells that it was old/stabilized leachate. The BOD_5/COD ratio also found very less which signifies that it has very less biodegradable organics and may have high concentration of heavy metals (Table 1). So, ICP-AES of leachate sample was performed to estimate the concentrations of heavy metals in leachate. Total solids (TS) concentration was found to be around 10910 mg/l out of which almost 70% were in suspended form while rest (3400 mg/l) were in form of total dissolved solids.

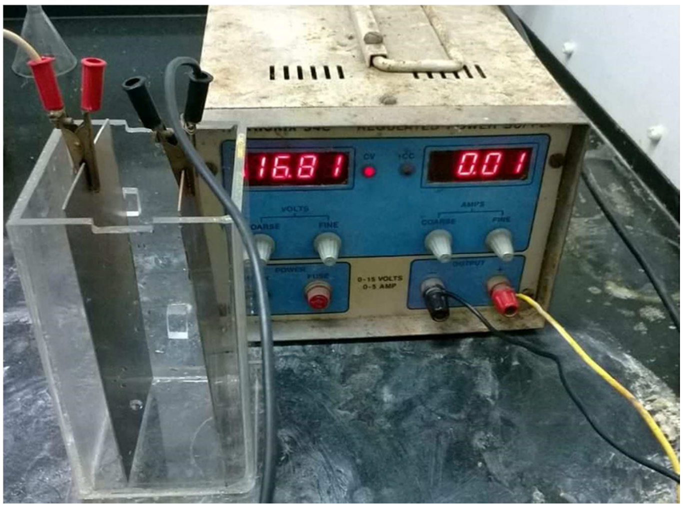

Figure 1. Experimental setup for electrocoagulation

3. Results and Discussion

The main process which happens in electrochemical process is electrolytic reactions which produce coagulants in aqueous phase. Pollutants get adsorbed on these coagulants and then get removed in sedimentation. The reactions involved in this process are (Ilhan *et al*., 2008)

$Al_{(s)} \rightarrow Al^{3+} + 3e^-$
$4Fe_{(s)} \rightarrow 4Fe^{2+}_{(aq)} + 8e^-$ at anode
$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$

$3H_2O + 3e^- \rightarrow 3/2H_2 + 3OH^-$ at cathode

$Fe_{(s)} + 2H_2O_{(l)} \rightarrow Fe(OH)_2 + H_2$ overall reaction
$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$

Species such as "$Al(OH)^{2+}$, $Al(OH)_2^+$, $Al_2(OH)_2^{4+}$, $Al(OH)_4^-$, $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$, $Al_8(OH)_{20}^{4+}$ forms initially due to reaction of Al^{3+} and OH^- and finally comes in form of $Al(OH)_3$"(Gürses *et al*., 2002). These are the species forms by Fe ions: "$FeOH^{2+}$, $Fe(OH)_2^+$, $Fe_2(OH)_2^{4+}$, $Fe(OH)_4^-$, $Fe(H_2O)_2^+$, $Fe(H_2O)_5OH^{2+}$, $Fe(H_2O)_4(OH)_2^+$, $Fe(H_2O)_8(OH)_2^{4+}$, $Fe_2(H_2O)_6(OH)_4^{2+}$, which transform finally into $Fe(OH)_3$" (Mollah *et al*., 2001).

3.1 Optimization of current density

Electrode materials used were aluminium and iron to compare their COD removal efficiency with Al and Fe chemical coagulants. They are cheap and readily available also. Current density was varied keeping electrolysis time as 60 mins with initial pH of 8. When the current density increased from 166 A/m^2 to 466 A/m^2 (Figs. 2 and 3) the removal efficiency of COD also increases from 27% to 47% in case of aluminium electrodes and 38% to 48% with iron electrodes. As the current density increases there is generation of more bubbles to remove the pollutants because of high current flow.

Table 2. Physical and chemical characteristics of landfill leachate

Parameter	Methods	Concentrations
pH	Digital pH meter	8.0-8.5
Color	-	Dark brown
Turbidity	Turbidity meter	177 NTU
BOD	Modified winkler's method	238±30 mg/l
COD	Standard closed reflux method	2304±152 mg/l
Conductivity	Conductivity metre	17mS/cm
TOC	TOC analyser	650±45 mg/l
BOD_5/COD	-	0.10
Total solids	Filtration and evaporation method	10910±152 mg/l
Total dissolved solids	Filtration and evaporation method	3400±61 mg/l
Total suspended solids	Filtration and evaporation method	7510± 105 mg/l
Chlorides	Argentometric method	349.53 mg/l
Total hardness	EDTA titrimetric method	1051.52 mg/l
Total alkalinity	Titration method	12450 mg/l
Fe	ICP-AES	1.06 mg/l
Na	ICP-AES	1412.43 mg/l
Cd	ICP-AES	0.09 mg/l
Ag	ICP-AES	0.346 mg/l
Al	ICP-AES	6.64 mg/l
Mn	ICP-AES	0.035 mg/l
Ba	ICP-AES	0.480 mg/l
B	ICP-AES	7.555mg/l
K	ICP-AES	1107.2 mg/l
Ca	ICP-AES	167.8 mg/l
Cr	ICP-AES	0.024 mg/l
Sr	ICP-AES	2.313 mg/l
Mg	ICP-AES	118.52 mg/l
Zn	ICP-AES	Not determined

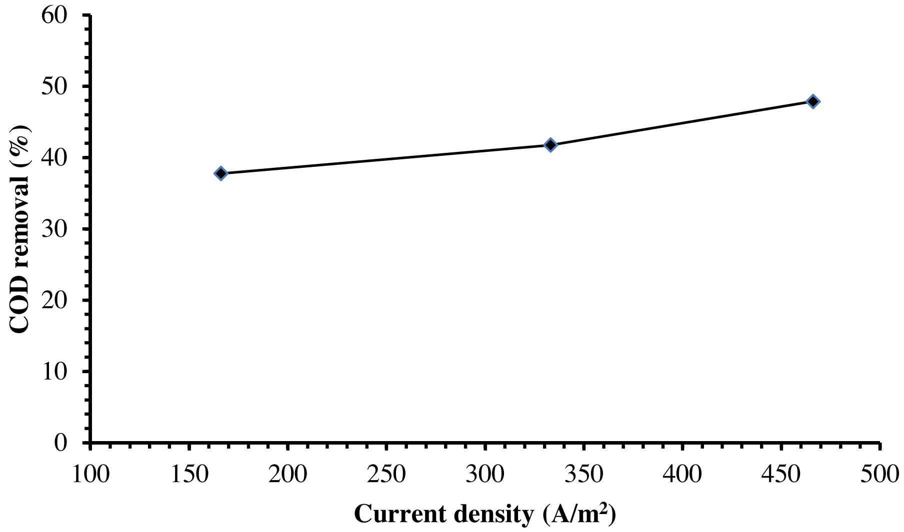

Figure 2. COD removal with current density using Fe electrode (Time = 60 mins, Initial pH = 8)

3.2 Optimization of electrolysis time

The electrolysis time affecting on COD removal was seen by varying time from 15 mins to 120 mins. The current density of 466 A/m^2 was maintained with initial pH of 8 while optimizing the time. When the time was varied from 15 mins to 120 mins (Fig. 5), the removal efficiency of COD increased up to 47% till 60 mins and then it became constant in case of aluminium electrode. Iron electrode gave (Fig. 4) 53% removal efficiency of COD at optimized time of 90 mins. Unit energy consumption increases from 25.2 KWh/m^3 to 202 KWh/m^3 with the time from 15mins to 120mins for Fe electrode. Increment of electrolysis time increases concentration of Al and Fe ions and their hydroxide. Final pH is seen to increase with the time due to formation of OH- ions shown in Figs. 8 and 9.

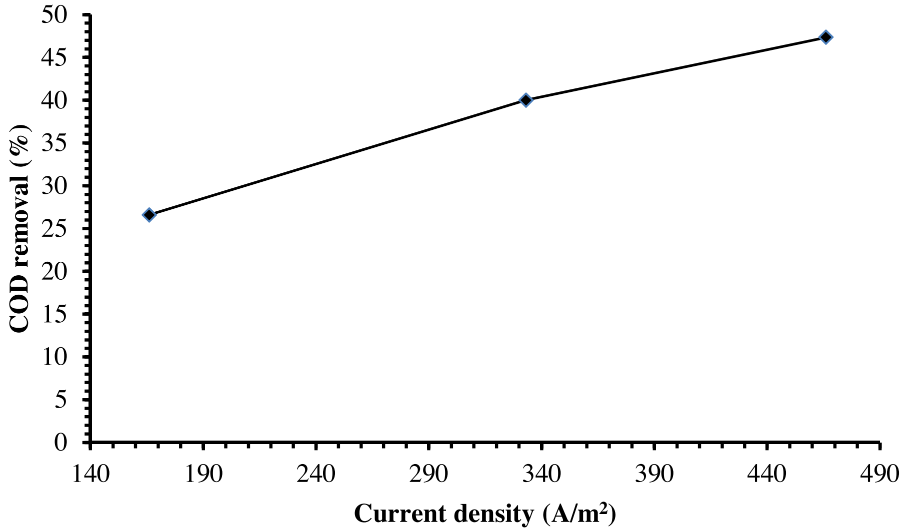

Figure 3. COD removal with current density using Al electrode (Time = 60 mins, Initial pH = 8)

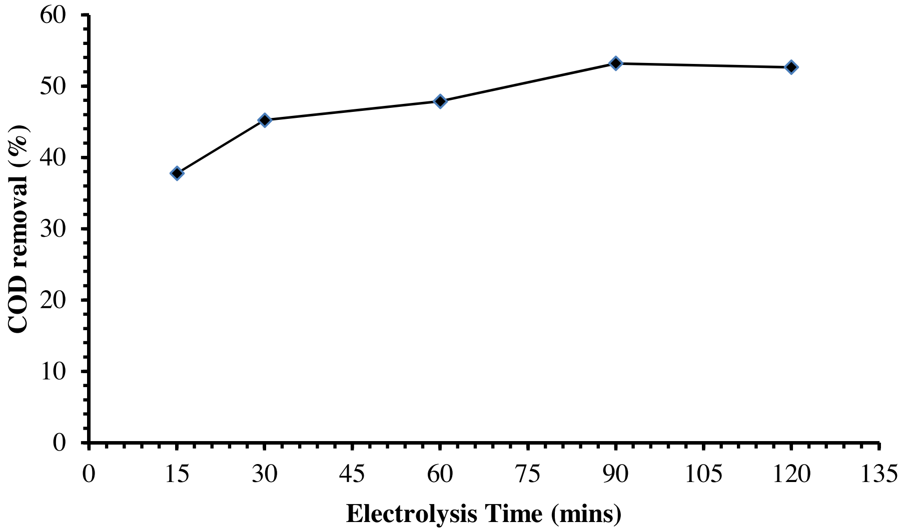

Figure 4. COD removal with electrolysis time using Fe electrode (Current density = 466 A/m^2, Initial pH = 8)

3.3 *Optimization of initial pH*

Initial pH has important role in the electrocoagulation process, so it needs to be optimized. pH optimization was done with optimized current density and optimized time of respective Al and Fe electrodes. Al electrode gave COD removal efficiency of 47% at optimum pH of 8 and 56% of COD removal at optimum pH of 6 with iron electrodes as shown in Figs. 6 and 7.

3.4 *Energy consumption*

Analysis of cost for performing electrocoagulation is done. The cost of electricity in Mumbai is INR 3.60 per KWh. The energy consumption is 151 KWh per m^3 for removing 56% COD from the leachate by using iron electrodes. So the cost of electrocoagulation came out to INR 542 per m^3 volume of treatment of leachate (Feng *et al.*, 2007). The limitation of cost analysis is that the cost of electricity needed in electrocoagulation for stirring is not included and the cost of Iron electrodes is also not included.

4. Conclusions

The performance of electrocoagulation was evaluated as a pretreatment of landfill leachate. Iron and aluminium electrodes were used for performing electrocoagulation. Iron electrode with current density of 466A/m^2 gave 56% removal of COD at optimized time of 90 mins and pH of 6. Aluminium electrode on same current density gave 47% removal of COD at optimized time of 60 mins and pH of 8. Iron electrode gave higher removal efficiency of COD as compared to aluminium electrode.

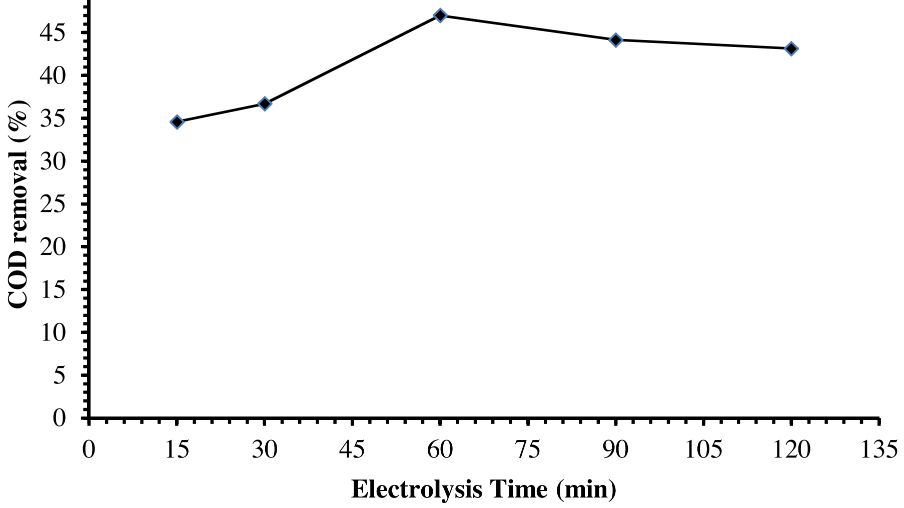

Figure 5. COD removal with electrolysis time using Al electrode (Current density = 466A/m^2, Initial pH = 8)

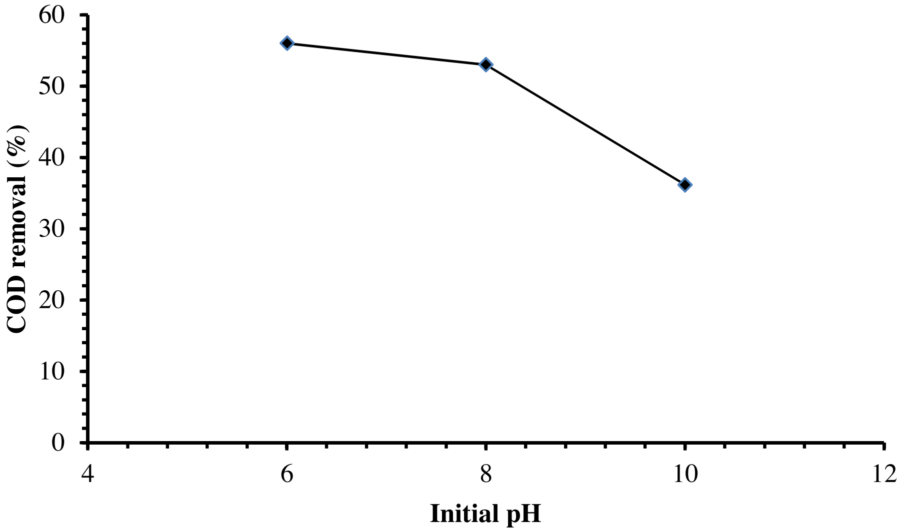

Figure 6. COD removal with pH using Fe electrode (Current density = 446A/m^2, Electrolysis time = 90 mins for Fe)

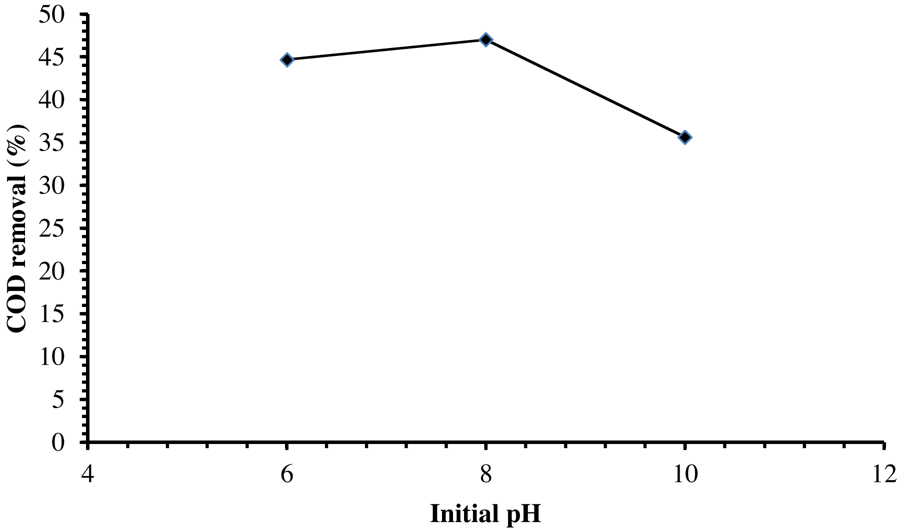

Figure 7. COD removal with pH using Al electrode (Current density = 446A/m^2, Electrolysis time = 60 mins for Al)

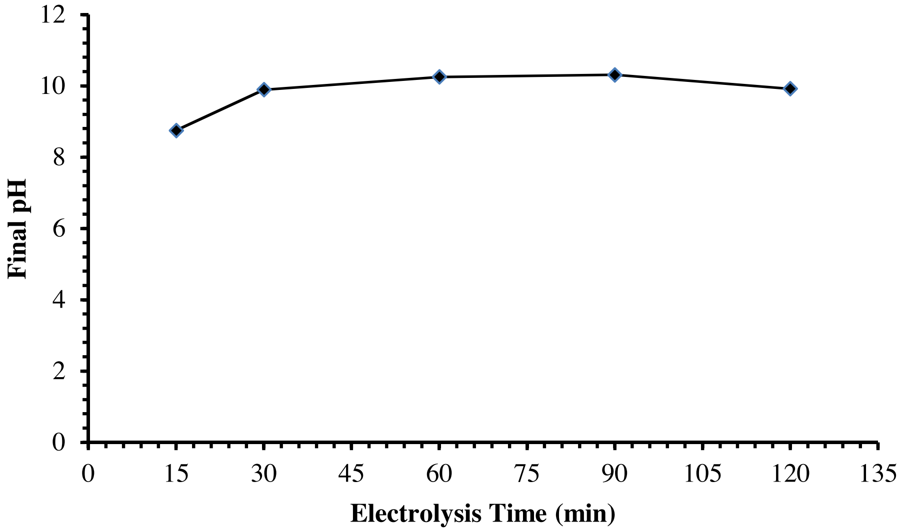

Figure 8. Final pH with electrolysis time using Fe electrode

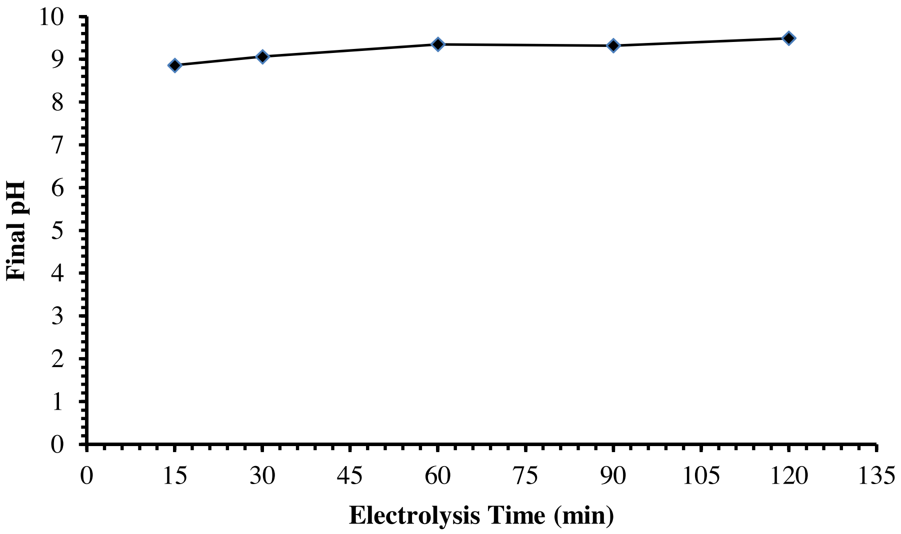

Figure 9. Final pH with electrolysis time using Al electrode

References

Amokrane A, Comel C, Veron J. Landfill leachates pretreatment by coagulation-flocculation. Water Research 1997; 31(11): 2775-82.

Bouhezila F, Hariti M, Lounici H, Mameri N. Treatment of the OUED SMAR town landfill leachate by an electrochemical reactor. Desalination 2011; 280(1-3): 347-53.

Chiang LC, Chang JE, Wen TC. Indirect oxidation effect in electrochemical oxidation treatment of landfill leachate. Water Research 1995; 29(2): 671-78.

Crawford JF, Smith PG. Landfill technology. Butterworth Scientific Ltd. 1985.

Ehrig HJ. Treatment of sanitary landfill leachate: biological treatment. Waste Management and Research 1984; 2(2): 131-52.

Farquhar GJ. Leachate: production and characteristics. Canadian Journal of Civil Engineering 1989; 16(3): 317-25.

Feng JW, Sun YB, Zheng, Zhang JB, Li S, Tian YC. Treatment of tannery wastewater by electrocoagulation. Journal of Environmental Sciences 2007; 19(12): 1409-15.

Gürses A, Yalçin M, Doğar C. Electrocoagulation of some reactive dyes: a statistical investigation of some electrochemical variables. Waste Management 2002; 22(5): 491-99.

Ilhan F, Kurt U, Apaydin O, Gonullu MT. Treatment of leachate by electrocoagulation using aluminum and iron electrodes. Journal of Hazardous Materials 2008; 154(1-3): 381-89.

Keenan JD, Steiner RL, Fungaroli AA. Landfill leachate treatment. Journal (Water Pollution Control Federation) 1984; 56(1): 27-33.

Khandegar V, Saroha AK. Electrocoagulation for the treatment of textile industry effluent-a review. Journal of Environmental Management 2013; 128: 949-63.

Knox K, Jones PH. Complexation characteristics of sanitary landfill leachates. Water Research 1979; 13(9): 839-46.

Kumar A, Patil RS, Dikshit AK, Kumar R. Air quality assessment using interpolation technique. Environment Asia 2016; 9(2): 140-49.

Labanowski J, Pallier V, Feuillade-Cathalifaud G. Study of organic matter during coagulation and electrocoagulation processes: application to a stabilized landfill leachate. Journal of Hazardous Materials 2010; 179(1-3): 166-72.

Lema JM, Mendez R, Blazquez R. Characteristics of landfill leachates and alternatives for their treatment: a review. Water, Air, and Soil Pollution 1988; 40(3): 223-50.

Li X, Song J, Guo J, Wang Z, Feng Q. Landfill leachate treatment using electrocoagulation. Procedia Enviromental Sciences 2011; 10(Part B): 1159-64.

Mollah MYA, Schennach R, Parga JR, Cocke DL. Electrocoagulation (EC)-science and applications. Journal of Hazardous Materials 2001; 84(1): 29-41.

Orkun MO, Kuleyin A. Treatment performance evaluation of chemical oxygen demand from landfill leachate by electro-coagulation and electro Fenton technique. Environmental Progress and Sustainable Energy 2012; 31(1): 59-67.

Top S, Sekman E, Hosver S, Bilgili MS. Characterization and electrocaogulative treatment of nanofiltration concentrate of a full-scale landfill leachate treatment plant. Desalination 2011; 268(1-3): 158-62.

Veli S, Öztürk T, Dimoglo A. Treatment of municipal solid wastes leachate by means of chemical-and electrocoagulation. Separation and Purification Technology 2008; 61(1): 82-88.

Wang ZP, Zhang Z, Lin YJ, Deng NS, Tao T, Zhuo K. Landfill leachate treatment by a coagulationphotooxidation process. Journal of Hazardous Materials 2002; 95(1-2): 153-59.

Wu JJ, Wu CC, Ma HW, Chang CC. Treatment of landfill leachate by ozone-based advanced oxidation processes. Chemosphere 2004; 54(7): 997-1003.

Yadav JS, Dikshit AK. Effect of pretreatment by coagulation on stabilized landfill leachate during anaerobic treatment. Cogent Environmental Science 2016; 2: 1-13.

Received 29 July 2016
Accepted 3 September 2016

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