Desalination and Water Treatment
www.deswater.com

doi:10.5004/dwt.2018.22263

115 (2018) 82–87
May

Performance evaluation of a biological landfill leachate treatment plant and effluent treatment by electrocoagulation

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Received 11 September 2017; Accepted 25 March 2018

ABSTRACT

A major problem in municipal waste landfills is generation of leachate, a dark black colored liquid with high concentrations of pollutants. The objectives of this study were to evaluate the efficiency of available leachate treatment methods at a biological treatment plant and the electrocoagulation (EC) process using aluminum and iron electrodes for treatment of effluent from the biological treatment plant. In this experimental study, leachate from the AqQala landfill in Gorgan was examined. Equipment for electrochemical unit included a power supply as well as iron and aluminum electrodes. The EC process was operated under different reaction times (20, 40, 60 min), pH values (3, 7, 9) and current densities (1.66, 3.33, 5A/m^2). The results showed that the effluent from the biological treatment plant has high concentrations of organic matter similar to wastewater, and should therefore be treated before discharge to the environment. According to the results, increasing the reaction time or the current density in the EC process increases the removal efficiency. The EC process is suggested as an alternative treatment process with high efficiency for the removal of organic matter, nitrate, phosphorous and turbidity in sewage treatment, which could prevent water and soil pollution.

Keywords: Leachate; Organic matter; Electrocoagulation; Nitrate; Phosphorous

1. Introduction

Sanitary landfill is the most common and economical method used today for disposal and management of industrial and municipal solid waste (MSW) in most developed and developing countries [1–3]. Up to 95% of total MSW collected worldwide is disposed of in landfills [2]. Leachate generation is a major problem of municipal waste landfills [1]. Leachate is a dark brown liquid that seeps out of waste and contains dissolved and suspended matter [2,3]. Decomposition of organic waste and rainfall can generate leachate at the bottom of landfills [4]. Landfill leachate contains high concentrations of organic pollutants that can change a quifer hydraulic conductivity and pollute surface water, soil and mineral resources, which may consequently affect human health and the aquatic environment [2,3,5].

Major sources of drinking water contamination are organic matter, nitrogen and phosphorus from landfill leachate [6]. Nitrate nitrogen is an inorganic compound and the last phase oxidation of ammonia and nitrogen resulting from organic matter. These ions or organic materials may enter drinking water and cause contamination or accumu-

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lation of MSW, chemical fertilizers and municipal sewage [7]. Presence of nitrogen compounds in drinking water may cause methemoglobinemia in infants and cancer in adults due to carcinogenic effects of nitrosamines [8].

Leachates are rarely treated in classical and conventional wastewater treatment plants despite the presence of high levels of pollutants such as organic matter, nutrients, pathogens and hazardous materials. Therefore, advanced and dedicated facilities are required for treatment of leachate before discharge to the environment or the wastewater collection system [3].

High levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and hazardous materials in landfill leachate are among the most important challenges in leachate management. In particular, landfill leachate can contain very high COD levels due to presence of high concentrations of biodegradable and non-biodegradable materials [9]. In recent years used new methods for treatment of environmental pollutants [10–16]. Various advanced treatment methods such as advanced oxidation processes, membrane methods, coagulation and flocculation, electrochemical and biological processes, combination of biological processes and advanced oxidation processes, electrolysis, and leachate recirculation can be used for purification of leachate and various environmental pollutants, depending on the quality and characteristic of leachate, operational and capital costs, regulations and discharge limits [5,14,17].

Study of Chemlal et al. reported that combination of advanced oxidation and biological processes is highly efficient for the removal of resistant organic matter from leachate [17]. Ahsan et al. studied leachate treatment by integrating electrolysis with activated carbon and found that 7V-4h retention time is the optimum parameter for removal of pollutants from leachate [5].

Electrocoagulation (EC) is another method used for water purification and wastewater treatment. Recently, there has been increased interest in the use of electrochemical methods for treatment of environmental pollutants in leachate and wastewater [13]. Electrochemical methods have been successfully used for the purification of refractory organic pollutants, toxic compounds, phenolic substances, natural organic matter and other pollutants from water and wastewater [14,18]. Many studies have investigated the electrochemical oxidation of leachate and paint, textile and tannery wastewaters with various types of pollutants [8,19,20]. Study of Ilhan et al. on leachate treatment by EC reported that an aluminum electrode is more efficient for removal of COD compared to an iron electrode (56% vs. 35%) after 30 min operating time [8].

This study aimed to treat leachate generated from AqQala landfill site (Golestan Province, Iran) using biological and electrochemical methods. The objectives of this study were:

- Evaluation of efficiency of current leachate treatment plant at the landfill site
- Evaluation of EC process for treatment of effluent from biological treatment plant
- Evaluation of the relationship between current density, reaction time and influent COD and BOD in the EC reactor using aluminum (anode) and iron (cathode) electrodes
- Determination of the optimum operational conditions (influent COD, current density, reaction time) for leachate treatment.

2. Materials and methods

This experimental study was performed on leachate generated from the AqQala landfall site in the Golestan Province, Iran. The landfill produces dark black liquid with high concentrations of COD and low BOD/COD ratio. This landfill site has an area of 120 hectare and receives 250 tons of MSW daily.

Properties of the leachate were analyzed and mean values of each parameter were calculated (Table 1). Efficiency of the current leachate treatment plant at the landfill site was evaluated by sampling in a one-year period. Experiments on the electrochemical degradation of landfill leachate were conducted at the laboratory or pilot plant scale. The electrochemical method was done using aluminum electrode (anode) and iron electrode (cathode) for the removal of COD, nitrate and phosphate from leachate. All the experimental analyses were performed according to the standard methods [21].

2.1. Leachate sampling

Experiments were run in a batch reactor. Leachate samples (8L) were injected into the reactor and tested under various retention times and current densities inside the reactor.

2.2. Pilot system and apparatus used

An electrochemical unit consisting of a power supply, laboratory-scale iron and aluminum plates, electrodes and solid waste landfill leachate was used. The power supply converted the alternating current to direct compensation. Iron and aluminum electrodes (20 cm size; 0.5 mm thickness) were placed 4 cm apart on a glass reactor (30 × 30 × 30 cm dimensions). The optimal volume of the reactor was 8 L.

Table 1
Properties of raw leachate from the AqQala landfill site

Parameters	Maximum	Minimum	Mean ±SD
Electrical conductivity (EC), ms/cm	36.4	33.7	35.47±1.21
Total suspended solids (TSS), mg/L	20200	15060	17980.66±2640.3
Total dissolved solids (TDS), mg/L	85100	34900	63825±25303
Turbidity, NTU	4150	3400	3790±347.3
COD, mg/L	45000	35000	41000±3915.7
BOD, mg/L	8700	7227	7743.2±584
Nitrate, mg/L	222	196	215.3±6.8
Phosphate, mg/L	92.6	75	84.65±7.26
Ammonia nitrogen, mg/L	2700	1950	2237.5±345
Sulfate, mg/L	1800	1300	1637.5±228.67
Chloride, mg/L	4100	3700	3925±170.7

The optimal height of electrodes in the leachate was 15 cm. In a series of examinations, four cathodes and four anodes were used as medium and installed 5 cm away from the floor of the sludge area. Output valve was installed, and 10 cm above the reactor was considered as free zone (Fig. 1).

The effects of electrical current density in the 20–60 V range and reaction time in the 20–60 min range were evaluated.

2.3. Experimental procedures and analytical methods

The EC process was operated under the following conditions: retention time of 20, 40, 60 min, pH of 3, 7,9, and current density of 1.66, 3.33, 5 A/m^2. Nitrate was measured by spectrophotometry (4500N) and phosphorus was measured by ammonium molybdate (4500P-C). Turbidity was assessed by nephelometry (2130-B) and COD was measured by a standard titrimetric method (C5220) for examination of water and wastewater [21]. The results were analyzed using Microsoft Excel and SPSS (version 20).

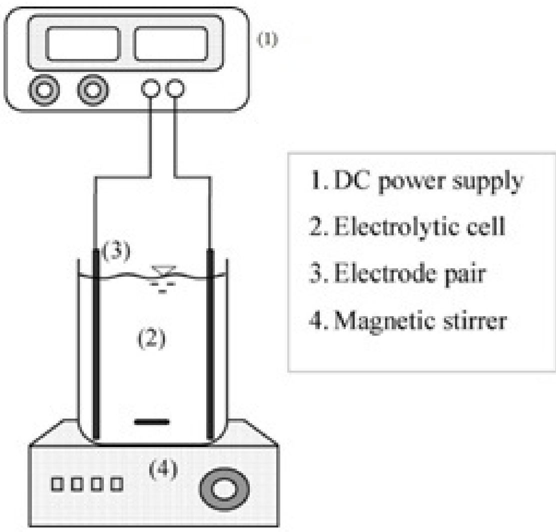

Fig. 1. A view of the reactor used in the study.

3. Results and discussion

The existing biological treatment system in the landfill site included septic tank (part of the suspended matter is settled), anaerobic system, primary aeration, secondary aeration and disinfection. The removal efficiency of various parameters from the effluent of biological treatment is presented in Tables 2–5.

The anaerobic process was highly efficient in removal of COD as the concentration of COD decreased from 41000 to 7386 mg/L (80.8%). In the primary aeration tank (extended aeration, HRT = 24 h, SRT = 5–15 d), concentration of COD decreased from 7386 to 1931.8 mg/L (Table 3).

In the secondary aeration tank (extended aeration, HRT = 24 h, SRT = 5–15 d), the concentration of COD decreased from 1931.8 to 510.2 mg/L (Table 4). Our results for the biological treatment system are consistent with the results obtained by Chemlal et al. that during the biological treatment of lechate produced by activated sludge was 80% [10].

The effluent of biological system had high concentrations of organic matter similar to wastewater, and should be treated before discharge to the environment (Table 4). Since the landfill site is located 25 km outside the city, connection to the wastewater collection system is not possible. Therefore, the effluent of biological treatment should be treated. In this study, the EC method was used for pre-treatment of leachate samples. The results of the potential differences are shown in Tables 5–7.

Table 2
Removal efficiency from effluent of the anaerobic process (SRT = 10–15 d)

Parameters	Maximum	Minimum	Mean ±SD	Efficiency (%)
EC, ms/cm	18.68	15.92	17.28±1.03	51.28
TSS, mg/L	340	257	305.4±32.4	95
TDS, mg/L	13800	11700	63825±25303	79.9
COD, mg/L	8800	6019	7386±1009.16	80.8
pH	7.6	7.3	7.46±0.11	-

Table 3
Removal efficiency from effluent of the primary aeration tank (HRT = 24 h, SRT = 5–15 d)

Parameters	Maximum	Minimum	Mean ±SD	Efficiency(%)
EC, ms/cm	16.35	13.4	14.89±2.56	14
MLSS, mg/L	3320	1545	2496.2±698.81	–
MLVSS, mg/L	2450	1130	1853.6±639.54	–
COD, mg/L	4058	1071	1931.8±1231.22	73.8
pH	8.54	7.45	8.23±0.44	–

Table 4
Removal efficiency from effluent of secondary aeration tank (HRT = 24 h, SRT = 5–15 d)

Parameters	Maximum	Minimum	Mean ± SD	Efficiency (%)
EC, ms/cm	16.35	11.12	14.17±2.46	4.8
MLSS, mg/L	3490	1720	2777±776.8	–
MLVSS, mg/L	2450	1250	1870±498.6	–
COD, mg/L	649	420	510.2±85.36	73.5
pH	9.9	7.9	9.29±0.84	–

Table 5
Potential differences of the parameters after treatment of leachate samples with EC method in pH= 3; 60 min

Parameter	Turbidity (NTU)	COD (mg/L)	Nitrate (mg/L)	Phosphorus (mg/L)
Raw leachate	2200	560	115	81
1.66 A/m^2	1856 (15.6)*	475 (15.1)	102 (11.3)	76 (6.1)
3.33 A/m^2	1454 (33.9)	362 (35.35)	91 (20.8)	68 (16.04)
5 A/m^2	1100 (50)	290 (48.21)	79 (31.3)	60 (25.9)

Table 6
Potential differences of the parameters after EC treatment in neutral pH for various durations

Time (min)	Parameter	Turbidity (NTU)	COD (mg/L)	Nitrate (mg/L)	Phosphorus (mg/L)
	Raw leachate	2325	580	120	85
20	1.66 A/m^2	1920 (17.4)*	500 (13.7)	109 (9.16)	80 (6.1)
	3.33 A/m^2	1623 (30.19)	390 (32.75)	96 (20)	70 (16.04)
	5 A/m^2	1247(46.36)	310 (46.5)	87 (27.5)	63 (25.9)
40	1.66 A/m^2	1850 (20.43)*	476 (17.9)	98 (18.3)	74 (12.9)
	3.33 A/m^2	1256 (45.97)	378 (34.8)	91 (24.16)	67 (21.17)
	5 A/m^2	854(63.26)	283 (51.2)	72 (40)	56(34.11)
60	1.66 A/m^2	1430 (38.49)*	432 (25.51)	90 (25)	71 (16.4)
	3.33 A/m^2	967 (58.4)	315 (46.68)	81 (32.5)	57 (32.9)
	5 A/m^2	256 (88.9)	113 (80.5)	49 (59.16)	32 (62.35)

Table 7
Potential differences of the parameters after EC treatment in pH = 9; 60 min

Parameter	Turbidity (NTU)	COD (mg/L)	Nitrate (mg/L)	Phosphorus (mg/L)
Raw leachate	2200	560	115	81
1.66 A/m^2	1900 (13.63)*	476 (15)	98 (14.7)	77 (4.93)
3.33 A/m^2	1621 (26.3)	370 (33.92)	72 (37.39)	69(14.8)
5 A/m^2	1243 (43.5)	300 (46.4)	41 (64.3)	62 (23.45)

We also investigated the efficiency of the EC method using iron and aluminum electrodes for the removal of organic matter, nutrients and turbidity. The below equations represent the electrochemical process using an iron electrode [22]:

Anode:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e \quad (1)$$

$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s) \quad (2)$$

Cathode:

$$H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq) \quad (3)$$

Overall:

$$Fe(s) + 2H_2O(l) \rightarrow Fe(OH)_2(s) + H_2(g) \quad (4)$$

The equations below represent the electrochemical process using an aluminum electrode [16]:

$$Al \rightarrow Al^{+3} + 3e^{-} \quad (5)$$

$$2H_2O + 2e^{-} \rightarrow 2OH^{-} + H_2 \quad (6)$$

$$Al^{+3} + 3H_2O \leftrightarrow Al(OH)_3 + 3H^{+} \quad (7)$$

The impact of current density, pH and reaction time is discussed below.

3.1. Effect of current density

Current density determines the coagulant dosage, an important parameter for controlling the reaction speed in the EC process. Increasing the current density reduces the time required for achieving the same removal efficiency. Moreover, elevating the current density increases bubble production and decreases the bubbles' size. As shown in our study, contaminants and sludge are removed faster at higher current densities (Figs. 2 and 3). In addition, electric current instability, flocculating impurities in the water and sediment pollutants are removed from the environment. The results of this study are consistent with results of Bazrafshan et al. [23]. In addition, results of study of Al-Anbari et al. are similar to our results regarding the use of iron electrodes [24]. It can be concluded that the electrical current affects the efficiency of the process and breakdown of organic matter and non-biodegradable materials [13]. It has been also reported that elevating the electrical current leads to the removal of color and turbidity from the leachate, and increases the efficiency [13].

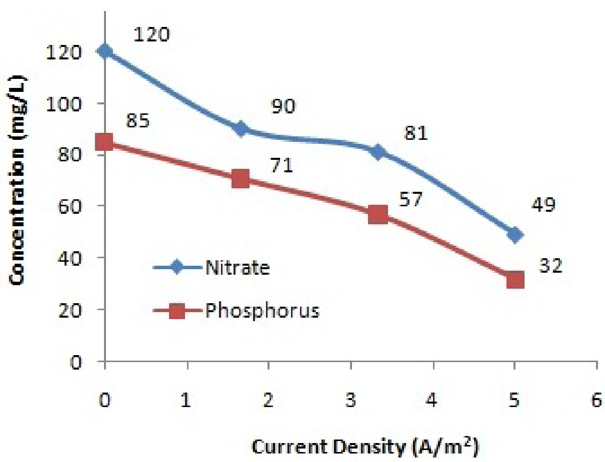

Fig. 2. Nitrate and phosphorus removal efficiency in the EC reactor (pH = 7; 60 min).

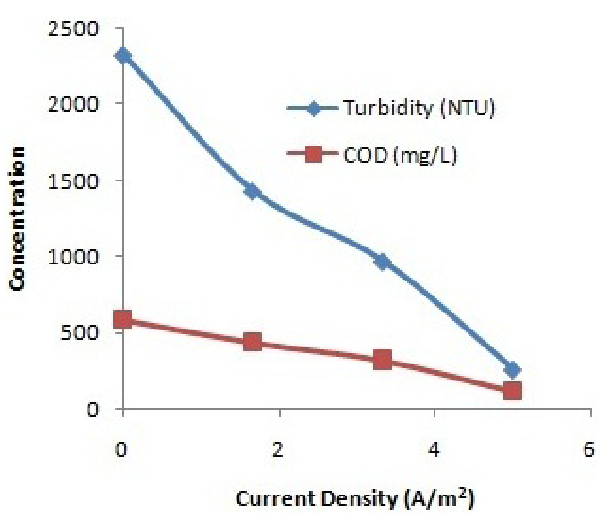

Fig. 3. COD and turbidity removal efficiency in the EC reactor (pH = 7; 60 min).

3.2. The effect of reaction time

Increasing the reaction time enhanced the efficiency of the treatment process (Table 6). This parameter should be kept as low as possible to reduce costs. Electric current reduction increased the time required for achieving the same removal efficiency. These results are in agreement with the results obtained by study of Moreaes et al. on elecrodegradation of landfill leachate [4]. In line with our study, a study showed that increasing the reaction time enhances removal of COD and BOD as well as the degradation efficiency [13].

3.3. The effect of pH

The results demonstrated that nitrate is removed in alkaline conditions (Table 7). However, since the studied parameters such as COD, turbidity and phosphorus were removed in neutral pH, it was determined as the optimum pH value. These results are consistent with the results of Mahvi et al. on the removal of phosphorus and ammonia nitrogen [25]. The mentioned study showed that the maximum efficiency of the reactor for phosphate removal was 99% at pH of 6, current density of 3A, detention time of 60 min, and influent phosphate concentration of 50 mg/L. The corresponding value for ammonia removal was 99% at pH of 7 under the same operational conditions as for phosphate removal. For both phosphate and ammonia, the removal efficiency was highest at neutral pH, with higher current densities and lower influent concentrations [25].

4. Conclusions

In this study, iron and aluminum electrodes were used as the cathode and anode, respectively. According to our results, the EC process can increase removal efficiency of organic matter, nutrients and turbidity. Increasing the reaction time increases the removal of COD, nutrients and turbidity. In addition, increasing the electric current reduces the time required for achieving the same removal efficiency and vice versa. Utilizing EC as a pre-treatment process is useful for the removal of organic matter, turbidity and nutrients. It can also reduce organic load and increase leachate degradation. Therefore, it is suggested to use this process as an efficient alternative for treatment of sewage, prevention of water and soil pollution and protection of water resources.

Competing Interests

The authors declare that they have no competing interest.

Authors' Contributions

Abdolmajid Fadaei, Mahem Tadrisi, Abotaleb Bay and Ali Naghizadeh performed the sampling and Laboratory analysis. Abdolmajid Fadaei and Mahdi Sadeghi were responsible for data analysis and manuscript preparation. All authors have read and approved the final manuscript.

Acknowledgements

This article has been derived from a research project supported by the Golestan University of Medical Sciences (under grant #931016204).

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