MJEN

MANAS Journal of Engineering
ISSN 1694-7398 | e-ISSN 1694-7398

Volume 9, Issue 2, (2021) Pages 122-128
https://doi.org/10.51354/mjen.928670

Environmental pollution size of the Bishkek Solid Waste Landfill and treatment of generated leachate wastewater

Venera Edilbek Kyzy[*1], Nurzat Şaykiyeva[1], Kubat Kemelov[1], Mustafa Dolaz[1,2], Mehmet Kobya[1,3]

[1] Kyrgyz-Turkish Manas University, Department of Environmental Engineering, Bishkek, Kyrgyzstan, venera127992@gmail.com, ORCID: 0000-0002-9345-3660, nurzat.saykiyeva@manas.edu.kg, ORCID: 0000-0000-1905-0086

[2] Kahramanmaraş Sütcü İmam University, Department of Environmental Engineering, 46040, Kahramanmaraş-Turkey

[3] Gebze Technical University, Department of Environmental Engineering, 41400, Gebze-Turkey

ABSTRACT

The disposal of municipal solid wastes (MSW) is one of the important issues today. The MSW is generally disposed of in a landfill. The disintegration of wastes in landfill generates the wastewater known as leachate and it became one of the budding environmental impacts. The landfill leachate seeps into natural ponds next to the Bishkek (Kyrgyzstan) landfill. The MSWs are dumped with an irregular landfill in Bishkek, and it has been observed that this situation creates many environmental pollution problems (air pollution due to the combustion of wastes and generated biogas, due to leakage of leachate from the landfill) around the landfill. The leachate in the ponds is not treated and leaks into the environment. In this study, the potential of the coagulation-flocculation(CF) and electrooxidation (EO) processes was investigated for the treatment of leachate from the sanitary landfill located in Bishkek-Kyrgyzstan. The initial COD (1400 ± 50 mg/L), TOC (540 ± 15 mg/L), and ammonia nitrogen (315 ± 10 mg/L) from landfill leachate were treated by the CF process as 33, 23, and 14% at pH 6.5 with alum dosage of 5 g/L, and 40, 29 and 10.1% at pH 8.5 with ferric chloride dosage of 5 g/L, respectively.

Removal efficiencies at applied currents of 1.0, 3.0, and 5.0 A with an EO reactor using boron-doped diamond (BDD) plate anode and stainless steel (SS) plate cathode were 67.20, 88.30, and 97.90% for COD, 60.10, 85.38, and 95.53% for TOC, and 48.9, 94.6 and 99.8% for ammonia nitrogen, respectively. As a result, it was seen that Bishkek's irregular solid waste landfilling leachate, which causes environmental pollution, was effectively treated with the EO process. By establishing a regular landfill, Bishkek municipal solid wastes must be disposed of in the landfill and treated of the leachate.

ARTICLE INFO

Research article

Received: 27.04.2021
Accepted: 14.06.2021

Keywords:
Solid waste landfill, landfill leachate treatment, coagulation, electrooxidation

[*]*Corresponding author*

1. Introduction

The amount of municipal solid waste (MSW) generated due to rapid urbanization and growing populations has increased even more today. According to the reports of the World Bank, it is estimated that about 2.2 billion tons of solid waste will be generated in 2025 and the management cost of these wastes will be $375.5 billion [1]. The amount of waste generated per person per day averages worldwide is 0.74 kg but ranges widely, from 0.11 to 4.54 kg. The quantity and the composition of the MSW are critical for the determination of the appropriate handling and management of these wastes. Among the different MSW management approaches, disposal of in landfills is still the most used and accepted method worldwide because of its low cost and relatively low maintenance requirements [2].

The interaction of waste with water that percolates through the landfill produces highly polluted wastewater termed as landfill leachate. During the decomposition process of wastes in landfills, one ton of waste is estimated to generate 0.20 m^3 of landfill leachate [3]. With the increasing age of a landfill, the characteristics of the leachate vary from one site to another. Various factors that affect the composition of the leachate include the type and composition of the MSW landfilled, the stage of the MSW decomposition, climate, seasonal variation, hydrology of the site, and conditions within the landfill such as its design and operation, pH, and moisture content. As landfill age increases, the biodegradable fraction of organic pollutants in leachate decreases due to anaerobic decomposition occurring in a landfill site. The old landfill leachate (> 10 years old) normally contains pH >7.5, high quantity of ammonia (>400 mg/L), moderately high strength of COD (<4000 mg/L), low BOD (80 mg/L), and a low BOD_5/COD ratio of less than 0.10. Unlike the old landfill leachate, young landfill leachate (< 5 years old) is typically characterized by pH <6.5, high BOD_5 (4000–13,000 mg/L) COD (30,000–60,000 mg/L), ammonia (<400 mg/L) concentrations and high ratio of BOD_5/COD (0.4–0.7) [4]. After all, the BOD_5/COD ratio of old leachate also decreases as the amount of carboxylic acid reduces and the amount of recalcitrant organic molecules increases. Due to the high levels of ammonia, heavy metals, and different organic compounds, landfill leachate can result in serious pollution for the environment [2].

To reduce a negative impact on the environment, a combination of physical, chemical, and biological methods is used for the efficient treatment of landfill leachate [5]. The coagulation-flocculation process is generally applied to reduce the pollution load of the leachate. The young leachates are effectively treated by biological treatment methods (aerobic, anaerobic, and anoxic). Membrane biological reactors (MBRs), with nitrification/denitrification steps, followed by membrane technologies, are commonly used to treat sanitary landfill leachates [6]. The desired discharge standards are met in the treatment of the leachate by membrane processes (nanofiltration and reverse osmosis) that follow the biological treatment of the leachate. However, most of the recalcitrant substances in leachate are difficult to degrade during the biological process. These recalcitrant substances can be removed with the membrane processes, but since membrane processes are a physical process, the leachate membrane concentrate typically represents 10-30% of the volume of the leachate influent [7]. Advanced oxidation processes (AOPs) are commonly used for the removal of the membrane concentrates and nonbiodegradable and/or toxic substances from especially old leachate. The AOPs are characterized by the highly reactive hydroxyl radicals (•OH) presence, which is suitable for a rapid and indiscriminate reaction with an organic compound inducing its almost total mineralization [8]. One of the AOPs is electro-oxidation (EO). Due to its effectiveness and ease in operation, the EO process has recently received significant attention for the treatment of wastewaters such as landfill leachate. This process has shown its efficacy for the destruction of refractory pollutants [9].

In this study, first, the environmental problems of the urban landfill of Bishkek (Kyrgyzstan) were investigated. Then, the treatability of the leachate that emanated from the existing landfill and formed natural ponds by the CF and EO processes was examined. COD, TOC, and ammonia nitrogen removal efficiencies at different coagulant dosages for CF and applied currents for EO processes were determined.

2. Material and methods

2.1. The Bishkek solid waste landfill area

Bishkek is the capital and largest city of Kyrgyzstan (Kyrgyz Republic). This city (coordinates of 42°52′29″N and 74°36′44″E) is situated at an altitude of about 800 meters, just off the northern fringe of the Kyrgyz Ala-Too Range, an extension of the Tian-Shan mountain range. These mountains rise to a height of 4,895 meters. The city covers an area of ~200 km^2. The annual average precipitation is around 440 mm. Average daily high temperatures range from 3 °C in January to about 31 °C during July (around −10°C in winter). The official population of Bishkek in 2020 is approximately 1,053,915 people and the population growth rate is approximately 2.3% (above the national average of 2.1%). However, many inhabitants (~400,000 person) live in Bishkek unofficial.

All municipal waste is delivered to the only operational dumpsite in Bishkek – the Bishkek Solid Waste Landfill (BSWL). The BSWL has located 12 km to the north of the city center and 300-600 m east of the Ala-Archa reservoir. The site is situated within city limits nearing the Alamedin district of the Chui region. The dumpsite is located on a 36-hectare area to the North of the City with favorable geological and hydrogeological conditions for landfill. However, it is estimated that over the years its dimensions have expanded up to 48 ha. The city landfill site has been operating since 1976, and today the population of Bishkek is about 1.4 million (400,000 inhabitants). Today, over 1010 tons of solid waste is collected daily in Bishkek, and the country has accumulated more than 100 million tons of waste, which is placed in the BSWL. According to these results, the amount of solid waste per capita ranges from 0.74-1.00 kg.

In 2013, the Kyrgyz government and the European Bank for Reconstruction and Development signed a loan agreement to finance the project "Improvement of Solid Waste Management System in Bishkek". The solid waste to be disposed of is 220,000 tons. The new solid disposal (the northern edge from the old BSWL is ~500 m); the maximum length of the site north to south of 715 m and the maximum width east to west of 366 m; the landfill site consists of three cells of 27,600 m^2, 31,200 m^2 and 30,200 m^2; thick of protective geotextile layer (high-density polyethylene) of 2 mm, the thickness of artificial geological clay barrier (measured after compaction) of the bottom layer and slopes in each cell of 0.50 m, a drainage layer (washed gravel of fraction 16/32 mm) to be placed on the protective geotextile) will be located next to the old city landfill, which after the construction is completed will be closed and reclaimed.

Figure 1. *General views from the Bishkek Solid Waste Landfill (November 2021).*

2.2. Characteristics of landfill leachate

Leachate samples in this study were supplied from the BSWL which islanded on 233 ha area at Bishkek (Kyrgyzstan) and this landfill is still operated. The landfill is composed of different cells and the leachate leaking from the landfill cells is collected in the natural lagoons near the landfilling. This landfill area leachate is not treated. The leachate sample leaking from the old landfill cells was used in this study. The collected landfill leachate was stored in a 4 °C refrigerator to keep the wastewater characteristics unchanged. The characteristics of the Bishkek landfill leachate (BLL) used of this study were as follows: pH 8.1 ± 0.2, conductivity 14.3 ± 0.5 mS/cm, chemical oxygen demand (COD)= 1400 ± 50 mg/L, biological oxygen demand (BOD_5)= 20 ± 2 mg/L, total organic carbon (TOC)= 540 ± 15 mg/L, and ammonia nitrogen (NH_3-N)= 315 ± 10 mg/L (Table 1).

Table 1. *The characteristics of landfill leachate*

Parameter	Value
pH	8.1 ± 0.2
conductivity	14.3 ± 0.5 mS/cm
chemical oxygen demand (COD)	1400 ± 50 mg/L
biological oxygen demand (BOD_5)	20 ± 2 mg/L
total organic carbon (TOC)	540 ± 15 mg/L
ammonia nitrogen (NH_3-N)	315 ± 10 mg/L.

2.3. Experimental set-up and procedures

Coagulation-flocculation (CF) experiments were conducted using a conventional jar test apparatus in a 250 mL beaker with a working volume of 100 mL. Ferric chloride ($FeCl_3.6H_2O$) and alum ($Al_2(SO_4)_3.18H_2O$) can both be used as coagulants to treat leachate. The initial pH of leachate in the beaker was adjusted to 6.50 for alum and 8.50 for ferric chloride by adding a 0.1-2 M H_2SO_4 or a NaOH solution. The pH values were selected based on the best performance of the coagulants and obtained optimum pH results from coagulation of raw landfill leachate in the literature, in order to reduce operating costs by pH adjustment. The desired coagulant doses (0.10, 0.20, 0.40, and 0.50 g/L) were added to the beaker, and the sample was then agitated under a rapid mixing (200 rpm) for 2 min followed by a slow stirring (30 rpm) for 30 min. During the rapid mixing stage, the pH was maintained at the initial value by adding NaOH. After a 60 min long settling, the supernatant was taken from the beaker for filtration (with Whatman membrane filter of pore diameter of 0.45 µm), and then the filtrate was used for chemical analysis. After analysis of samples, the COD, TOC, and NH_3-N removal percentages were calculated. Bulk solution after coagulation-flocculation was filtered membrane filters to determine the amount of sludge (dried for 24 hours in an oven at 105 ºC).

The electro-oxidation (EO) experiments were conducted in batch mode, without stirring, and using 1000 mL of landfill leachate. A boron-doped diamond (BDD) plate on niobium anode and a stainless-steel plate cathode (20 × 6 cm) with the same dimension, both with an area of 120 cm^2, were used. The electrodes were arranged parallel to each other at a distance of 1.60 cm. The applied current intensities evaluated were 1.0 A (41.67 A/m^2), 3.0 A (125 A/m^2), and 5.0 A (208.33 A/m^2), at room temperature (22±3 ºC) and without the addition of a background electrolyte. A volume of V = 1000 mL of landfill leachate in the batch EO reactor was treated in each experiment. During the experiments, leachate samples were periodically collected from the EO reactor and filtered by a 0.45 µm microspore membrane filter before analyses. The leachate in the reactor was well mixed by a magnetic stirrer (Daigger model), and a direct current (dc) power supply (GW Instek, GPD-4303S Bench PSU model, 0-3 A, 0-30 V) was used to conduct the experiments under constant current conditions. Adjustments to the pH were made by the addition of concentrated H_2SO_4 or NaOH solutions. Each experiment was performed at least twice, and the results presented in this work are the average values.

2.4. Chemicals and analytical methods

COD, BOD, TOC, and NH_3-N in raw and treated landfill leachate samples were measured according to the Standard Methods [10]. The COD of the leachate samples was determined using the titrimetric open reflux method described by the Standard Methods. TOC was determined by a TOC analyzer (Shimadzu, TOC-L model, Japan). BOD was determined for cultivating 5 days at a constant temperature of 20 ºC using an OXITOP® system. The nitrate, nitrite, sulfate, and chloride concentrations were measured using the HACH spectrophotometer (DR 2000 model). Conductivity was measured with a conductive meter (YSI, 30 models) and pH was measured with a pH meter (Thermo Scientific, Eutech pH 150). All the experiments were carried out at room temperature (20 ± 1 ºC). All chemicals used were of analytical grade.

3. Result and discussion

3.1. Environmental pollution size of the BSWL

Waste sorting is carried out by informal players at various stages of the supply chain, from the waste collection points to the dumpsite. There is no formal sorting of waste taking place in the city. About 1.5 million m^3 of municipal solid waste is generated in the city annually, about 220 thousand tons of waste per year. Waste pickers within the town take some valuable materials from the waste at collection points, but the waste in collection trucks was analyzed and still contains 28% of valuable recyclables (composition of the municipal wastes; 49% organics, 1% textiles, 8% plastics, 1% metals, 8% glass, 10% paper or cardboard, and 22% other).

There are major environmental and social problems associated with the dumpsite. The solid wastes are dumped with an irregular landfill in Bishkek. Recyclable wastes (such as plastic and metal wastes) from the wastes brought to the landfill area by garbage trucks are sorted irregularly by people living near this area. The municipal waste is unloaded over a large area, providing easy access by waste pickers. Because it's not surrounded by any fences, currently informal waste picking and sorting take place at the BSWL and a number of informal settlements are located within its sanitary protection zone. Also, the dumped wastes are not compacted or covered by layers of soil, giving easy access to the waste by rats, birds, insects, and dogs for food, breeding, and living in the waste. In some parts of the landfill area, it is seen that the spilled waste is burning, and smoke is generated because of burning. There is also an air pollution problem in the region due to the storage of irregular solid wastes and the burning of biogas in some places in the solid waste landfill area and these combustion emissions are inhaled by residents in the region. Therefore, there are methane emissions, a major greenhouse gas, across the landfill area. Some light garbage is scattered all over the district near the landfill area, and in the summertime, the stench spreads right up to the shore. There is no fence or other perimeter around the dumpsite enabling access to the waste by dogs and people. Polluted water (landfill leachate) from the site collects in the clay pit to the north of the site and in the pond to the east of the site with a risk of contaminating the Ala-Archa river and groundwater. The large artificial reservoir (it is a surface area of 5.1 km^2 and an annual capacity of 39 million m^3) of the Ala-Archa river is located ~250 m (new landfill of 300 m) to the south of the BSWL landfill location.

Informal settlements have been built near the landfill area. About 900 people a year are involved in collecting recyclables on the dumpsite with up to 200 people them working there on a typical day. Their activities make it difficult to close any area of the BSWL. There are single-story houses near the landfill with infrastructure problems and people built without permission. Although no health problems are stated regarding the residents of the waste landfill, many houses do not have drinking and utility water, the site is considered to be responsible for poor health by the residents to the west and southeast of the site. The access road of the dumpsite is not maintained and is dilapidated. This leads to additional noise, vehicle emissions, dust, and mud from vehicles. Part of the old waste deposits and the main leachate pond is located within the protection zone of a gas pipeline to the East of the site, and these problems have to be resolved during the recultivation of the dumpsite.

3.2. Treatment studies with CF process of BLL

Coagulation-flocculation (CF) is a simple process used to treat landfill leachate [11]. This process has been widely used in the pre-or post-treatment of landfill leachate to enhance the biodegradability of leachate or to remove organic matters (especially refractory organics) to reduce the pollution load of wastewater [12]. In the coagulation-flocculation process, when an inorganic coagulant such as alum and ferric chloride is added to water containing a colloidal suspension, the cationic metal ion (Al^{3+}, Fe^{3+}) from the coagulant neutralizes the negatively charged electric double layer of the colloid. The hydrolyzed coagulant species come into contact with impurities, forming destabilized particles during the fast mixing step. The collision of these destabilized particles (an essentially physical step) then forms larger particles or flocks, which can be removed by means of sedimentation, flotation, or rapid filtration. The main parameters employed to evaluate the efficiency of this process are pH and coagulant dosage. To study the efficiency of the CF process for the removal of COD, TOC, and NH_3-N, two types of coagulants were tested; aluminum sulfate (alum) and ferric chloride, and in addition to coagulant type and dosage effects were also assessed. The effect of alum and ferric chloride dose on CF efficiency was shown in Figure 2.

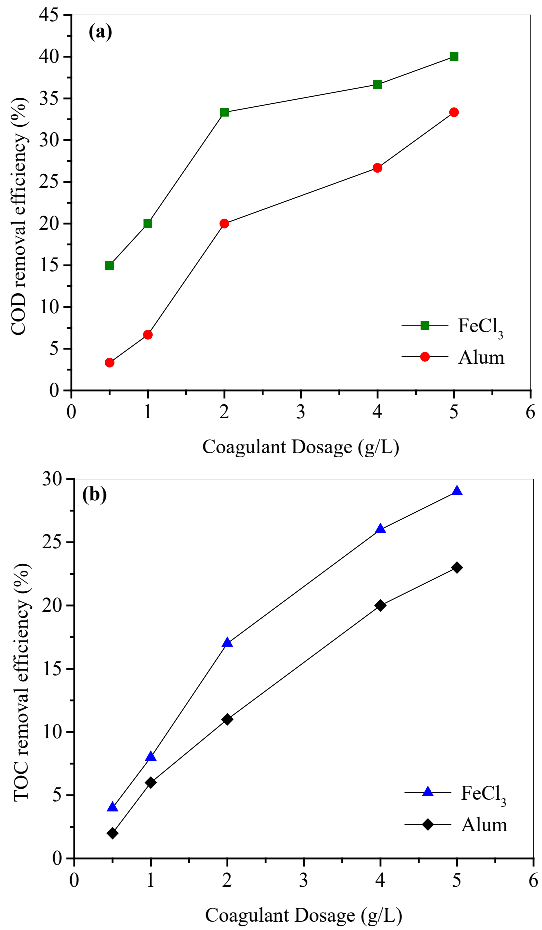

Figure 2. *Removal efficiencies at different dosages of coagulant for alum and $FeCl_3$, (a) COD, and (b) TOC.*

The COD and TOC removals increased to 15% (1020 mg/L) to 40% (720 mg/L) and 4% (1152 mg/L) and %29 (880 mg/L) for ferric chloride at pH 8.5, and 3.3% (1160 mg/L) to 33.3% (800 mg/L), and 2% (1176 mg/L) and 23% (925 mg/L) and for alum at pH 6.5, respectively, when coagulant dose increased from 500 to 5000 mg/L (Figure 2). At coagulant dose of 500, 1000, 2000, 4000 and 5000 mg/L, ammonia nitrogen removal was 4.1, 8.4, 10.4, 12 and 14% for alum and 2.3, 4.5, 7.3, 8.2, and 10.1% for $FeCl_3$, respectively. Considering these results, COD, TOC, and NH_3-N removal efficiencies were low in the treatment of stabilized leachate with CF process, and higher removal efficiency for the elimination of the organic compounds and ammonia nitrogen was obtained with iron chloride than alum. Iron and aluminum hydroxides flocks in the CF process would be formed and the complex formation between the hydroxides and the organic compounds enhanced the removal efficiency. A few organic substances in the landfill leachate, like some special humic and fulvic substances, could not be effectively removed by the coagulation process. Therefore, it is seen that COD and TOC removal efficiencies for both coagulants are low. The removal mechanisms of organic compounds in the leachate in the CF process could be charge adsorption–neutralization and complexation followed by precipitation. Other researchers have also reported similar results regarding treatment by the CF process of landfill leachate [11, 13, 14]. Amount of produced sludge (after dried at 105 °C, 24 hour) at coagulant dose of 500, 1000, 2000, 4000 and 5000 mg/L was 1.42, 2.38, 2.26 and 2.75 g/L for alum and 1.49, 2.12, 2.53 and 3.96 g/L for $FeCl_3$, respectively. It was observed that the treatment efficiency of landfill leachate was not very high. In addition, a large amount of treatment sludge arises in this process. This is the disadvantage of the CF process. The concentration of humic substances is high in stabilized leachates. Therefore, it is very difficult to treat such wastewater with the CF process. Ultimately, it is necessary to treat the stabilized leachate by an oxidation process such as EO. In addition, there is no treatment sludge problem in this process.

3.3. Treatment studies on electro-oxidation of BLL

In recent years, the electro-oxidation (EO) process has been successfully applied to the degradation of toxic and nonbiodegradable organic pollutants for wastewaters [15]. Compared with conventional processes, EO has attractive advantages such as high oxidation efficiency, amenability to automation, little or no need for the addition of chemicals, and no secondary pollution, etc. In addition, the boron-doped diamond (BDD) film electrode used in the EO process has received great attention in wastewater treatment for its wide potential window, high anodic stability, and almost complete mineralization of organic matters [16]. Besides, the EO process has been successfully applied for landfill leachate treatment [17]. At BDD anodes, organics oxidation is thought to take place mainly by mediated hydroxyl radical oxidation, whereas ammonia removal occurs through indirect oxidation by means of electro-generated active chlorine.

In this study, the treatment of leachate by the EO process was carried out by using BDD anode and SS cathode electrodes. COD and TOC removals at different applied currents depending on the EO time are shown in Figure 3. The COD concentration of landfill leachate was 1400 ± 50 mg/L, residual COD concentrations were reduced as 460 mg/L (67.2%), 164 mg/L (88.3%), and 30 mg/L (97.9%) for applied currents of 1.0, 3.0, and 5.0 A at the end of 260 min EO time, respectively (Figure 3a). At currents of 1.0, 3.0, and 5.0 A and the end of 260 min EO time, the TOC concentration decreased from 536.6 mg/L to 214.4, 78.9, and 24.1 mg/L, respectively (Figure 3b). In other words, TOC removal was found to be 60.3, 85.4, and 95.5% at 1.0, 3.0 and 5.0 A applied currents. Ammonia nitrogen removal efficiency at 1.0, 3.0, and 5.0 A was 48.9, 94.6, and 99.8%, respectively. Considering the results obtained, it shows that the EO process is a very effective process in the oxidation of leachate. BDD anodes show that very effective in both ammonium-nitrogen removal and TOC removal. In the EO process, there is the oxidation of organic substances to CO_2, H_2O, and simpler organic substances, and nitrogen gas oxidation of ammonium nitrogen.

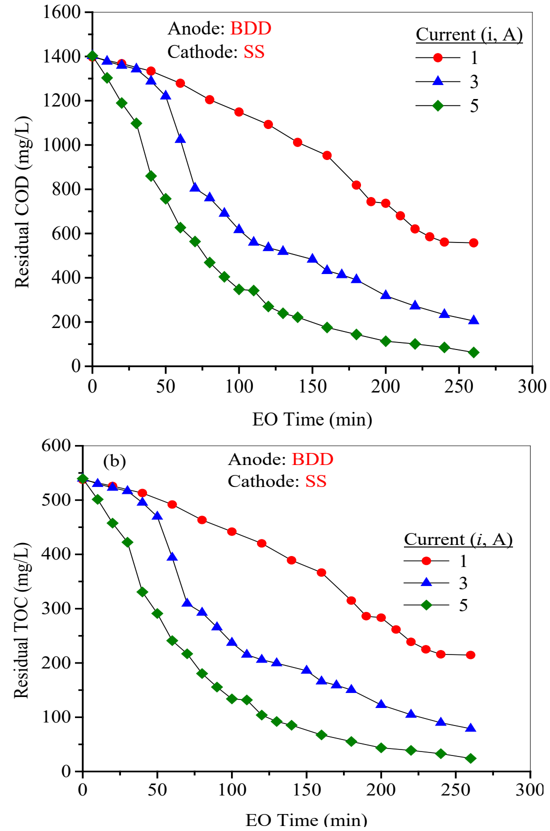

Figure 3. *Removal efficiencies at different applied current from the BLL: (a) COD, (b) TOC.*

4. Conclusion

It was observed that the irregular solid waste field in Kyrgyzstan Bishkek caused some environmental pollution and problems. Air pollution is the biggest problem as a result of the burning of wastes together with the gases from the solid waste landfill. In addition, the proximity of settlements indicates that many health and hygienic problems will arise in the future. It is seen that the water resources very close to the solid waste landfill area and the groundwater in the area will be affected. It is obvious that solid waste leakage waters leak and form small ponds in the region, causing environmental pollution. The treatability of the leachate by coagulation-flocculation (CF) and EO processes has been investigated. COD, TOC, and ammonia-nitrogen from landfill leachate with the CF process were removed 40, 29, and 10.1% at pH 8.5 with $FeCl_3$ dosage of 5 g/L, respectively. It was observed that the CF process was not very effective in Bishkek landfill leachate treatment. COD, TOC, and ammonium-nitrogen by EO process using BDD anodes were removed as 97.90, 95.5, and 99.8% at the applied current of 5 A, respectively. As a result, it was seen that Bishkek's irregular solid waste landfilling leachate, which causes environmental pollution, was effectively treated with the EO process. By establishing a regular landfill, Bishkek municipal solid wastes must be disposed of in the landfill and treated of the leachate.

Acknowledgments

This study was published from the thesis of the graduate student Venera Edilbek Kyzy. The authors thank the Kyrgyz-Turkish Manas University and the Municipality of Bishkek

References

[1]. Iskander S.Md., Zhao R., Pathak A., Gupta A., Pruden A., Novak J.T., He Z., "A review of landfill leachate induced ultraviolet quenching substances: Sources, characteristics, and treatment", Water Research, 145 (2018) 297-311.

[2]. Renou S., Givaudan J., Poulain S., Dirassouyan F., Moulin P., "Landfill leachate treatment: review and opportunity", J. Hazard. Mater. 150 (2008) 468–493.

[3]. Kurniawan T. A., Waihung Lo., Chana G., Mika E. T. Sillanpaa., "Biological processes for treatment of landfill leachate", Journal of Environmental Monitoring, 2010, 12, 2032–2047.

[4]. Foo K.Y., Hameed B.H., "An overview of landfill leachate treatment via activated carbon adsorption process", Journal of Hazardous Materials 171 (2009) 54–60.

[5]. Gao J., Oloibiri V., Chys M., Audenaert W., Decostere B., He Y., Langenhove H.V., Demeestere K., Hulle S.W.H.V., "The present status of landfill leachate treatment and its development trend from a technological point of view", Rev Environ Sci Biotechnology, 14 (2015) 93–122.

[6]. Ahmed F.N., Lan C.Q., "Treatment of landfill leachate using membrane bioreactors: A review", Desalination, 287, (2012), 41-54.

[7]. Zhang Q.Q., Tian B.H., Zhang X., Ghulam A., Fang C.R., He R., "Investigation on characteristics of leachate and concentrated leachate in three landfill leachate treatment plants", Waste Management, 33 (2013) 2277–2286.

[8]. Gautam P., Kumar S., Lokhandwala S., "Advanced oxidation processes for treatment of leachate fromhazardous waste landfill: A critical review", Journal of Cleaner Production, 237 (2019) 117639.

[9]. Mandal P., Dubey B.K., Gupta A.K., "Review on landfill leachate treatment by electrochemical oxidation: Drawbacks, challenges and future scope", Waste Management, 69 (2017) 250-273.

[10]. APHA (2005) Standard Methods for the Examination of Water and Wastewater. 21st Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

[11]. Fleck E., Gewehr A.G., Cybis L.F.A., Gehling G.R., Juliano V.B., "Evaluation of the treatability of municipal waste landfill leachate in a SBR and by coagulation-flocculation on a bench scale", Brazilian Journal of Chemical Engineering, 33 (2016) 851-861.

[12]. Long Y., Xu J., Shen D., Du Y., Feng H., "Effective removal of contaminants in landfill leachate membrane concentrates by coagulation", Chemosphere, 167 (2017) 512-519.

[13]. Orescanin V., Ruk D., Kollar R., Mikelic I.L.,Nad K., Mikulic N., "A combined treatment of landfill leachate using calciumoxide, ferric chloride and clinoptilolite", J. Environ. Sci. Health A, 46 (2011) 323-328.

[14]. Maranon E., CastrillonL., Fernandez-Nava Y., Fernandez-Mendez A., Fernandez-Sanchez, A., "Coagulation–flocculation as a pretreatment process ata landfill leachate nitrification–denitrification plant", J. Hazard. Mater., 156 (2008) 538-544.

[15]. Garcia-Segura S., Ocon J.D., Chong M.N., "Electrochemical oxidation remediation of realwastewater effluents-A review", Process Safety and Environmental Protection, 113 (2018) 48-67.

[16]. Anglada A., Urtiaga A., Ortiz I., Mantzavinos D., Diamadopoulos E., "Boron-doped diamond anodic treatment of landfill leachate:Evaluation of operating variables and formation of oxidationby-products", Water Research, 45 (2011) 828-838.

[17]. FernandesA., PachecoM.J., CiríacoL., LopesA., "Review on the electrochemical processes for the treatment of sanitarylandfill leachates: Present and future", Applied Catalysis B, 176 (2015) 183-200.