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Co-disposal of sludge generated during landfill leachate treatment with household solid waste

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ABSTRACT

The landfill leachate treatment system inevitably will consist of processes that generate sludge. This sludge must be disposed in a way that minimizes its environmental impacts. The objective of this work is to evaluate the impact of co-disposal of sludge generated in leachate treatment plant with household solid waste (HSW). The sludges from leachate treatment evaluated in the present work were generated in a forced evaporation treatment system and in a lime treatment step. Nine cells simulating landfill were set up to evaluate the impact of sludge co-disposal with HSW. During 225 d of monitoring, the results showed that the cells were in the acid phase of waste degradation and, for all parameters except chemical oxygen demand (COD) and total organic carbon (TOC), the cells showed similar behavior to the control cells. Leachate from co-disposal cells E (evaporator sludge) presented greater COD and TOC than leachate from control cells (cell C), which in turn presented greater values than leachates from co-disposal cells L (lime sludge). The higher content of organic matter may have influenced waste degradation inside the cell with evaporator sludge. On the other hand, the lime in sludge may have reacted with organic matter inside the cells.

Keywords: Coagulation/flocculation; Co-disposal; Evaporation; Sludge

1. Introduction

Landfill is the most used technology for the treatment of municipal solid waste (MSW) worldwide. Although, it is not considered the most appropriate solution, in some countries, disposal in sanitary landfills is still practically the only technique applied to deal with such waste [1]. The generation of a contaminant liquid, the landfill leachate, continues to be unavoidable in this practice of solid waste final disposal, which has as main environmental impacts the pollution of surface water and groundwater [2,3]. The landfill leachate is the liquid effluent derived from the decomposition of organic matter in the residual mass, with a series of natural compounds, dissolved and suspended [4].

Leachate is a liquid that usually presents dark color, strong smell that is formed by the microbiological degradation of

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organic matter present in the solid waste within the landfill and the natural moisture of the organic matter that infiltrates the inner layers of the landfill cells as well as the rainwater that percolates the waste pile [5,6]. The composition of leachate depends on some factors, such as: landfill's age, quality and quantity of solid waste disposed, biological and chemical processes that occur in the landfill and the amount and percolation of rainwater [7,8]. Therefore, leachate characteristics vary over time and from one place to another, so that the choice of a more appropriate treatment becomes a difficulty in the management of such wastewater [9].

In order to solve this issue, over the years, effluent treatment technologies have been developed in order to minimize environmental damage. The technologies used for landfill leachate treatment may be (i) biological processes (ii) chemical and physical processes [10]. However, to meet stringent quality standards for the direct discharge of wastewater into surface water, it is commonly necessary to develop integrated treatment methods, i.e., a combination of chemical, physical and biological steps [10].

According to Aziz et al. [11], in general, biological treatment methods are effective for freshly produced leachate, but are unsuccessful for the leachate treatment originated from old landfills. In contrast, physical–chemical processes which are not favored for fresh leachate treatment could be applied for old leachate treatment. Renou et al. [12] used lime as a coagulant agent to cause precipitation as a pre-treatment of leachate to improve the efficiency of a following treatment by reverse osmosis. Treatment with lime is traditionally used to temporarily eliminate hardness from water by decarbonation, but several studies have been done focused on the removal of organic molecules with high molecular weight, such as humic and fulvic substances [4].

The leachate treatment and landfill gas recovery should be managed in an integrated way in order to minimize risks posed by waste disposal [13]. Evaporation using energetic power from landfill gas can be used to separate humic suspensions from leachate and concentrate leachate into a small volume at (or close to) crystallization point, thus reducing its contained toxicity and non-biodegradability [14].

There are few data on the consequences of recirculation of sludge and concentrates to the landfill in the literature. Bilgili et al. [15], who evaluated the recirculation of reverse osmosis concentrate, asserts that the concentrate's recycle presents advantages such as distribution of nutrients and enzymes and dilution of compounds that inhibit the microorganisms' action in the solid waste degradation. In addition, landfill stabilization time can be reduced [16,17]. On the other hand, maintaining concentrate recirculation may lead to an inhibition of the methanogenic degradation phase due to the high concentration of organic acids that are toxic to methanogenic microorganisms [17,18]. The recycling of concentrate can alter the quality of the leachate generated, increasing the concentration of inorganic and organic compounds [18].

The objective of this study was to evaluate the polluting impact of the leachate generated from the solid household waste co-disposal with waste from both steps of leachate treatment process in Seropédica Landfill (RJ): lime treatment and evaporation. For this, three types of experimental landfill cells were assembled in triplicate: one type of cell with only HSW, considered control; the second one, co-disposal cell containing HSW and lime sludge and the third one co-disposal cell containing HSW and evaporator sludge. The quality of the leachate generated from each cell was monitored over time, and the results were compared statistically.

2. Materials and methods

2.1. Evaluated landfill

The Seropédica landfill, which is located in the city of Rio de Janeiro State, began operations in April 2011 in a land with more than 2 million m^2 and its leachate landfill treatment plant has the capacity to treat 1,000 m^3/d of leachate [19]. A daily volume of 800 m^3 is collected, which receives pre-treatment with lime before proceeding to an air stripping unit to remove ammonia. Leachate from the equalization pond is pumped into a CO_2 withdrawal tank to reduce acidity. The lime slurry is then added. In alkaline conditions, the insoluble compounds precipitate and sediment, forming the sludge at the bottom of the reactor. Then, the sludge is withdrawn through pumps and directed to a geobag where the sludge will dry and return to the landfill. After the treatment with lime, the leachate is sent to the biological treatment (anoxic tank) and, after that, it goes to nanofiltration.

In a pilot plant, the leachate is also treated by a forced evaporation process inside the landfill, where methane gas and solar energy are used as energy sources. Just like the sludge from lime treatment, the leachate concentrate from evaporation is also recirculated to the landfill.

2.2. Experiments

The experimental work was carried out in a controlled system using nine cells which are high density polyethylene containers of 50 kg waste capacity (dimensions of 57.5 × 51.5 × 100 cm), as shown in Fig. 1(a). The experimental cells were designed as illustrated in Fig. 1(b).

In order to simulate a real landfill, rainfall was simulated using a watering can according to the precipitation conditions of the Seropédica Landfill area. The artificial rain precipitation was based on the rainfall data of the climatological station of National Institute of Meteorology, INMET, Seropédica Station (A601), during the second half of 2016. This period was chosen due to the experiment occurring mostly in the second half of 2017 (May to November). Therefore, a daily rainfall precipitation of 1.91 mm was applied to the cells.

Three models of cells were evaluated, performing each model in triplicate: the control cell (only household solid waste – HSW; cells C); HSW and concentrate from evaporator, also called evaporation sludge (cells E) and HSW and sludge from lime treatment (cells L). The proportion of sludge used in each cell was according to the proportion of sludge generation per volume of leachate in the landfill. In turn, the volume of leachate generated in the landfill was associated with the mass of waste deposited in the landfill. Calculations were performed by Elias [19] and reached values of kg of sludge produced per kg of waste deposited in Seropédica Landfill. Thus, the following ratios were calculated and reproduced in the cells: 4.80×10^{-6} kg of evaporator sludge per kg of deposited waste and 0.005 kg of sludge generated in lime treatment per kg of deposited waste [19].

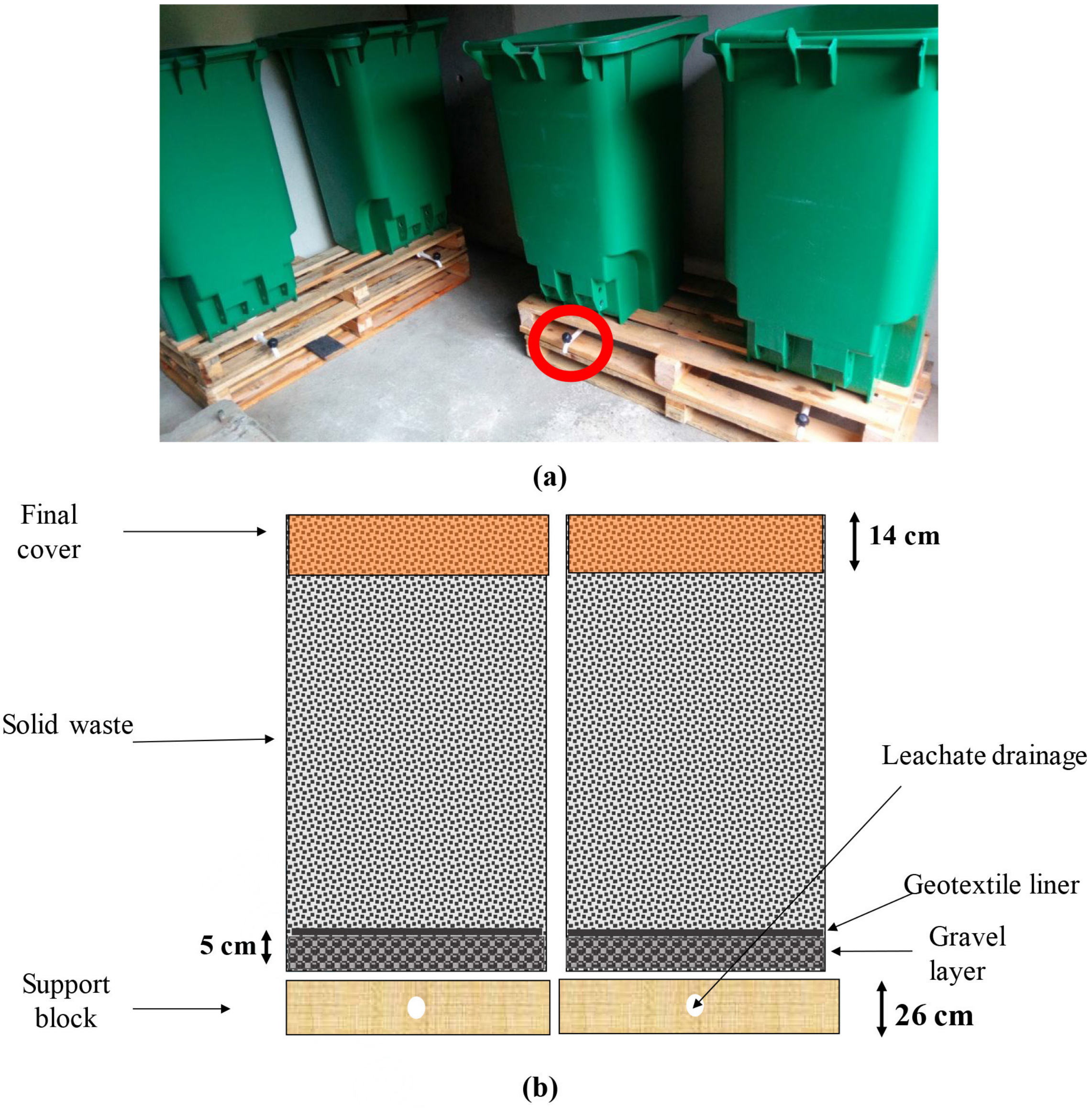

Fig. 1. Experimental cells. (a) photo of high-density polyethylene containers (leachate drainage in detail); and (b) schematic project of experimental cells.

Leachates generated in cells were monitored by measuring physicochemical parameters that were carried out according to the procedures recommended by Standard Methods for the Examination of Water and Wastewater [20]. Table 1 shows the methods and equipment used.

The HSW used in the experiment was collected in Recreio dos Bandeirantes neighborhood, in the city of Rio de Janeiro. Samples from COMLURB (Municipal Company of Urban Cleaning of Rio de Janeiro city) truck were used and the HSW was characterized before being arranged in the experimental cells. For avoiding vector proliferation and reducing odors, a 14 cm layer of clay was placed above the HSW layer and compacted with a cylindrical tool specimen measuring 10 cm in diameter and 19.5 cm tall. The sludge from evaporator (Fig. 2(a)) was collected in the equipment installed in Seropédica Landfill. The lime treatment sludge (Fig. 2(b)) was collected in geobags arranged in Seropédica Landfill, next to the Leachate Treatment Station, used to store and dry the sludge resulting from the primary treatment with lime (Fig. 2(c)).

The HSW gravimetric evaluation was performed on the following components: paper; cardboard; plastic (polyethylene, polypropylene and polystyrene); glass (colorless/colored); metal (ferrous/non-ferrous); textile; putrescible organic matter; wood; electro-electronic materials; inert materials and others. Total nitrogen, total carbon, total fixed solids and total organic matter were evaluated in both sludges based on the methodology of Kiehl [21] and adapted by COMLURB [19].

Ryan-Joiner test (using a significance level of 5% ($\alpha = 0.05$)) was applied to verify the normality of data from each physicochemical parameter. For evaluating whether the triplicate results of each cell were statistically similar (95% of confidence) the Shapiro-Wilk test was performed. In order

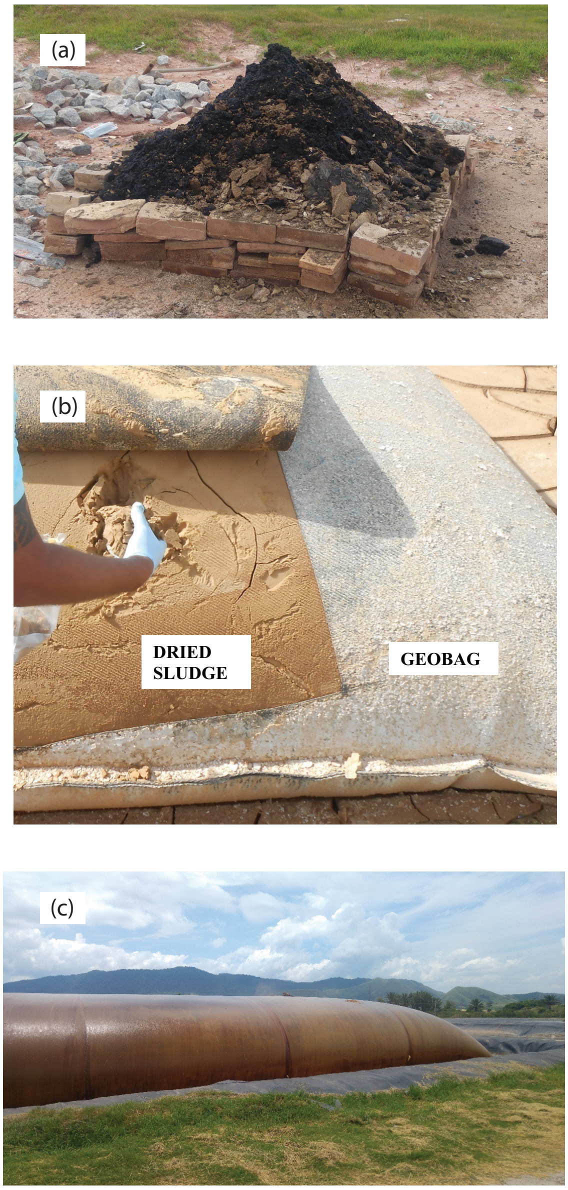

Fig. 2. (a) Sludge from evaporator; (b) sludge from lime treatment in a geobag and (c) details about geobag used for sludge dehydration.

to analyze the impact of sludges on leachate quality, the results were evaluated using Mann-Whitney test, adopting a confidence interval of 95%. For statistical tests, the software Minitab 18 (Minitab Inc.) was used. The boxplot graphs were built using Minitab 18 and the information presented in this type of graph is shown in Fig. 3.

3. Results and discussion

Table 2 shows the physical composition of household solid waste that was used to compose the cells. Putrescible

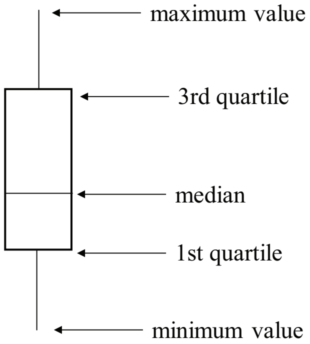

Fig. 3. Information obtained from a boxplot graph.

Table 2
Gravimetric composition of HSW used in the experimental cells

Material	Composition (%)
Paper	10.6
Cardboard	4.8
Plastic	21.7
Glass	4.7
Metal	2.3
Putrescible organic matter	50.5
Textile	0.8
Wood	0.5
Electro-eletronic materials	0.3
Inert materials	3.6
Others	0.2

Table 1
Analytical methodologies for physicochemical parameters [20]

Analysis	Method	Equipment
Absorbance at 254 nm	5910–B	Spectrophotometer Shimadzu (UV-1800)
Chloride	5910–B	Burette and erlenmeyer
Chemical oxygen demand	5220–D	Spectrophotometer Hach (DR2800) - COD Digital Reactor
Conductivity	2510–B	Conductivimeter - MS Tecnopon/mCA 150
Total organic carbon	5310–B	TOC Analyser - Shimadzu (TOC-V CPN)
Total alkalinity	2320–B	Automatic Burette
Turbitidy	2130–B	Turbidimeter- Policontrol AP2000
Ammonia nitrogen	4500–NH3 D	Ion-selective ammonia electrode -Orion 290A+
pH	4500–H+ B	pHmeter-Quimis/QH0045

organic matter represented the highest percentage in the composition (50%), which consists of fruits, vegetables and food remains. Plastic (22%) was the second largest percentage in composition; the third one was paper (11%). These results are as expected for the HSW generated in Rio de Janeiro city in 2016: 53.2% of putrescible organic matter; 14.8% of paper/cardboard and 20.2% of plastic [19].

Table 3 presents the characteristics of both sludges used in the experiments. They presented high inorganic composition, being the lime sludge the one with the highest composition percentage. Although, in the evaporation process the loss of volatile organic compounds contributes to the decay of the organic matter, this sludge still presented higher content of organic matter than the primary treatment sludge. It should be noted that the total carbon content of the primary waste is higher due to $CaCO_3$ formed during the treatment with lime, since the leachate has a high content of carbonates and bicarbonates, i.e., high alkalinity [2].

Figs. 4(a)–(i) show the leachate characteristics over time of confinement. Ryan-Joiner normality test showed the triplicate data from the cells showed that they were non-parametric. Although, the results showed, at times, numbers with high dispersion, normality comparison test showed that the results from all three cells of each type were similar to each other (using Shapiro-Wilk test, confidence limit of 95%).

According to the monitoring data, the pH varied between 4.3 and 7.0 (Fig. 4(a)) characterizing an acid environment inside the experimental cells, which shows that, throughout the monitoring period, the cells remained in the acidic phase of waste degradation [22].

Since the volume of rain precipitation was the same in all cells during monitoring and the HSW was homogenized prior to being placed inside the containment, the turbidity behavior over time (Fig. 4(b)) appears to be due to the heterogeneity of wastes within the cells. Another study with an experimental cell conducted by Silva [23] showed a gradual decrease of leachate's turbidity over time of confinement (800 d) and the advance of degradation of solid wastes caused a blockage of pores inside the waste and, as a consequence, there was a decrease of percolation of smaller suspended solids in the leachate. This behavior was not observed in the present study, probably due to the shorter monitoring period (225 d).

Chloride is a conservative contaminant, that is, it is not degraded but its concentrations can be increased over time [2]. Chloride concentration can vary within a range of 30 mg/L to 5,000 mg/L during all phases of solid waste degradation in a landfill [22]. In this work, chloride concentration varied from 100 to 5,648 mg/L (Fig. 4(c)), presenting a declining trend. According to Lima et al. [24], who carried out a study about three different landfills, all located in Rio de Janeiro State (Brazil), during three years, the leachates evaluated in such study presented a range of 1,521–4,715 mg/L.

Table 3
Results of composition of sludges

Parameter (%)	Evaporator sludge ("E")	Lime treatment sludge ("L")
Total nitrogen	0.88	0.70
Total organic matter	35.80	12.41
Total carbon	19.9	6.89
Total fixed solids	64.19	87.59

There was a variation of conductivity over time, but with a tendency for certain stability, unlike what happened with chloride. The conductivity values ranged from 7.4 to 25 mS/cm (Fig. 4(d)), showing a substantial presence of dissolved solids in the leachate.

According to Fig. 4(e), the ammonia nitrogen concentration ranged from 261 to 1,901 mg/L. Ammonia nitrogen is released from the waste mass mainly by decomposition of proteins. The only mechanism by which the concentration of ammonia nitrogen may decrease during the decomposition of organic matter is leaching out because there is no mechanism for its degradation under methanogenic conditions [3]. During the acetogenic phases, the biological degradation of amino acids and other nitrogenous compounds takes place and can collaborate to increase concentrations of ammonia nitrogen in the leachate. Another study [25] that performed an experimental landfill in Belo Horizonte City (Minas Gerais State, Brazil) showed a variation in the range of 400–2,150 mg/L during the acid phase. Silva [23] observed that the concentration of ammonia nitrogen tends to increase over time during the HSW cell monitoring, presenting a range of 12–1,639 mg/L.

The alkalinity can verify the presence of bicarbonates and carbonates through the transformation of the organic matter into CO_2 by the anaerobic activity in the landfill. According to Fig. 4(f), a gradual drop in alkalinity concentration occurs until 139 d. From the 140th day, the results presented an increasing tendency due probably to an advance of anaerobic degradation. Leachate from cells presented concentrations ranged from 327 to 8,063 mg $CaCO_3$/L, which are within the range of values for the acid phase of degradation found in the literature [22], 140–9,650 mg $CaCO_3$/L.

For organic matter evaluation in leachate, COD, TOC and absorbance at 254 nm were measured. The absorbance at the wavelength of 254 nm is used to verify the presence of organic compounds, such as lignin, tannins, humic substances and various aromatic compounds, in water and effluent treatment processes [26,27]. Humic substances are in high concentration in old landfill leachates. According to Fig. 4(g), the results showed a variation over time that may be attributed to the heterogeneity of waste in the cells.

The concentration obtained in the present work is lower than those observed in methanogenic phase landfills located in Rio de Janeiro State (Brazil) [24]. Unlike the landfills, where leachate from older methanogenic refuse is mixed with leachate from fresher refuse in the acid phase and it is not possible to relate leachate composition to processes within the waste layers, in this present work, there was no mixing between old and fresh waste, therefore the waste in the cells had not yet reached the methanogenic degradation phase.

$SUVA_{254}$ (absorbance at 254 nm/TOC ratio) is an "average" absorptivity for all the molecules that comprise the TOC in a water sample and is strongly correlated with percent aromaticity [26]. $SUVA_{254}$, therefore, is shown to be a useful parameter for estimating the aromatic carbon content in aquatic systems. For landfill leachate samples, the aromaticity is correlated with humic substances [28], are generated

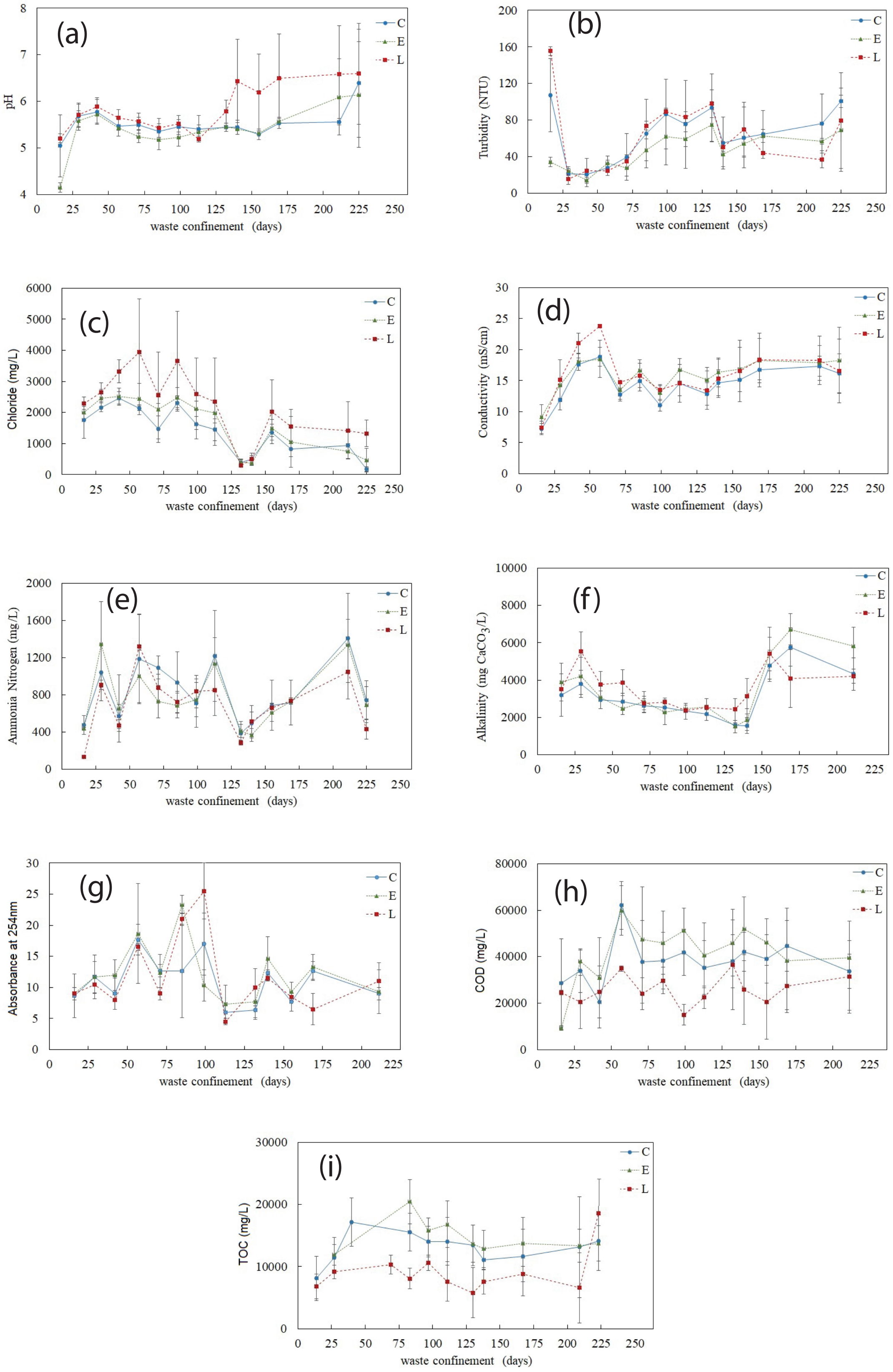

Fig. 4. Results of monitoring of physical-chemical parameters: (a) pH; (b) turbidity; (c) chloride; (d) conductivity; (e) ammonia nitrogen; (f) alkalinity; (g) absorbance at 254 nm; (h) COD and (i) TOC. C: cells C – only household solid waste; E: cells E – household solid waste and evaporator sludge; L: cells L – household solid waste and sludge from lime treatment.

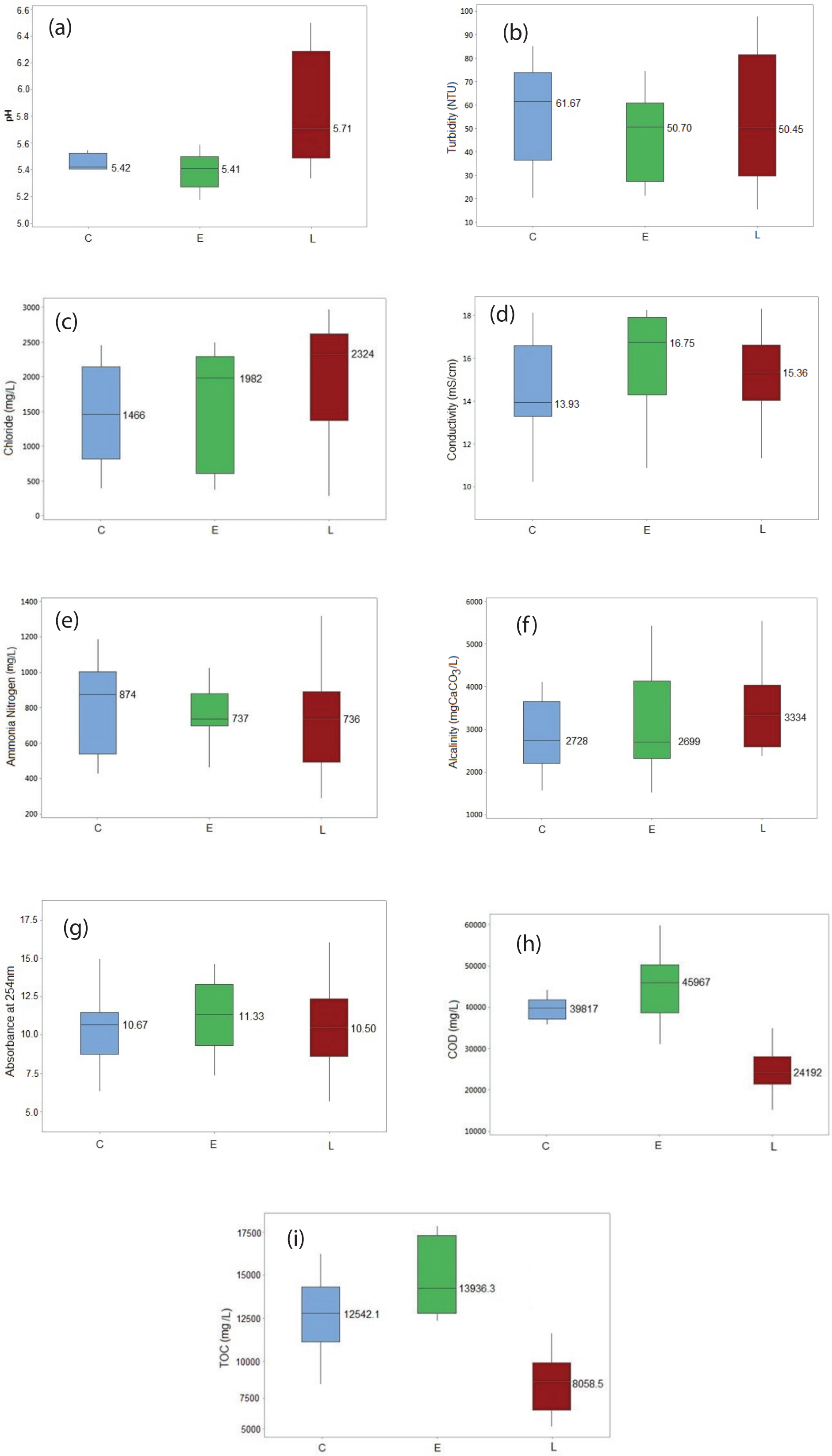

Fig. 5. Physical-chemical parameter boxplot graphs: (a) pH; (b) turbidity; (c) chloride; (d) conductivity; (e) ammonia nitrogen; (f) alkalinity; (g) absorbance at 254 nm; (h) COD and (i) TOC. C: cells C – only household solid waste; E: cells E – household solid waste and evaporator sludge; L: cells L – household solid waste and sludge from lime treatment.

during methanogenic phase of waste degradation. For the leachates originated from the cells, $SUVA_{254}$ did not show a tendency with the time, for control cells (C cells) values in the range of 3.35–17.9 × 10^{-4} (L/mg.cm) were calculated; for cells that simulated co-disposal of sludge from lime treatment with HSW (L cells), 4.63–34.1 × 10^{-4} (L/mg.cm) and for cells that simulated co-disposal of sludge from evaporator with HSW (E cells), 3.75–20.3 × 10^{-4} (L/mg.cm). These values are below for river and lake waters evaluated by Weishaar et al. [26]. These findings corroborate the fact that the cells had not yet reached the methanogenic degradation phase.

As shown in Table 3, HSW gravimetric composition present high content of organic matter, and this fact will reflect in the leachate. In general, all cells generated leachate with high concentration of COD and TOC throughout the monitoring period (Figs. 4(h) and (i)). The COD varied from 13,950 to 73,050 mg/L, showing the characteristic of new landfills that have high availability of organic matter that are easily degraded [3]. These values coincide with the acid phase of degradation phase of organic matter found in the literature [22], that vary in the range of 1,500–71,000 mg/L. High COD (8,870–76,536 mg/L) was also observed in the leachate generated in an experimental landfill in Belo Horizonte City (Brazil) [25] in the acid phase. Another experimental landfill, in Lebanon [2], presented COD of 45,000–1,20,000 mg/L.

In general, the results of TOC in leachate from the cells showed a similar trend to COD. The values obtained were high (4,480–27,752 mg/L) and were in accordance to typical values for waste acid phase degradation (500–27,700 mg/L) [22].

According to Chian [29], COD/TOC ratio > 2.8 indicates presence of biodegradable organic compounds in leachate. During the monitoring, average values of COD/TOC ratio for three types of cells varied in the range of 2.71–2.97, showing a biodegradable leachate, reinforce the acid phase of waste degradation, regardless of cell type.

Absorbance at 254 nm/COD ratio for the leachates originated from the cells were calculated and did not show a tendency with the time as well as Absorbance at 254 nm/TOC ratio: 1.55–12.8 × 10^{-4} (L/mg.cm) for control cells (C cells), 1.82–9.89 × 10^{-4} (L/mg.cm) for cells that simulated co-disposal of sludge from lime treatment with HSW (L cells) and 1.47–9.59 × 10^{-4} (L/mg.cm) for cells that simulated co-disposal of sludge from evaporator with HSW (E cells). The relations containing COD are little discussed in the literature for landfill leachate samples, mainly due to the great variability of this parameter can present. One source of variability of the COD measurement is the presence of inorganic constituents that may contribute to COD, such as Fe (II), Mn (II), chloride and sulfide that are present in the landfill leachate [3].

For a better understanding of these results, Figs. 5(a)–(i) presents the values in boxplot graph according scheme presented in Fig. 3. The median of each parameter is shown in Fig. 5 and Table 4 presents results of Mann-Whitney test for comparing the results from the co-disposal cells with the control cell.

According to Fig. 5 and Table 4, except for COD and TOC, for all other parameters, the three models of cell showed similar results, demonstrating that the co-disposal of these sludges influenced, in part, the degradation of the household solid waste during the waste degradation, when the proportions of sludge used in co-disposal experiments are the same as the ones for sludge generation per landfilled waste in Seropédica landfill.

Sludge co-disposal influenced the results of COD and TOC of leachates, presenting the following profile: COD and TCO in cell E (co-disposal evaporator sludge + HSW) > COD and TCO in cell C (control cell, only HSW) > COD and TCO in cell L (co-disposal lime sludge + HSW). The evaporator sludge induced to generation of a leachate with a higher concentration of organic matter whereas the lime sludge led to a leachate with a lower organic matter content. As observed in Table 2, lime sludge presents high content of inorganic matter, which comes probably from unreacted lime that may react with organic matter inside the cell [30]. The removal of organic compounds is very quick and it starts as soon as precipitation of the first $CaCO_3$ crystals starts. Several mechanisms can play a part in the removal of organic matter by lime and the most important is the co-precipitation [30].

The sludge from evaporator featured high content of organic matter (Table 1). Even though this sludge was present in small quantity (4.80 × 10^{-6} kg of evaporator sludge

Table 4
Results (*p*-values) of the Mann-Whitney tests for C, E, and L

Parameters	Samples	*p*-values	Statistical meaning[a]
Absorbance at 254 nm	C and E	0.5057	No
	C and L	0.7503	No
	E and L	0.6645	No
Alkalinity	C and E	0.7075	No
	C and L	0.1939	No
	E and L	0.4025	No
Chloride	C and E	0.7583	No
	C and L	0.1008	No
	E and L	0.1824	No
Conductivity	C and E	0.4887	No
	C and L	0.5727	No
	E and L	0.0820	No
COD	C and E	0.0464	Yes
	C and L	0.0001	Yes
	E and L	0.0001	Yes
TOC	C and E	0.0036	Yes
	C and L	0.0039	Yes
	E and L	0.0009	Yes
Ammonia nitrogen	C and E	0.5727	No
	C and L	0.5338	No
	E and L	0.8375	No
pH	C and E	0.4304	No
	C and L	0.0786	No
	E and L	0.0639	No
Turbidity	C and E	0.2382	No
	C and L	0.9591	No
	E and L	0.5050	No

[a]No = Results do not present statistical difference; and Yes = Results do present statistical difference

per kg of landfilled waste), this sludge influenced the quality of leachate. Such influence was more significant on COD and TOC of leachates, probably because the acid phase is the most active degradation phase [3,22], where there is the hydrolysis of organic compounds present and the formation of volatile fatty acids, amino acids and other compounds of low molar mass and gases.

4. Conclusion

Three types of experimental landfill cells were constructed to evaluate the influence of the co-disposal of two types of sludge from a leachate treatment station. For this evaluation, leachate from cells was monitored during 225 d.

The composition of the sludges from evaporator and lime treatment presented high inorganic composition, being the lime treatment sludge the highest composition percentage (87.59% against 64.19%) due to $CaCO_3$ formed during the treatment. The sludge from evaporator presented higher content of organic matter (35.80%) than the lime treatment sludge (12.41%).

The leachate quality varied over the landfilling time, despite of this the results are compatible with the literature for a leachate generated in a municipal solid waste landfill. It is noteworthy that the cells remained in the acid phase throughout the whole study (225 d), evidenced by the results of organic matter (COD and TOC), pH, absorbance at 254 nm and alkalinity in the leachates generated in all the cells.

Statistical analysis showed that there were no significant differences for most of the evaluated parameters for leachate generated, except for COD and TOC. In the other words, during the 225 d of landfilling, the co-disposal of the sludges influenced the degradation of the household solid waste in different ways: the evaporator sludge induced to generation of a leachate with a higher concentration of organic matter whereas the lime sludge led to a leachate with a lower organic matter content. Finally, studies showing the effects of co-disposal during methanogenic phase of waste degradation should be carried on.

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