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Assessment of Combined Treatment of Landfill Urban Solid Waste Leachate and Sewage Using *Danio rerio* and *Daphnia similis*

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Abstract The co-treatment from Morro do Céu landfill leachate with domestic sewage in the Icaraí STP was monitored with regard to the behavior of toxicity of its inflows and outflow. Leachate not exceeded 1.5% in volume in the plant. The acute ecotoxicological tests showed that, although leachate is far more harmful to *D. rerio* (LC50 ≈ 4) and *D. similis* (LC50 ≈ 5) than sewage (LC50 ≈ 62; LC50 ≈ 22), statistically the mixture of leachate with sewage did not result in a more toxic inflow (LC50 ≈ 57; LC50 ≈ 12) for treatment than raw sewage. After treatment, the outflow toxicity (LC50 ≈ 76; LC50 ≈ 16) complied with the environmental laws.

Keywords Leachate treatment · Co-treatment · Aquatic toxicity · Morro do Céu's landfill

The combined treatment of sanitary landfill leachate with domestic sewage in a sewage treatment plant (STP) is adopted in a number of countries in order to reduce landfill operating costs, where the cost of leachate treatment may be quite high, especially when it is still necessary even after decades of the landfill shuting down (Diamadopoulos et al. 1997; Ehrig 1998; Marttinen et al. 2003).

If, from the operating aspect of landfills, the combined treatment may be a solution for the difficulties found in treating leachate separately, from the operating aspect of sewage treatment plants, the question is about interferences that leachate might cause in the treatment processes, including the increase in toxicity of the treated effluent. Such questions arose from the different characteristics of leachate in relation to domestic sewage, such as high concentrations of recalcitrant organic compounds, ammonia nitrogen and salinity.

The purpose of this study is to assess the efficiency of the combined treatment of leachate from an urban solid waste landfill in a sewage treatment plant using ecotoxicological testing as one of the key tools.

Materials and Methods

The combined treatment of Morro do Céu landfill leachate in Icaraí STP was monitored throughout more than 1 year. Monitoring consists of acute ecotoxicological tests, plus physicochemical characterization and assessment of the inflows and outflow of the treatment, in order to check whether the introduction of leachate impaired the efficiency of treatment in Icaraí STP.

Morro do Céu landfill is located approximately 10 km from the center of Niterói (Rio de Janeiro State, Brazil). Currently the landfill receives around 750 tons of solid waste a day. Since 2004, all leachate produced in the landfill has been sent for treatment to the STP in Icaraí neighborhood. Icaraí STP primary treatment is chemically assisted, consisting of screening, grit removal, coagulant

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mixing tank, settling tank and sludge dewatering. The plant effluent is sent to treatment in a sea outfall. It is worth to mention that the inflow to Icaraí STP now consists of domestic sewage plus the leachate from Morro do Céu landfill.

Flow monitoring data were assessed to determine the proportion of leachate in relation to sewage in Icaraí STP. Daily flow data were assessed between January 2007 and September 2008.

Samples of the mixture of sewage plus inflowing leachate and the outflow of Icaraí STP, of the raw sewage contribution to the plant and leachate from Morro do Céu landfill were collected for characterization and ecotoxicological tests. The samples of the inflow to the plant were collected after the bar screening and before the fine grating in Icaraí STP; samples of outflow were collected in a passage box that combined outlet pipes of the four settling tank existing in Icaraí STP; raw sewage samples were collected in a manhole after São Francisco pumping station at the corner of Rua Lemos Cunha with Avenida Almirante Ary Parreiras; leachate samples were collected in Morro do Céu landfill at the spillway located before the leachate inlet in the line connecting the landfill to the sewage collection network.

The physicochemical characterization tests were performed in the Sanitary Engineering Laboratory (LES/UERJ), in samples collected between April 2007 and September 2008. The parameters analyzed and their analytical methods numbers in accordance with APHA (2005) were: pH (4500-H^+), turbidity (2130 B), colour (2120 B), BOD_5 (5210 B), COD (5220 B), chloride (4500-Cl^- B), total dissolved solids (2540 C), total suspended solids (2540 D), ammonia nitrogen (4500-NH_3 F) and phosphorus (4500-P E).

The test-organisms used on ecotoxicological tests were *Danio rerio* (zebrafish) and *Daphnia similis* (microcrustacean). The tests were performed in the Environmental Health Promotion and Assessment Laboratory of Oswaldo Cruz Foundation under CETESB (1990) and ABNT (2003) standards, with adaptations. *Danio rerio* test-organisms were purchased at a fish breeding and remained in acclimation for 10 days in aquarium supplied with filtered and dechlorinated water before tests using. *Daphnia similis* were cultivated in laboratory in reconstituted water (hardness between 40 and 48 mg/L $CaCO_3$) and fed with *Ankistrodesmus falcatus* algae. The exposure time of each test was 48 h. The samples were collected between November 2006 and February 2008, totaling eleven test groups. Each test group covers those tests on fish and microcrustaceans for all samples collected on a certain day.

Statistical tests were done using the Minitab 15 software. Hypothesis tests were used to compare two samples data: *T* Test average testing (parametric) and Mann–Whitney Test (non parametric), both with a confidence level of 95%.

Results and Discussion

The leachate volume in relation to the sewage volume treated in the STP was stable between 0.37% and 1.22%, not exceeding the 2% recommended for studies on combined leachate-sewage treatment (Henry 1985; McBean et al. 1995).

Table 1 shows the results of monitoring the leachate from Morro do Céu landfill, the raw sewage contributing to Icaraí STP and inflow and outflow of Icaraí STP. For each parameter the average value and interval of range between

Table 1 Characterization of leachate from Morro do Céu, contributing sewage, Icaraí STP inflow and outflow

Parameter	Unit	Morro do Céu Landfill/Icaraí STP							
		Leachate (N = 25)		Raw sewage (N = 25)		STP inflow (N = 29)		STP outflow (N = 29)	
		Average	Range	Average	Range	Average	Range	Average	Range
pH	–	7.9	7.5–8.5	7.2	6.7–7.6	7.1	6.3–7.5	7.1	6.5–7.4
Turbidity	UNT	21.3	2.0–70.5	99.0	11.0–328.4	167	20.6–584.2	61	11.4–155.8
Real colour	CU	3,145	1,148–6,200	170	67–298	274	86–655	165	76–445
BOD_5	mg O_2/L	421	158–815	103	74–141	185	105–553	96	22–173
COD	mg O_2/L	1,428	685–1,913	172	53–316	381	124–936	169	69–417
Chlorides	mg/L	2,095	247–5,727	68	28–163	117	49–563	174	33–984
TDS	mg/L	5,677	4,590–7,623	368	187–603	475	293–940	389	20–840
TSS	mg/L	114	40–473	169	100–250	279	87–500	129	58–570
NH_3-N	mg NH_3-N/L	904	522–1,394	31	11–70	32	17–63	33	20–51
P	mg/L	5.5	5.4–5.5	3.8	2.7–4.9	3.8	3.8–3.9	3.8	3.7–3.9

N = number of samplings

the minimum and maximum values are presented, relating to the set of monitoring results obtained.

Statistical tests using COD sample data (*T* Test and Mann–Whitney Test, $\alpha = 0{,}95$) permit to infer that, since leachate has a significantly higher COD than the raw sewage, when these two inflows are mixed there is an increase in the COD value at the STP inflow in relation to the COD value of raw sewage. It may also be inferred that COD is removed from the inflow to the outflow of the STP.

Statistical tests (*T* Test and Mann–Whitney Test, $\alpha = 0{,}95$) permit also to infer that although the leachate has a significantly larger concentration of ammonia nitrogen at the STP inflow, the mixture of these two inflows does not increase the ammonia nitrogen at the STP inflow in relation to raw sewage. It is also concluded that the ammonia nitrogen concentrations are not altered from the inflow to the outflow of the plant. Non-removal of ammonia nitrogen in the Icaraí STP was expected since the plant consists only of primary treatment with addition of coagulants.

The removal of the COD values in Icaraí STP was approximately 56%. In relation to total suspended solids, the removal was 67%. These removals are as expected for an STP operating with chemically-assisted primary treatment, according to Jordão and Pessôa (2005). It may be inferred that, in the monitoring period, the introduction of leachate in the treatment process did not impair its performance in terms of COD and SST removals.

The average value of ammonia nitrogen at the STP outflow, 33 mg/L, would not conform to the limit set by the technical standard NT-202 of Rio de Janeiro State Environment Institute (FEEMA 1986), of 5 mg/L, if the treatment ended in the Icaraí STP. Only in two of the 29 samplings performed did the ammonia nitrogen values conform to the limits set by this law. However, the effluent from Icaraí STP still follows for treatment in a sea outfall.

Physicochemical monitoring showed that, in the period of analysis, the introduction of leachate in the sewage treatment did not cause interferences in the treatment processes. However, the more commonly adopted effluent treatment techniques do not always guarantee a toxicity-free effluent (Rutherford et al. 2000; Silva et al. 2004). In order to prevent effluent discharge causing acute or chronic toxic effects to the aquatic biota and human health, its control must not to be restricted to physicochemical pollution-control parameters. Ecotoxicological tests are important tool for a more complete control of the sources of water pollution.

For the analysis of the ecotoxicological tests, the toxicity factors were determined for the organisms *Danio rerio* and *Daphnia similis*. Toxicity factors correspond to less dilution of the sample (1:1, 1:2, 1:4 etc.) in which death or immobility did not occur in more than 10% of the organisms (LOEC – Lowest Observed Effect Concentration). Lethal concentrations were also determined at 50% of the organisms in the tests (LC50), representing the necessary concentration of the effluent tested to cause death in 50% of the test-organisms. Figure 1 shows the graphic distribution (Box-plot) of the LC50 values in the tests with *Danio rerio* and Fig. 2 in the tests with *Daphnia similis*. Table 2 shows the range between the minimum and maximum values of toxicity factors from tests for the samples.

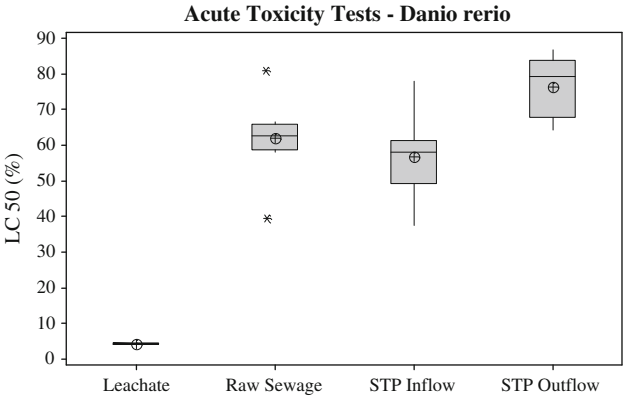

Fig. 1 Graphic distribution of LC50 values for acute toxicity tests with *D. rerio* – Morro do Céu landfill leachate, raw sewage, inflow and outflow of Icaraí STP

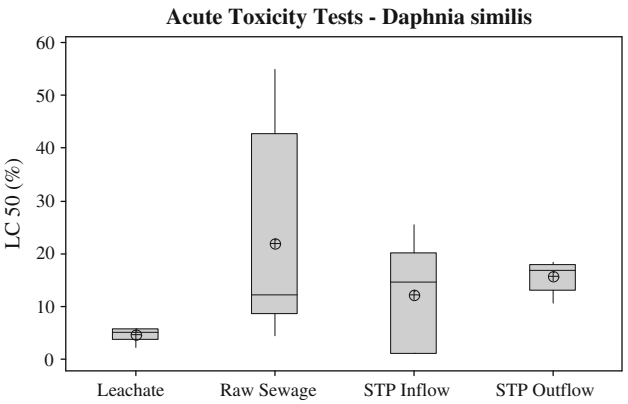

Fig. 2 Graphic distribution of LC50 values for acute toxicity tests with *D. similis* – Morro do Céu landfill leachate, raw sewage, inflow and outflow of Icaraí STP

The tests performed with *Danio rerio* resulted in a toxicity factor varying between 2 and 4 toxicity units (TU) for samples collected at the STP inflow and varying between 1.3 and 2 TU for samples from the plant outflow. The landfill leachate had a toxicity factor varying between 32 and 64 TU and raw sewage contributing to the plant had between 2 and 4 TU for tests using the same type of fish. All results of the eleven tests on *Danio rerio* with samples collected at the plant outflow comply with the effluent toxicity limit established in the prevailing Rio de Janeiro

Table 2 Range of toxicity factors values for acute toxicity tests with *D. rerio* and *D. similis* - Morro do Céu landfill leachate, raw sewage, inflow and outflow of Icaraí STP

Sample	Toxicity Factors (Range)	
	Danio rerio Tests	*Daphnia similis* Tests
Leachate	32–64	32–64
Raw sewage	2–4	4–32
STP inflow	2–4	8–16
STP outflow	1.3–2	8–16

legislation, to the value of 8 TU (FEEMA 1990). In accordance with the local legislation on toxicity control, leachate cannot be discarded into the environment without treatment, due to this high toxicity.

In the tests on *Daphnia similis*, the toxicity factor for the STP inflow and outflow varied between 8 and 16 TU; for raw sewage between 4 and 32 TU, and for leachate between 32 and 64 TU. There are no Brazilian regulations that set toxicity limits for effluents in tests using *Daphnia similis*. Administrative Rule no. 017 of Santa Catarina State Environment Foundation (FATMA 2002) sets a maximum limit of toxicity of 1 TU for *Daphnia magna* for effluents from domestic sewage treatment plants. Considering the similarity between these microcrustaceans, the Icaraí STP outflow would fail to conform to the limit set by the FATMA regulation, if the treatment ended in the STP.

The results of the statistical analyses of the LC50 toxicity data for fish and microcrustaceans are given in Table 3. The results indicated that for tests with *Danio rerio*, the average values of the sample data of the STP inflow (LC50 $\approx$ 57) and outflow (LC50 $\approx$ 76) are statistically different, with a confidence interval of 95%. The comparison between the sample data of raw sewage (LC50 $\approx$ 62) and STP inflow showed that there is no statistical evidence that the average values of the sample data of toxicity for these samples are different, with a confidence interval of 95%. Observing the distribution of LC50 values in the tests, shown in Fig. 1, and the results of the statistical analysis, it is possible to conclude that leachate (LC50 $\approx$ 4) has much higher toxicity for fish than raw sewage. Nevertheless, the leachate-sewage mixture does not increase the toxicity in the samples collected in the STP inflow. The results indicate that, after treatment, the plant outflow has a reduced toxicity for fish in relation to its inflow.

The statistical analysis of the LC50 toxicity data for *Daphnia similis* in the STP inflow (LC50 $\approx$ 12) and outflow (LC50 $\approx$ 16) showed that there is no statistical evidence that the average values of the sample data of toxicity for these samples are different, with a confidence interval of 95%. Statistical comparison between the sample data of toxicity in raw sewage (LC50 $\approx$ 22) and in the STP inflow shows evidence that they are not different. In the case of sample data of toxicity for *Daphnia similis* in leachate (LC50 $\approx$ 5) and raw sewage, the results of the statistical test showed that the averages are different. Based on the distribution of LC50 values in the tests, shown in Fig. 2, and the results of the statistical analyses, it is possible to infer that leachate is more toxic for the microcrustaceans examined than raw sewage, but does not cause a significant increase in toxicity in the samples collected at the plant inflow, and that there is no significant reduction in toxicity for this organism in the treatment used in the STP.

Statistical analysis of correlation between the LC50 and COD values, LC50 and ammonia nitrogen values and

Table 3 Results of the statistical analysis applied to acute ecotoxicity data (LC50) with *D. rerio* and *D. similis* of inflowing samples and effluent to Icaraí STP

Sample	Normal distribution[1]	Compared sample data	Hypothesis test[2]	*p* Value[3]
Danio rerio				
Inflow	Yes	Inflow × Outflow	*T* test	0.000
Outflow	Yes			
Raw sewage	Yes	Inflow × Raw sewage	*T* test	0.327
Leachate	Yes	Leachate × Raw sewage	*T* test	0.000
Daphnia similis				
Inflow	Yes	Inflow × Outflow	*T* test	0.397
Outflow	Yes			
Raw sewage	No	Inflow × Raw sewage	Mann–Whitney test	0.4047
Leachate	Yes	Raw sewage × Leachate	Mann–Whitney test	0.0217

[1] Obtained by normality testing: Anderson–Darling, Ryan-Joiner and Kolmogorov–Smirnov. [2] Hypothesis tests used to compare two samples: *T* Test average testing (parametric) and Mann–Whitney Test (non parametric), both with a confidence level of 95%. [3] p value < 0.05 (95% significance): the null hypothesis is rejected (that the averages of the sample data are equal); p value > 0.05: there is no statistical evidence to say that the averages of the sample data are different

LC50 and chlorides values, to the leachate, the raw sewage, the STP inflow and outflow were done. These tests were carried out to verify if the variability of toxicity could be explained by the variability of pollutants included in the parameters indicated.

All coefficients of correlation found indicated very week ($0.00 < r < 0.19$) and weak ($0.20 < r < 0.39$) correlations except for LC50 to *Daphnia similis* and ammonia nitrogen at the STP inflow, where a strong correlation was found ($r = 0.79$).

The regular monitoring of leachate co-treatment from Morro do Céu landfill with domestic sewage in Icaraí STP allows to conclude that although the leachate is much more toxic to the organisms tested than domestic sewage there is no increase in toxicity due to the addiction of leachate at the STP inflow compared to raw sewage. The co-treatment, where the contribution of the leachate flow did not exceed 1.5% of the total inflow, also did not cause significant interferences in the Icaraí STP treatment processes.

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