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Proposition and Evaluation of an Experimental System of Physical and Chemical Processes for Treatment of Leachate

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Abstract

The treatment of leachate from landfills of urban solid waste has become a major challenge for the scientific community since not always a treatment system adopted for one region becomes suitable for another, due to the great variability of the composition of the leachate. The treatment systems to be adopted should take into account the particularities of the region in order to make the system economically viable. In general, the conception adopted as the scope of this research consisted of a system of low cost, easy implementation, simple operation and good removal of pollutants. During the pilot scale analyzes, a flow rate of 0.1 L/s was adopted, which is equivalent to about 10% of the actual flow of the Muribeca Landfill, located in Jaboatão dos Guararapes, state of Pernambuco, Brazil. The designed pilot station is composed of three steps: chemical precipitation, ammonia stripping and reactive barrier with activated carbon. The results of this study showed an average removal performance of BOD (> 80%) and COD (> 85%) higher than the 80% removal efficiency required by state legislation for the treatment of leachate, making it sufficient to launch in the rivers.

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The concentration of ammonia for all the tests performed was above that allowed by federal legislation due to the low detention time adopted for the ammonia stripping stage. As to the color of the leachate, in general it did not give a marked change of coloration to the recipient body after its release, being in accordance with the federal legislation. Estimating the final cost of the real-scale treatment, an average value below the one practiced in Brazil was obtained.

Keywords: Waste; effluent; improvement; efficiency; cost.

1. Introduction

In the last decades, the generation of residues has been taking on frightening proportions due to the new habits of society, which has been replacing durable consumer goods with disposables in order to favor the demand for goods, services and comfort of the population [1]. In the past, when the communities were smaller, the amount and composition of residues did not bring as much concern, because their chemical constitution was predominantly organic and biodegradable. At the present time, residues are produced in large quantity, being a good percentage composed of materials of medium to difficult biodegradability [2]. For this reason, they cannot be discarded without previous treatment. In addition, the possibilities of reuse and / or recycling of the products must be considered. Uncontrolled generation and inadequate disposal of solid waste have generated serious environmental degradation problems, causing changes in the soil, air and water resources, resulting in pollution of the environment and reduction of the quality of life of man. One of the most important soil, groundwater and surface contaminants, leachate, is the result of the digestion of solid organic matter plus the water present in the landfill from the rains and the moisture present in the waste. Due to the high concentration of organic matter and other inorganic materials, the leachate constitutes a pollutant extremely aggressive to the environment, requiring treatment prior to its release into the receiving body [3]. The type of treatment must be defined according to the quantity and characteristics of the leachate generated and the requirements of the legislation depending on the receiving body. In Europe, leachate treatment uses advanced technologies, but its high cost and the different leachate composition may prevent these techniques from being implanted in Brazil. According to [4], several research and development efforts have been advocated to use membrane separation technology, mainly for treatment of leachate in landfills, resulting in environmental and economic benefits. The biggest problem is associated with the availability of an economically viable technology, in addition to the management of sophisticated and sustainable natural resources. In addition, membrane fouling and concentration polarization are important issues. In Germany, in the City of Leppe, for example, a leachate treatment system consisting of coagulation, flocculation with $Ca(OH)_2$, sedimentation, peroxide/UV and granular bed of activated carbon was installed, obtaining a reduction of about 92% of COD (Chemical Oxygen Demand) for a maximum flow rate of 2 L/s. In France, Reference [5] used nanofiltration followed by chemical coagulation, and obtained a COD removal between 70 and 80%, being in accordance with the required by environmental legislation. Reference [6] used chemical treatment using Aluminum as a chemical coagulant with different doses, obtaining removal efficiencies of 82.5%, 80.5%, 82.5% and 82.5% for turbidity, conductivity, TDS, BOD and COD respectively in aluminum 90 mg/L. Everyone was faced with the problem of cost. In Brazil, when it is defined by treatment of the leachate in situ, the stabilization ponds are often used, which have the disadvantage of having a very large area for implantation. As an example, we can mention the Solid Waste Landfill of Muribeca-PE, which treats its leachate through stabilization ponds followed by a biochemical system, also having as an alternative the treatment through recirculation. However, the Gramacho landfill - RJ, stands out in Brazil for having installed the only large treatment station with systematic operation. The treatment system consists of pond equalization, physical-chemical coagulation treatment and clarification and pH correction, followed by aerobic biological treatment by activated sludge. The polishing of the leachate is obtained by the process of nanofiltration membranes. The leachate generated at the two landfills of Greater São Paulo (Bandeirantes and São João) are transported to the sewage treatment stations of the SABESP concessionaire, where they are discharged. In this article a pilot scale leachate treatment system is conceived that involves three different processes. The design of this system was based on the knowledge of the characteristics of the leachate generated at the Muribeca Landfill with the support of a large bibliographical review, as described below. Based on studies carried out by several authors [7, 8, 9, 10, 11, 12, 13, 14, 15] it was observed that the chemical precipitation with hydrated lime in several leachate treatments in the world showed an efficiency of up to 60% of the BOD (Biochemical Oxygen Demand), 72% of COD, 60% of Ammonium Nitrogen, 90% of heavy metals, 70 to 90% color, turbidity, suspended solids, and dispersed oils. These results demonstrate a partial efficiency that complemented with other steps will tend to achieve a good overall performance. On the other hand [16], analyzing the studies by , [17] reported that the chemical precipitation with calcium hydroxide was not effective in the removal of BOD, COD and nitrogen due to the low flocculation time adopted by the author which was about six times smaller than the one used in this article. According to [16], the landfill leachate was found to have a high concentration of TDS, COD, BOD5 and NH_4-N, and calcium hydroxide removed up to 75% COD at a dose of 20 g/l. More than 90% of the turbidity was removed by the coagulation process using aluminum hydroxide and calcium. In the next step, using the elevation of the pH by the calcium hydroxide previously added, ammonia stripping was performed. According to [15], among the physico-chemical processes, it is the most effective for the removal of ammoniacal nitrogen, where favoring the volatilization of the non-ionized ammonia is obtained by increasing the contact between leachate, air and elevation of pH. Excellent results were obtained by several authors – [17, 19, 20] - in the removal of ammonia and even in the removal of COD. Reference [19] performed the ammonia stripping process on the Jar Test and obtained ammoniacal nitrogen removal by up to 98%. Reference [20] by monitoring 15L of leachate contained in a vessel, removed about 79% of ammoniacal nitrogen [17], performing a combined method of chemical precipitation with hydrated lime followed by ammonia stripping, obtained a removal of about 99% of ammoniacal nitrogen and 55% of COD. The Reactive Barrier System using activated carbon was chosen as the final polishing of the treatment adopted. Its study was based on [21], who obtained a good performance in the removal of organic compounds as tertiary treatment (about 48% of COD). Activated carbon was chosen as an alternative material to compose the barrier due to the low cost, high sorption capacity and selectivity. In addition, studies by several authors [22, 23, 24, 25] proved the efficiency of activated carbon for the treatment of leachate obtaining a removal of COD of 59 to 94%. Reference [12] reported that activated carbon adsorption allowed the removal of 50-70% of COD and ammoniacal nitrogen. A study was made by [26] in Germany - activated carbon columns to treat biologically pretreated leachates with COD 879-940 mg/L. The removal efficiency of non-biodegradable organic compounds and color is very high. The COD value of the effluent dropped to about 80 mg/L, which reached 91% of COD removal. Another study on leachates produced in the La Zoreda landfill in Asturias, Spain, treated with activated carbon, resulted in 85% COD removal of leachates that had previously been recirculated and biologically pretreated with pH 1.5. The activated carbon reduced the initial COD concentration effectively from 1300 mg/L to below 200 mg/L with a homogenization time of 2 hours [27]. The leachate treatment system adopted: Chemical Precipitation followed by Ammonia Stripping and Permeable Reactive Barrier (PRB) was tested in laboratory scale (batch system) and Pilot Scale in the field (continuous flow system). The efficiency and launching standards of the pilot scale system were guided by the federal legislation [28], and the state. It is noteworthy that the Minas Gerais state standard was used to analyze the efficiency of removal of BOD and COD because its legislation is the only one in Brazil directed to the treatment of landfill leachate of urban solid waste. The objective of this work was to evaluate and propose an experimental treatment system for leachate of urban landfills of solid waste using a physical and chemical process, analyzing its efficiency and launching standards, based on Brazilian federal legislation.

2. Materials and Methods

This section is divided into three parts. The first is a brief history of the Muribeca Landfill (Jaboatão dos Guararapes, Pernambuco, Brazil). The second part presents the care taken during the collection, preservation and sampling of the leachate at the Muribeca Leachate Treatment Station and during its arrival at the laboratory. The physical-chemical parameters that constituted the physical-chemical characterization of the leachate were also presented. The third stage presented the methodology of the pilot tests of the system in a continuous flow scale based on the studies of the laboratory tests, besides presenting the methodologies of the tests to obtain the efficiency of the system. This system was built and operated at the Muribeca landfill.

2.1. History

The landfill is located in the rural area of Jaboatão dos Guararapes, in the locality of Muribeca dos Guararapes, near the Integration Hub in Prazeres - Jaboatão, about 16km from the center of Recife. The layout area is among the following coordinates: 280,000 to 282,000 East and 9,096,000 to 9,098,000 North, occupying a total area of 60 hectares, with a perimeter of 3,848 meters. It was the largest landfill in operation in the state of Pernambuco, receiving around 2,400 tons of regular solids (household waste), bulky solids (scraps and scrapings) and pruning residues by July 2009. The average gravimetric composition of the landfill, based on secondary data: 46.3% of organic matter; 12.2% paper / cardboard; 19.4% plastic; 1.9% metal; 2.7% wood; 3.5% of textile materials; 0.8% rubber and leather; 1% glass; 3.6% of disposable diapers; 6% coconut and 2.6% others. This region has been degraded since 1985, when the landfill operated as an open pit. In 1994, a local diagnosis was made to recognize its physical environment: geology, hydrogeology, geotechnics, morphology, water resources and meteorology, allowing the recognition of the subsoil, the superficial and deep-water sheets and the mapping of rock failures. After the diagnosis, a study of the waste treatment process and environmental recovery was started, aiming at the transformation of the landfill into a controlled landfill. This process consisted of the construction of nine cells, with a mean width and length of, respectively, 200 x 200 m, and height ranging from 20 to 40 m. In 2002, with the study of the waste treatment process and the environmental recovery of the Muribeca landfill duly approved by the State environmental agency, work began on the implementation of gas and leachate drainage systems, in addition to the implementation of the Leachate Treatment System. The conception adopted was a biological treatment through stabilization ponds (01 anaerobic followed by 03 facultative) and biochemical treatment through phytoremediation. Regarding the efficiency of the Leachate

Treatment Station, the state environmental agency stated that the effluent showed high values of COD and BOD after verification of the results of the physico-chemical and toxicity test certificates. After the passage through the anaerobic pond and the third facultative pond, the effluent shows a reduction of about 87% in BOD and 34.5% in COD. As can be seen, with respect to the BOD removal rate, the system performs reasonably well, but with respect to COD the system needs to greatly improve its operational performance. However, the content of heavy metals is within the scope of existing environmental legislation. The closure of Muribeca's Controlled Landfill occurred in July 2009, as it was characterized by the Public Prosecutor's Office as an inadequate form of disposal of municipal solid waste. In this same period, besides the prohibition of the entrance of new residues, the recovery of this landfill began, realizing the total coverage of the plateaus and the planting of native species of the Atlantic Forest in the whole area. There is a natural tendency of the leachate to become less biodegradable since the BOD / COD ratio tended to be decreasing, which would compromise the current treatment system adopted (Stabilization Ponds), necessitating the elaboration of a treatment system using physical and chemical processes to treat leachate efficiently.

2.2. Collection Technique

The sampling technique was based on the [29] and consists of an apparently simple task. It was necessary to obtain a representative and stabilized sample of the sampled effluent and local conditions that could interfere both in the interpretation of the data and in the laboratory determinations. Some precautions were taken during collection of effluent samples at the entrance of the Leachate Treatment System:

- The collected samples should not have large particles, or debris, or leaves;
- The samples were collected in a vial against the current;
- About 5 liters of leachate were sampled in each sampling campaign, conditioned in plastic bottles previously sterilized for the physico-chemical analyzes;
- For the microbiological assays about 200 milliliters were sampled in previously sterilized glass containers. After sampling, the vials were placed in an ice bath at a temperature of approximately 4 °C;
- The frequency of the sample depended on the type of sampling performed.

Sampling is of fundamental importance in the monitoring, not constituting solely in the collection of the samples to be analyzed but involving the planning of the sampling activities from the field to the laboratory. Two types of sampling were performed for these studies: simple and composite. Simple sampling was performed in a single sample at random. For this research, this type of sampling was performed during pilot scale trials. The composite sampling was formed by small and different aliquots collected over time. This type of sampling was carried out in this research for the characterization of leachate in different months of the year. It should be noted that for each day of sampling, ten aliquots of 500ml of leachate were collected in the interval of one hour, between 8 and 17 hours, forming at the end of the day a homogeneous sample of 5 liters. The samples were collected at the entrance of the Decantation Pond of the Muribeca Landfill Leachate Treatment Station, where all leachate from the landfill is concentrated, as indicated in Figure 1. Due to the great variability of leachate composition, the collected samples were previously analyzed for their physicochemical characterization. To characterize the leachates, the following parameters were selected: COD, BOD, pH, conductivity, color, turbidity, alkalinity, solids series, ammoniacal nitrogen and heavy metals (Iron, Manganese, Zinc, Chromium, Copper, Lead and Nickel). The methodology adopted for physico-chemical analysis of the leachate was based on the procedures established by the Standard Methods for the Examination of Water and Wastewater [30].

Figure 1: Leachate Collection Point.

2.3. Pilot Scale Test

The Pilot Station was designed with 7 treatment units, built in acrylic, with the purpose of visually accompanying the processes that occur within this system as observed in Figure 2. These were interconnected by 1 "diameter PVC hoses with 1% slope to favor effluent passage through gravity. The station was designed based on the physical-chemical characteristics of the leachate from the Muribeca Landfill. In addition, the flow used for the pilot scale was 0.1 L/s, about 10% of the actual flow rate of the Muribeca leachate treatment. The determination of hydraulic holding time for flocculation units and reactive barrier of the pilot scale system was based on the best performance obtained in COD removal during laboratory tests. On the other hand, the ammonia stripping unit based its design on the removal of ammoniacal nitrogen. The decanter was scaled based on the method of [31], which treated sewage efficiently using sedimentation as one of its stages. For this research, the variables used by the author were adequate to the characteristics of the leachate to be treated. As for its characteristics, it has a prism shape with an approximate volume of 0,2 m^3, where its length is double the width to facilitate the sedimentation of the precipitate.

Figure 2: Sequence of the Pilot Station: A) Chemical Precipitation; B) Decanting; C) Ammonia stripping; D) pH correction; E) Reactive Barrier; F) Mixing Box for Lime and Water; G) Mixing Box for Acid and Water.

As for the sizing of the mixing tanks, they were also based on the studies of [31], with the best stirring time in the removal of COD from the leachate according to the results obtained during laboratory scale tests. They have cube shapes, in order to obtain a homogeneous mixture, with dimensions of 0.60 x 0.60 x 0.60m. The lime and acid dosages were performed by automatic dispensers of type AWG 5900 - 120 A, with electronically adjustable flow rate with digital control between 40.0 and 120.0 L/h and still equipped with a non-toxic silicone hose. The rotation of 120 rpm for stirring in the mixing ponds was also based on laboratory tests. As for the stage of ammonia stripping on a pilot scale, an aeration rotation superior to the air flow injected in the leachate was used during the laboratory tests in order to obtain a better performance in the removal of ammonia. The unit has a cube shape, with dimensions of 0.60 x 0.60 x 0.60 m and the propeller used to perform the system bubbling has a rotation of 480 rpm. The Reactive Barrier System was dimensioned in accordance with the existing system in the Muribeca Landfill Treatment System, with the barrier having compatible dimensions in real scale. The pilot scale reactive barrier was constructed entirely of stainless steel. Its screen has a diameter of 200 mesh. This barrier was inserted into a cube-shaped acrylic box (0.60 x 0.60 x 0.60 m), where its base and sides were filled with silicone to prevent leachate from passing through. The system start-up was performed by filling all the boxes with leachate (as in Figure 3), except for the reactive barrier system, simultaneously connecting all mechanical agitators and the peristaltic pump.

Figure 3: Start-up of the System in Pilot Scale.

The crude leachate from the decantation pond of the Muribeca Landfill Leachate Treatment Station was pumped through a peristaltic pump, model GA 9300, with a flow rate of up to 350 L/h and also equipped with a non-toxic silicone hose. The leachate was fed to the flocculation box through the automatic doser. After the flocculation step, through the PVC hoses, the leachate, by gravity, reaches the decantation stage. The quantification of the sludge generated was based on the laboratory tests performed by [19]. The sludge generated by the precipitation step was removed in the final step of each test performed in order not to compromise the system hydraulic detention time (HDT). This removal is performed through a valve in the base of the decanter. After the decantation stage, the leachate is then removed to a stripping box where it is aerated through a mechanical stirrer (with an approximate rotation of 480 rpm) to perform the volatilization of free ammonia with a 30-minute HDT. Upon passing the ammonia stripping step, the leachate is still gravitationally taken to the hydrochloric acid dosing step, where the acid was diluted with water in the ratio of 1:9. It tends to lower the pH to fit the launching standard since the latter is above 11. The propeller rotation of both mixing boxes is approximately 120 rpm and the hydraulic holding time for each was 20 minutes. With the adjusted pH, the leachate is gravitated to the reactive barrier system where the adsorption process occurs through the activated carbon, with HDT of approximately 10 minutes according to the percolation tests performed. Afterwards, the analysis of the release standards for each parameter analyzed in the leachate was carried out, in accordance with the state and federal laws, since the effluent disposal stage occurs. The analyzes consisted in the removal of aliquots of 500mL of crude and treated leachate at each stage - Precipitation, Stripping, Acid Dosing and Reactive Barrier. Four tests were carried out, lasting 2 hours each. The following parameters were analyzed: color, turbidity, BOD, COD, conductivity, temperature, dissolved oxygen and pH. The total detention time for the system was 2 hours, where the detention time for the leachate and lime milk mixing box was estimated to be about 30 minutes; the settling box in 30 minutes; the stripping box in 20 minutes; the mixing box of the leachate with acid in another 30 minutes, and finally the reactive barrier system in about 10 minutes. The sampling was simple, where the volume of liquid effluent was collected in a single sample. Regarding the preservation of the sample, it was performed according to the techniques used and described in [29].

3. Results and Discussion

3.1. Sample Characterization

In this stage, the characterization of the leachate of the Muribeca Landfill was carried out, obtaining a range of values (minimum and maximum) for all parameters obtained, comparing with other leachate characteristics of Brazilian landfills. The initial characterization of the leachate also served as a basis for the choice of the treatment system to be adopted. The results of the characterization of the leachate made through the composite sampling in the period in which the leachate was most concentrated are presented in Table 1, and these results are discussed throughout this section. It should be pointed out that during the collection period the vast majority of waste from the landfill was old (t > 5 years), with only a small fraction of new waste. The maximum pH range was between 8.2 and 8.7, indicating a landfill leachate in the methanogenic phase, as observed by [32]. At this stage there is decomposition of acid fermentation products which are converted into methane (CH_4), humic substances and water. With this pH range, the low concentration of heavy metals present in the leachate of the Muribeca Controlled Landfill can be justified since the high pH reduces the availability of contaminants [33]. According to [34], this pH range is within the range of values most probable for Brazilian landfills. According to Table 1, it was observed that the alkalinity has a maximum concentration range between 5,867 and 8,375 mg/L, which, according to [34], is in the maximum range of Brazilian landfills.

Table 1: Characterization of the leachate of the Muribeca Landfill.

Parameters	*Aug/07*	*Sep/07*	*Nov/08*	*Dec/08*	*Nov/09*	*Dec/09*	*Maximum Range*
pH	8,46	8,58	8,70	8,63	8,21	8,36	8,21 - 8,70
Alkalinity (mg/L $CaCO_3$)	5.867	7.666	7.838	7.600	8.375	6.917	5.867 - 8.37
BOD_5 (mg/L)	2.320	2.430	3.185	3.190	1.140	500	500 - 3.190
COD (mg/L)	3.307	3.467	4.293	4.735	3.600	3.800	3.307 - 4.73
BOD_5/COD	0,70	0,70	0,74	0,67	0,32	0,13	0,13 - 0,74
Color (Hz)	8.683	8.645	10.550	10.355	8.850	8.830	8.645 - 10.5
Turbidity (NTU)	193,3	163,2	137	188	106,8	80,3	80,3 - 193,
Conductivity (mS/cm)	18,24	20,63	21,33	19,40	24,16	24,73	18,24 - 24,7
Nitrogen Amoniacal (mg/L)	1.708	1.446	1.532	1.125	2.900	2.050	1.125 - 2.90
Total phosphorus (mg/L)	14,62	8,25	13,75	11,5	9,75	NA**	8,25 - 14,6
Sulfates (mg/L)	764	967	880	662	NA**	NA**	662 - 967
Sulfides(mg/L)	1,05	1,26	1,06	1,23	0,37	0,65	0,37 - 1,26
Chlorides (mg/L)	227	245	760	NA**	230	140	140 - 760
ST (mg/L)	8.990	10.100	11.469	10.804	10.772	10.862	8.990 - 11.4
SDT (mg/L)	7.022	8.188	9.387	9.524	10.012	9.944	7.022 - 10.01
SST (mg/L)	1.968	1.912	2.082	1.280	760	920	760 - 2.082
Fe (mg/L)	5,78	7,23	9,21	6,46	7,22	4,45	4,45 - 9,21
Mn (mg/L)	0,22	0,22	0,31	0,26	NA**	NA**	0,22 - 0,31
Zn (mg/L)	1,03	1,97	1,37	0,79	1,20	NA**	0,79 - 1,97
Cr (mg/L)	0,16	0,26	0,33	NA**	0,10	0,28	0,10 - 0,33
Cu (mg/L)	0,2	0,7	0,12	ND*	NA**	NA**	0,12 - 0,7
Pb (mg/L)	ND*	ND*	0,1	NA**	NA**	NA**	ND - 0,1
Ni (mg/L)	0,14	0,22	0,30	0,12	NA**	NA**	0,12 - 0,30

* Not detected ** Not analyzed

According to [35], the results of the algal toxicity test suggests that the concentration of ammonia is the most important factor in the toxicity of the landfill leachate. According to [34], a maximum concentration range of 1,125 to 2,900 mg / L was obtained for the leachate under study, and is characterized by the maximum range of Brazilian landfills. On the other hand, according to [36], through calculations using mathematical regression applied to physico-chemical and toxicological parameters, they obtained confirmation that alkalinity and ammonia may be the main contributors to the toxicity attributed to leachate. Thus, it is necessary that the pH and the alkalinity of the leachate that will be released in the receiving body be controlled, so as not to create favorable conditions for the ammonia to appear in the toxic form. In the specific case of the Muribeca landfill leachate, concentrations of ammoniacal nitrogen varying between 1,125 and 2,900 mg / L, with a high alkalinity value and a pH 8.6, may indicate that the ammoniacal nitrogen is in the ionized form NH_4^+. However [37] explains that in alkaline environment, there is a possibility of increasing the concentration of the non-ionized form (NH_3) which is toxic. Also according to Table 1, the BOD_5/COD ratio could be observed a change in the biodegradability of the leachate during the analyzed years. In the years 2007 and 2008, the landfill received urban waste daily, while at the end of 2009 the Muribeca Landfill no longer received residue and the cover layer was already fully implemented, which may have contributed to the reduction of the BOD_5/COD. The total solids are subdivided into: Suspended and Dissolved. The total solids, suspended or dissolved, can be organic (or volatile) and inorganic (or fixed) and that according to their chemical concentrations can result in aesthetic and environmental problems. According to Table 1, it was verified that the concentration of Dissolved Total Solids corresponds to approximately 80% of the Total Solids, indicating that the dissolved solids are predominant in the leachate composition, being in agreement with [34], which stated in terms of solids, predominate in leachate dissolved solids, unlike domestic effluents, where suspended solids predominate. The true or actual color of the leachate is related to dissolved solids and colloids, more specifically to the presence of humic and fulvic substances. Reference [38] observed that over time the aromatic molecules and components of the humic substances also increase, that is, as the leachate grows older, the color tends to become more concentrated. According to Table 1, of the characterization of the leachate, no significant change in the color of the leachate after the closure of the landfill has been noticed. The most probable concentration range found for the color ranged from 8,645 to 10,550 Hz, which may indicate a concentrated leachate in humic and fulvic substances. Turbidity is related to the suspended solids that cause diffusion and absorption of light, caused by plankton, bacteria, clays and suspended silts, sources of pollution that throw thin material and others. It is due to the presence of colloidal particles, in suspension, of organic or inorganic nature and other microscopic organisms. According to Table 1, the turbidity varied between 80.3 and 193.3 UNT, showing a very turbid effluent when compared to the sewage, indicating the need for physical or physico-chemical process for its removal in the leachate. The electrical conductivity of a material is determined by the presence of dissolved substances that dissociate into anions and cations depending on the temperature. Metallic ions generally combine with nonmetallic compounds (acids or bases) called binders. In a landfill the most common binders are certain anions (chlorides, phosphates, sulfates), nitrogen, humic acids and amino acids [39]. In the analyzed leachate samples, the maximum range obtained was 18.24 and 24.73 mS/cm at the entrance of the Muribeca Landfill Leachate treatment system for different periods. All life forms are affected by the presence of metals depending on the dose and the chemical form. It should be noted that, in general, metals are essential for the growth of all types of organisms, from bacteria to even humans, but they are required in low concentrations and can damage biological systems. The measured levels of some heavy metals in the samples are shown in Table 1. Among the values of heavy metals presented, it is observed that the majority of these are well below the maximum values allowed for discharge of effluents in receiving bodies, except for Iron levels that are above the launch standard by [28], confirming statements by [17], that the concentration of heavy metals in the landfill leachate in the fermentation stage should have low levels of heavy metals due to metallic solubilization and complexation of volatile fatty acids, and the risks of environmental contamination are due more to the processes of accumulation [40]. High iron concentration found, may also be justified by the high content of this metal present in the clay used as the residue cover layer in the Muribeca Landfill. In general, the characteristics of the leachates presented in Table 1, tended, of course, to be reduced after closure, since the Muribeca landfill did not receive any new residues and has its coverage layer effected. Thus, the BOD / COD ratio tended to decrease, the availability of the metals becomes lower as a function of the pH increase and the amount of total phosphorus available may have been reduced by the consumption of the microorganisms inside the cell. However, an increase in ammoniacal nitrogen was observed after landfill closure. Reference [41] reports that the concentration of nitrogen in the leachate is not particularly dependent on the degradation phase at which the solid residue is subjected. In both phases, simple and methanogenic acid formation, most landfill leachates contain high concentrations of nitrogen, mainly in the form of ammonium ion. An effluent containing ammoniacal nitrogen in concentrations ranging from 1,125 to 2,900 mg / L, with a high alkalinity content and a pH of 8.6, together with COD values above 3,000 mg / L is considered, according to [42], as difficult to treat by biological method, mainly due to the high toxicity that the nitrogen can offer. In addition, high leachate color values make it difficult to treat leachate through stabilization ponds, since the essential colors (green and blue) for the photosynthetic process cannot be absorbed by the microorganisms present in the ponds. Finally, for an efficient treatment in the removal of the organic matter of a leachate that tends to recalcitrance, it is necessary to use physicochemical and / or adsorptive processes efficient in the reduction of compounds of difficult biodegradation and ammoniacal nitrogen. Thus, in this research were carried out studies of chemical precipitation with hydrated lime, followed by stripping the ammonia and having as final polishing the Reactive Barrier. The studies of each step of the suggested treatment will be presented in the next section.

3.2. Installation and Operation of the Pilot Station

Pilot scale trials were conducted in the field near the Muribeca Leachate Treatment Station for a period of three months. Six tests were performed. However, the first two were performed only to adjust and monitor the functionality of the system (leaks, propeller rotation ...), and their results were not presented. Pilot scale tests 1 and 2 were based on a medium biodegradability leachate, while tests 3 and 4 were based on a readily biodegradable leachate. The chemical precipitation stage used was the concentration of lime milk (17 g/L) and flocculation time (30 minutes) considered ideal for COD removal, determined during laboratory tests. This stage was fundamental in the proposed system, since it obtained a good performance in the removal of color and turbidity, parameters considered the main ones responsible for the saturation of the reactive barrier. In addition, the chemical precipitation provided a pH rise higher than 11, considered ideal for ammonia stripping. In the Stripping unit, the aeration lasted only 20 minutes, a much shorter time than necessary. In addition, air injection was not used as proposed in laboratory tests in order to avoid leakage points or even cracks in the acrylic box. Thus, a surface aeration was used with an efficiency similar to the flow rate of 10 L / min. It was observed that the performance obtained in this unit was well below when compared to the laboratory tests. The average pH obtained at this stage was 12.5, the same as the chemical precipitation. In the pH correction step, a homogenization system with rotation of 120 rpm was used for a homogenization time of 30 minutes, mixing leachate and hydrochloric acid - diluted with water at a ratio of 1: 9. The average pH that contributed in this unit was, on average, 11.7; with the addition of acid, dropped to 9, the maximum value allowed for launch, according to the requirements of [28]. During the reactive barrier stage, the pH was practically unchanged.

3.3. Performance of the Pilot Station by Units

Table 2 shows the average performance of each treatment unit proposed for the four pilot scale trials performed with medium biodegradability leachate from the Muribeca landfill. The maximum and minimum percentage obtained for each parameter during several steps were also presented in Table 2.

Table 2: Maximum and minimum percentage of reduction for each treatment step.

Sample:	*Chemical precipitation*	*Ammonia stripping*	*PH correction*	*Reactive barrier*
Ammonia	Mín. 3,9%	Min. 9,8%	Min. 2%	Min. 21,2%
	Mean 13,5%	Mean 12,6%	Mean 6,2%	Mean 40,6%
	Max. 20,5%	Max. 15,1%	Max. 9,5%	Max. 56%
Conductivity	Min. -54,4%	Min. 0,1%	Min. 19%	Min. - 8,8%
	Mean 48,3%	Mean 6,6%	Mean 28%	Mean 8,8%
	Max. -44,9%	Max. 14,1%	Max. 35%	Max. 31%
Turbidity	Min. 68,1%	Min.-43,3%	Min. -43,3%	Min. 15,5%
	Mean 79,6%	Mean - 8,8%	Mean -13,5%	Mean 33%
	Max. 88,8%	Max. 22,6%	Max. 9,7%	Max. 64,7%
COD	Min. 27,6%	Min. 3,5%	Min. 23,7%	Min. 18,9%
	Mean 45,7%	Mean 8,6%	Mean 30%	Mean 50,5%
	Max. 58,2%	Max. 16%	Max. 34,3%	Max. 63,9%
Color	Min. 74,6%	Min. 3,9%	Min. 6,9%	Min. 41,5%
	Mean. 85%	Mean 8,8%	Mean 30,3%	Mean 59,4%
	Max. 97,9%	Max. 13,1%	Max. 68,5%	Max. 81,2%

a) Chemical Precipitation Unit:

Analyzing the chemical precipitation stage, it was observed that the average performance in the removal of Color, Turbidity, COD and ammonia were, respectively, 85%; 79.6%; 45.7% and 13.5%, for an average pH of 12.5. In turn, the conductivity increased by an average of 48.3%. Overall, the color removal performance ranged from 74.6 to 97.9%; the turbidity removal ranged from 68.1 to 88.8%; while removal of COD varied from 27.6 to 58.2% and ammonia was removed in the range of 3.9 to 20.5%. These results are superior to those obtained by [19], who analyzed in the laboratory three samples of medium biodegradability leachate from the Muribeca

Landfill using chemical precipitation with solid hydrated lime at an average pH of 12.5. The removals obtained by the author were 10.3 to 28.6% of COD; 64.8 to 85.5% of the color; 50 to 70% of turbidity. Reference [17] obtained superior performances for the parameters of conductivity (maximum reduction of 12%) and ammonia (maximum removal of 31%). Reference [43] obtained a COD removal lower than that obtained in this research, where the performance obtained by the authors ranged from 30 to 45% for pH 12 using lime to treat urban waste landfill leachate. The high performance of the chemical precipitation with hydrated lime in the removal of COD, color and turbidity when compared to other authors, may be related to the quality of the lime used in the treatment, which has less amount of impurities (SiO_2, Al_2O_3, Fe_2O_3, P_2O_5) when compared to commercial limes. In order to evaluate the ideal lime milk concentration as well as the flocculation time, laboratory tests were performed based on the removal of COD, because a fast test result was obtained when compared to BOD. In addition, color removals, turbidity and conductivity were also evaluated. Another hypothesis would be the characteristic of the medium-biodegradable leachate that has organic matter with molecular weight above 50,000 gmol / L, facilitating the precipitation of the contaminants, according to [23]. The third hypothesis would be the flocculation time superior to that used by the several authors, Reference [17, 44] that did not exceed the time of 20 minutes. This last hypothesis would be more probable since [17] used the medium biodegradability leachate from the Muribeca landfill and the same type of lime to treat the leachate. However, the author used a flocculation time of only 5 minutes, about six times less than that used in this research.

b) Ammonia Stripping Unit:

The average performance of ammonia removal in the stripping unit was 12.6%; the color with 8.8%; COD (8.6%) and Conductivity (6.6%). Meanwhile turbidity increased by an average of 8.8%. The stripping efficiency of ammonia was mainly influenced by pH. The alkalinization of the medium with $Ca(OH)_2$ probably promoted the displacement of the dissociation equilibrium of the ammonia in the direction of release of this in the molecular form (NH_3), which was stripable. However, the low performance in the removal of ammonia was due to the short hydraulic holding time. In general, the performance in the removal of ammonia varied in the range of 9.8 to 15.1%; the color removal ranged from 3.9 to 11.4%; the removal of COD varied in the range of 3.5 to 16% and the conductivity underwent removals ranging from 0.1 to 14.4%. Although the tests were performed with different aerations in the laboratory, the results presented regarding COD removal indicated that the increase of air flow practically does not interfere with the reduction of the final concentration of this parameter, since the results corresponding to the air tests were very similar to those presented by the non-aeration test. Therefore, a justification for low COD removal values may be related to the fact that the reduction occurs due to the precipitation of the compounds over the monitoring period or the volatilization of organic compounds. Reference [17] performed the ammonia stripping with different air flow rates (2, 5, 10 L/min) in the laboratory, obtained ammonia removals in about 99% for a time of 12 hours, and flow rates varying between 5 and 10 L/min. [45] compared different concentrations (0, 3, 5 and 10 L/min) over time and maintained the sample at pH 12, obtaining maximum removal values for ammonia at about 95.3% at 10 L/min and 89.9% at 5 L/min in 12 hours. Results from other studies reported in the literature, using pretreated leachates with calcium hydroxide and pH 12, indicated an 85% stripping removal with an aeration of 7.6 L/min and 93% using 5 L/min for one period of 17 and 24 hours, respectively [35, 46]. It was found that the detention time of 20 minutes used in this unit greatly impaired the performance in the removal of ammonia and other parameters. During the laboratory tests carried out for this research, as observed in sub-item 4.3, the time of detention of 12 hours obtained similar performance to those recorded by the aforementioned authors. The COD removal performance during the stripping stage was also well below when compared to the studies by [17] that obtained COD removal in the range of 34 to 41%, in a laboratory scale. The authors also found that the increase in air flow did not promote large changes in COD reduction, since the difference between 2 and 10 L / min was only 8.5%, confirming the need for a higher detention time at this stage, since the increase in air flow did not increase COD removal efficiency.

c) pH Correction Unit

The pH Correction unit is not designed to remove contaminants, but only to lower the pH to the conditions required by [28]. However, analyzing the unit, it was observed a good performance in the removal of Color, COD and conductivity, obtaining even superior efficiencies to the stage of the Ammonia Stripping. In general, the color removal performance was 6.9 to 68.5%; the conductivity reduction ranged from 19 to 35%; while removal of COD varied from 23.7 to 34.3% and ammonia still decreased by 2 to 9.5% as a result of possible volatilization. The average removal performance was 30.3%; 30%; 28% and 6.2%, for color, COD, conductivity and ammonia, respectively. In turn, the turbidity suffered an average increase of 13%. In fact, the pH correction unit may have functioned as an aeration step, where the agitation performed by the propeller at a rotation of 120 revolutions per minute can insert dissolved oxygen, transforming the ammonia into nitrite and / or nitrate, in addition to reducing the COD and color content.

d) Reactive Barrier System with Activated Carbon

In general, as final polishing, the system obtained a good performance in the removal of color (59.4%), COD (50.5%), ammonia (40.6%), turbidity (33%) and conductivity 8.8%) for a pH of 9. The removal of the contaminants may have occurred through a physical adsorption process, since the activated carbon is an excellent adsorbent due to its large specific surface. The removal of the leachate color by activated carbon varied in the range of 41.5 to 81.2%. This high color removal efficiency is mainly due to the reduction of the long chain molecules present in the humic substances of the leachate during the chemical precipitation stage, facilitating adsorption in the activated carbon micropores. Through the adsorption capacity of the activated carbon, COD removal varied in the range of 18.9 to 63.9% and ammonia in up to 56%, being in agreement with [11] that obtained a removal of 50 to 70% of COD and ammonia for landfill leachate. In addition, Reference [8, [47] obtained a clarified leachate with 25.4% removal of COD. The removal of turbidity varied from 15.5 to 64.7%. This variation of the turbidity performance is due to the behavior of the reactive barrier, which functions as an activated carbon filter, being able to obtain a low or high performance in function of the efficiency of the treatments that precede it. The conductivity had its worst performance with an increase of about 8.8% and obtaining a better performance with a reduction of 31%, also its efficiency varies according to the primary and secondary treatments, where the low performance in the chemical precipitation can provide an excess of calcium ions, raising the conductivity, thus reducing the bearing capacity of the barrier system.

3.4. Pilot Station Overall Medium Performance

Table 3 presents a mean of all the performances obtained, by parameters, for the pilot scale tests performed, as well as the overall average performance of the adopted system. In general, the system obtained on average a removal of 94.6% of color; 83.2% COD; 80% BOD; 84.5% Turbidity; 58.2% of Ammonia and a reduction in Conductivity of 10.6%.

Table 3: Average reduction percentage for each treatment step.

Test	*Ammonia (%)*	*Conductivity (%)*	*Turbidity (%)*	*COD (%)*	*BOD (%)*	*Color (%)*
1	66,4	12,2	89,8	81,9	NA*	95,9
2	43,8	14,1	82,8	74,3	NA*	88,2
3	65,1	15,4	90,4	87,2	80,0	97,3
4	57,3	0,7	75,0	89,2	80,0	97,0
Mean	58,2	10,6	84,5	83,2	80,0	94,6
Standard deviation	10,4	6,7	7,2	6,7	0,0	4,3

*Not analyzed

Several authors have published pilot and real-scale work to determine an efficient and economically viable treatment system. Reference [48] suggested, using a large-scale system, the use of a biological treatment with three batch reactors (with nutrient dosages and pH control in each tank), followed by an equalization tank, before passing through a flotation system through dissolved air and, as polishing, the effluent was treated through a wetland system. This system was designed to treat a flow rate of 3.5 L/s for a COD of 8,000 mg/L and 2,500 mg/L of ammonia. For an initial BOD of 688 mg/L, the authors obtained a 99.85% removal, whereas for an initial COD of 5,990 mg/L, the removal was 83.13% and for Ammonia with an initial concentration of 1460 mg/L, 99.9% removal was obtained. Comparing with the mean results obtained on a pilot scale, Reference [53] obtained a higher removal for BOD. However, for an average pH of 8.3 used by the authors, it is probable that all ammonia has been nitrified to the nitrate form, being this parameter above the maximum allowed for the current legislation. The leachate color was not analyzed for this research. Reference [49] performed real-scale tests in Malaysia, using the following sequence: biological treatment followed by flotation, Wetland and Irrigation, as observed in Figure 4.69. The authors obtained a removal of 42.7% of COD, 95.3% of BOD, in addition to an ammonia reduction of about 99%, and an increase of Nitrate by more than 90%, since through the diffusion with air and neutral pH, practically oxidize all the ammoniacal nitrogen in nitrate. The efficiency of COD removal portrayed by the authors was low when compared to the system conceived. However, the efficiency of BOD removal and ammonia reduction were higher. However, there was a transformation of the ammonia into nitrate through the oxidation inserted in the treatment, being with a very high value and percentage for release according to [27]

3.5. Cost analysis

In general, it was noted that the higher financial cost was linked to direct costs, specifically in the purchase of inputs of hydrochloric acid and activated carbon. However, it is worth highlighting the possibility that these values fall sharply due to the large quantity purchase of these inputs. By calculating the final cost of the treatment in terms of direct and indirect costs, an average value of \$6.20/m^3 of treated leachate is obtained. The costs were calculated considering the m^3 treated leachate for the pilot scale. For a full-scale treatment, also adding the direct and indirect cost, the total cost for a treatment with average flow rate of 1 L/s, the total value of \$ 6 for each m^3 of treated leachate was obtained. Currently, the City Hall of Recife treats the leachate at Muribeca Landfill through stabilization ponds, costing around \$ 1,5/m^3. Reference [50] suggested the value of \$ 4,60/m^3 of leachate treated only for the step of Ammonia Stripping by raising the pH to 10. However, authors treating leachate with a piston flow reduced the cost to \$ 7,5/m^3. Reference [51] indicated the use of advanced oxidative processes using fenton reagent and obtained a cost of \$ 5,50/m^3. Reference [52], studying the treatment of leachate with PAM ($MgCl_2.6H_2O$ and $Na_2HPO_4.12H_2O$), estimated a cost of \$ 336,00/m^3 of treated leachate. Based on the conception adopted for this study and the flow rate of 1 L/s, it was observed that the total cost suggested by [58] was R\$ 4.96 - Coagulation, Stripping and Activated Granular Carbon - a percentage of 83% lower when compared to the one performed by this study. But some factors must be considered. Initially, the dollar value used by [44] was 16 years ago. In addition, the indirect cost was not considered in this survey, being well outdated to the reality of a treatment station. In general, the cost of treatment obtained for this study - \$ 6,58 - was below that found by other authors. However, the different forms of cost evaluation often make it impossible to compare studies.

3.6. Pilot Scale System Limitations

The ammonia stripping box was sized for a detention and homogenization time below the minimum 12 hours required, so as not to lose the characteristic of a pilot structure. The use of a higher rotation aeration system would require more sophisticated equipment as well as a higher energy expenditure.

4. Conclusion

The chemical precipitation is an essential tool for the treatment of leachate, even for different BOD / COD ratios, since it presented a good performance in the removal of BOD, COD, Color and Turbidity of the leachate of the Muribeca Landfill. It was observed that the color tends to decrease with the pH increase since there is a greater availability of the Ca^{++} divalent cation, increasing the molecular weight, mainly of the organic salts, precipitating the organic matter, as observed in the Pearson correlations that varied from strong to very strong for the relation color versus pH. In relation to the study of Ammonia Stripping, the mean concentration of ammoniacal nitrogen - in the 12 hour period - for the flows of 4, 7 and 10 L/min were, respectively, 13, 7 and 2 mg/L, reaching all flow rates analyzed on a bench scale, values below 20 mg/L (limit established by CONAMA Resolution 430/11 for the discharge of effluents). In general, it was observed that the stripping method can be promising not only for the removal of ammoniacal nitrogen, but also for COD. However, air pollution still presents as one of the main drawbacks of the method, requiring targeted studies aimed at reducing it. As for the reactive barrier system with activated carbon, it should be used as the final polishing step of a leachate treatment system, since the kinetic profile analyzes for crude and pre-treated leachates showed a better performance in the removal of COD, Ammonia and Color for the pretreated leachate.

5. Recommendations

As for future recommendations, it is suggested to use experimental design (ED) techniques in order to optimize factors conditioning the precipitation reaction, using an optimization study for different variables that interfere in the process, besides analyzing the quantity and sludge quality generated by chemical precipitation during pilot scale trials. Resizing the ammonia stripping box to 12 hours can be considered an essential recommendation in order for the pilot scale system to function efficiently in the removal of ammoniacal nitrogen. However, in order not to lose the characteristic of a pilot structure, it is suggested to use the most efficient rotation aeration system.

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