

BIOLOGICAL TREATMENT CONJUGATED OF LANDFILL LEACHATE AND WASTEWATER

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Abstract:

Landfill leachate is a liquid waste with high concentrations of organic and inorganic matter, recalcitrant compounds, ammoniacal nitrogen, among other contaminants that can cause adverse effects on the environment. In view of its chemical characteristics, the leachate needs treatment before being launched into receiving bodies. Therefore, the objective of the present work was to evaluate the performance of a biological treatment system for landfill leachate plus domestic sewage, on a pilot scale, consisting of a UASB reactor, a percolator biological filter (PBF) and an anoxic reactor (AR). The substrate used to feed the UASB reactor consisted of a mixture of domestic sewage (97%) plus landfill leachate (3%). The mean efficiencies for the removal of total and filtered chemical oxygen demand, total suspended solids were, respectively, 82, 64 and 88%. Low efficiency of removal of ammoniacal nitrogen was observed in the FBP, providing a reduction of 16%. In the anoxic reactor, the denitrification process was observed, producing effluent with an average concentration of 0.42 mg.L⁻¹.

Keywords: Wastewater; biological treatment; nitrification; denitrification.

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INTRODUCTION

The economic development associated with population growth has directly influenced the generation of urban solid waste (USW), which requires proper disposal and treatment (Besen & Fracalanza, 2016; Miao *et al.*, 2019). Currently, the most appropriate technical option for the final destination of USW is the sanitary landfill (Aharoni *et al.*, 2017; Han *et al.*, 2016). However, this method of destination produces leachate from sanitary landfill, which is a liquid waste with complex chemical characteristics.

According to Sá *et al.* (2012), about 55% (percentage by weight) of USW are made up of putrescible organic matter. When confined to a sanitary landfill and in the presence of a significant percentage of water and in a medium with no free molecular oxygen, the bioconversion process of this organic matter generates leachate from the sanitary landfill, a liquid residue that has high concentrations of ammoniacal nitrogen and recalcitrant organic matter, which tend to hinder the treatment of this effluent (El-Gohary & Kamel, 2016; Bashir *et al.*, 2013).

The inadequate management of leachate generated in landfills can cause negative environmental impacts, in order to compromise the availability and quality of natural resources. To protect the environment, the sanitary landfill leachate must be collected and treated properly, so that current regulations can be met before being released into bodies of water (Dia *et al.*, 2018).

Several studies on the treatment of landfill leachate are being developed, however, due to the high cost and complexity to reach the launch standards, its treatment can be considered a great environmental challenge, being necessary the search for technologies that enable a viable treatment of this effluent. Methods based on biological processes have been widely used in the treatment of leachate because they are considered a simple and low cost treatment (Yong *et al.*, 2018).

One of the alternatives for the treatment of leachate from landfills is the combined treatment with domestic sewage. The combination has been shown to be a good alternative, being investigated by several authors, who consider this a suitable solution for cities that have a Sewage Treatment Station (ETE) and that allows the ability to receive leachate contribution, without any negative interference in their performance regarding the efficiencies of removing carbonaceous material, nutrients and microorganisms. (Nascentes *et al.*, 2016).

Experiments with UASB reactors, activated sludge, percolating biological filters, submerged aerated biofilter, stabilization ponds, physical and chemical processes, or a combination of these have been studied (Ferraz *et al.*, 2014; Oliveira *et al.*, 2015; Wu *et al.*, 2019). In the combined biological treatment of landfill leachate and domestic sewage the association of anaerobic, aerobic and anoxic processes can provide

greater efficiency in removing nitrogenous and carbonaceous material (Renou *et al.*, 2008).

Anaerobic systems, such as UASB reactors, which are widespread in the treatment of domestic sewage can be applied in the treatment of leachate in order to remove carbonaceous organic matter (Abdelgadir *et al.*, 2014). However, these processes do not allow efficient removal of nutrients, and percolating biological filters (PBF), in turn, can be used in the polishing of effluents from anaerobic reactors, removing nitrogen compounds through oxidation, in an aerobic environment, and can later be removed in another reactor that has an anoxic environment, through its reduction.

In this scenario, recent studies show that among the various processes available, the technologies that perform the combination of anaerobic, aerobic and anoxic processes have been shown to be a viable treatment option, presenting advantages in terms of economic and technical aspects, as these systems can promote the removal of carbonaceous material, nitrification and denitrification (Oliveira *et al.*, 2015; Silva & Leite, 2015; Leite *et al.*, 2017).

In this perspective, the present work aims to analyze the performance of the process of combined treatment of landfill leachate and domestic sewage in a system consisting of anaerobic upflow sludge blanket (UASB), percolating biological filter (PBF) and anoxic reactor (AR), with an emphasis on biological removal of nitrogenous and carbonaceous material.

MATERIALS AND METHODS

The experimental work was carried out on the physical premises of the Estação Experimental de Tratamentos Biológicos de Esgotos Sanitários (EXTRABES) located in the Tambor *district of* Campina Grande (7°13'11" S, 35°52'31" W; altitude 550 m).

The preparation of the substrate used in the feed of the UASB reactor consisted of the mixture of domestic sewage in the proportion of 97% with landfill leachate in the proportion of 3% (percentage by volume), being prepared daily the volume necessary for feeding the reactor. The definition of the proportion of leachate to be used in the treatment was obtained from the relation between the leachate flow rate produced at the landfill and the domestic sewage flow rate produced by the population of the city of Campina Grande.

The leachate used in this study was collected at regular four-month intervals at the landfill in the Metropolitan Region of the city of João Pessoa, capital of the state of Paraíba. After collection and storage, the leachate was transported to the physical facilities of the EXTRABES laboratory, and chemical characterization was then carried out. The domestic sewage used for the preparation of the substrate came from a residential building, located in the city of Campina Grande – PB, 50 meters from the land belonging to EXTRABES,

being collected daily in a polyethylene box used in the storage of the domestic sewage generated in the housing unit.

The experimental system consisted of a reservoir for storing the substrate, an anaerobic upflow reactor and sludge blanket (UASB), a percolating biological filter (PBF) and an anoxic reactor (AR), being made with 150 mm PVC tubes, as shown in **Fig. 1**. The volume of the UASB reactor was 42 L, usable height of 2.37 m, and at the top a 150 mm PVC joint with a 100 mm reduction was installed, to which a 100 mm tube was formed forming the separator, UASB-Y configuration. The PBF had a unitary capacity of 35 L, with 17 L filled by crushed stone N° 4 (void index: 49%) and a useful height of 1.80 m. The volume of the anoxic reactor is 17.5 L, with 15 L of the total volume filled by rigid PVC conduit (void index: 86.5%) and usable height of 1.00 m.

Figure 1 shows the scheme of the experimental system for the treatment of domestic sewage/landfill leachate during the monitoring period. The substrate was prepared and stored in a reservoir and piped to the UASB reactor using a metering pump (ProMinent®, modelo CNPB 1002). The substrate was evenly distributed at the bottom of the UASB reactor and in an upward manner came into contact with the sludge blanket. The effluent from the UASB reactor was stored in a reservoir with a capacity of 8 L and, by means of a pump, was distributed on the surface of the supporting material of the percolating biological filter, six times a day. The effluent (PBF) was stored and pumped by means of a metering pump (ProMinent®, modelo CNPB 1002) for feeding the anoxic reactor.

The start of operation of the experimental system occurred after the inoculation of the UASB reactor with 8.4 L of sludge, 20% of the total volume of the reactor. The inoculum sludge came from an anaerobic reactor that treated domestic sewage and landfill leachate. In the UASB reactor, a volumetric organic load of 2.7 kg.m⁻³.day⁻¹, volumetric hydraulic load of 3 m³.m⁻³.day⁻¹ and hydraulic detention time of 8 h.

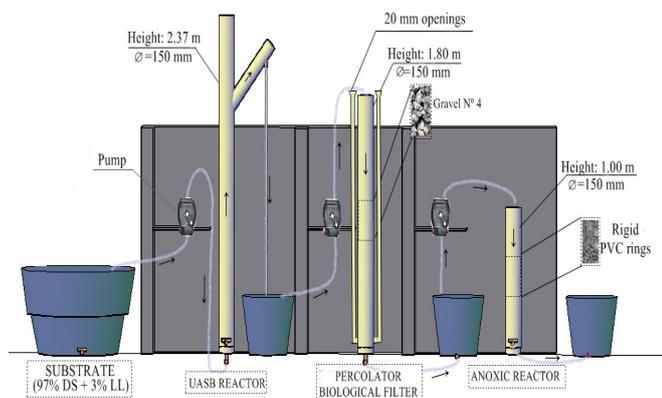


Fig. 1 Schematic representation of the experimental installations of the biological treatment system.

Table 1. Dimensions of the *upflow* anaerobic sludge blanket (UASB), percolating biological filter (PBF) and anoxic reactor (AR).

	UASB	PBF	AR
Useful height (m)	2.37	1.80	1.0
Volume (L)	42	35	17.5
Half support	-	Brita n° 04	PVC conduit
Diameter (mm)	150	150	150

The percolating biological filter was operated under unsaturated flow conditions, and the support medium is, therefore, permanently subject to the renewal of the air that naturally circulates in its empty spaces, providing the necessary oxygen for the respiration of the microorganisms. As shown in **Fig. 1**, the PBF had openings of 20 mm in diameter on the sides to favor the entry of air at the bottom of the PBF and to allow natural aeration of the medium. The feeding of the PBF with the effluent from the UASB reactor was carried out through a metering pump and a distributor with uniform orifices in the downward direction and occurred intermittently, with the duration of each cycle corresponding to 04 h, totaling a quantity of six daily cycles. In the percolating biological filter, volumetric organic load of 1.2 kg.m⁻³.day⁻¹, volumetric hydraulic load of 4.0 m³.m⁻³.day⁻¹, surface application rate of 2.7 m³.m⁻².day⁻¹ and affluent flow of 48 L.day⁻¹.

In the anoxic reactor, the effluent flow was descending and the hydraulic detention time was 12 hours. The organic volumetric load applied to the reactor was 1.2 kgCOD.m⁻³.day⁻¹ and the volumetric hydraulic load of 4.0 m³.m⁻³.day⁻¹. **Table 1** shows the physical parameters of each reactor that makes up the experimental system.

Monitored parameters and analytical methods employed

The monitored parameters were: pH, alkalinity, volatile fatty acids (VFA), total and filtered chemical oxygen demand (COD_T and COD_F, respectively), total suspended solids (TSS), volatile suspended solids (VSS), total Kjeldahl nitrogen (TKN), ammoniacal nitrogen (N-NH₄⁺), nitrate (N-NO₃⁻), nitrite (N-NO₂⁻), total phosphorus (PT) and orthophosphate (P-PO₄⁻³), being analyzed according to the methodology recommended by the American Public Health Association (2012).

RESULTS AND DISCUSSION

Chemical characterization of landfill leachate and domestic sewage

Table 2 presents the parameter data from the chemical characterization of the landfill leachate (LL) and

domestic sewage (DS) used in the preparation of the substrate.

Analyzing the data presented in **Table 2**, there are high concentrations of ammoniacal nitrogen in the landfill leachate, ranging from 2,320 to 2,570 mg.L⁻¹. According to Lee *et al.* (2010), these high values are associated with the decomposition of organic matter and the hydrolysis of proteins present in the landfilled waste. Domestic sewage showed an average ammoniacal nitrogen concentration of 87.8 mg.L⁻¹, a value much lower than that presented by LL, which allows the preparation of the substrate (97% DS and 3% LL) with adequate concentration for the development of microorganisms, enabling biological treatment, since ammoniacal nitrogen concentrations varying between 50 and 200 mg.L⁻¹ do not interfere with the metabolic activity of microorganisms in anaerobic reactors (Shalini e Joseph, 2012).

The behavior of the hydrogen potential (pH) did not show significant variations and is within the range presented in the literature for leachate with similar characteristics, presenting a tendency to a basic pH (Naveen *et al.*, 2017; Dia *et al.*, 2018; Xiao *et al.*, 2013). According to Porowska (2015), after the first stages of oxidation of organic matter and due to the continued anaerobic degradation at the landfill, methanogenesis becomes the predominant phase. In this phase, there is a reduction in the levels of acetic acid and other organic acids generated previously, which causes an increase in the pH of the medium, justifying the results obtained in this work.

During the monitoring period, high concentrations of organic matter in terms of COD were observed throughout the leachate characterization. Based on the values found, the leachate can be classified as stabilized, regarding the BOD₅/COD ratio (Silva *et al.*, 2016). The values obtained in this relation indicate the biodegradability of this effluent.

Table 2. Data from chemical characterization of landfill leachate and domestic sewage.

Parameters	LL	DS
pH	7.92	7.2
Alkalinity (mg CaCO ₃ .L ⁻¹)	12339±2.5	424±8.3
VFA (mg H _{AC} .L ⁻¹)	2074±1151	142±11.6
COD _T (mg.L ⁻¹)	5701±1038	641±7.7
COD _F (mg.L ⁻¹)	2927±677.2	310±6.6
BOD ₅	1077±95.5	347±7.3
TSS (mg.L ⁻¹)	212±1	360±11.6
VSS (mg.L ⁻¹)	169.6±23.6	332±3.8
TKN (mg.L ⁻¹)	2540±35	103±1.7
N-NH ₄ ⁺ (mg.L ⁻¹)	2360±146	87.8±1.9
TP (mg.L ⁻¹)	17.5±0.5	7.9±0.2
P-PO ₄ ⁻³ (mg.L ⁻¹)	8.8±4.2	3.9±0.4

LL: Landfill leachate; DS: Domestic sewage; VFA: Volatile fatty acids; COD_T: total chemical oxygen demand; COD_F: filtered chemical oxygen demand; TSS: total suspended solids; VSS: volatile suspended solids; TKN: *total Kjeldahl nitrogen*

It was observed that this relation remained around 0.19, which indicates a low degree of biodegradability, that is, it is a leachate from an old landfill, being confirmed, in fact, by the time of operation ASMJP, which has been operating since 2003, being approximately 17 years old (AMOR *et al.*, 2015).

During the monitoring period, high concentrations of VFA were observed, one of the main contributors of COD in leachate (Budi *et al.*, 2016). The average concentration of alkalinity was 12,339 mgCaCO₃.L⁻¹, values similar to that obtained in this study were also verified by Budi *et al.* (2016) and Naveen *et al.* (2017) when investigating leachate from landfills in Malaysia and India, respectively. High concentrations of alkalinity in leachate are associated with significant amounts of ammonium bicarbonate generated during the decomposition of organic material present in grounded USW (Mandal *et al.*, 2017).

Table 3 shows the results obtained during the monitoring period of the experimental system. In **Table 3**, the pH values remained stable, with small variations. These pH variations are acceptable, causing no inhibition of microbial activity (Lettinga *et al.*, 1999). The anaerobic process provided an increase in 41 mg CaCO₃.L⁻¹, reaching average concentration of 774 mg CaCO₃.L⁻¹ in the effluent of the UASB reactor. This increase in the value of alkalinity is mainly due to the consumption of VFA and ammonification reactions, where the breakdown of nitrogenous organic compounds causes the release of ammonia and hydroxyl (OH⁻) (van Haandel & van der Lubbe, 2012).

In the PBF (**Table 3**), the pH values were reduced due to the consumption of alkalinity, confirming the occurrence of the nitrification process. During the monitoring period there was a low consumption of alkalinity and low production of nitrate, theoretically, the nitrification process causes the consumption of 7.14 mg CaCO₃ per mg of N-NH₄⁺ converted to N-NO₃⁻ (van Haandel & van der Lubbe, 2012). During this period there was an average consumption of total alkalinity of 153 mg CaCO₃.L⁻¹, which theoretically corresponds to the oxidation of 21.5 mg NH₄⁺.L⁻¹. This performance may be associated with the low amount of oxygen present in the PBF and the low rate of nitrification. In the PBF effluent, a low reduction in total alkalinity is observed in the monitoring period, with an average concentration of 633 mg CaCO₃.L⁻¹.

In the anoxic reactor, the production of alkalinity is observed, and the parameters presented when compared to each other (effluent PBF and effluent AR) have the typical behavior of effluents that have gone through the denitrification process. The anoxic reactor showed production of 48 mg CaCO₃.L⁻¹. The increase in alkalinity in the AR effluent indicates that the denitrification process and reduction of NO₃⁻ to N₂.

Table 3. Chemical characteristics (mean values \pm standard deviation) of the substrate and effluents from the experimental system

PARAMETER	SUBSTRATE	UASB	PBF	AR
pH	7.6	7.74	7.57	7.63
Alkalinity (mg CaCO ₃ .L ⁻¹)	733 \pm 13.3	774 \pm 12.4	632 \pm 48	681 \pm 31.8
VFA (mg H _{AC} .L ⁻¹)	226 \pm 11.5	87 \pm 7.6	69 \pm 4.2	63 \pm 3.9
COD _T (mg.L ⁻¹)	933 \pm 25.3	331 \pm 27	226 \pm 21	161 \pm 7.9
COD _F (mg.L ⁻¹)	368 \pm 43	218 \pm 55	152 \pm 29	130 \pm 12
TSS (mg.L ⁻¹)	457 \pm 33	84 \pm 7.0	67 \pm 6.9	52 \pm 2.9
VSS (mg.L ⁻¹)	420 \pm 1.0	69 \pm 6.5	60 \pm 7.5	47 \pm 2.4
TKN (mg.L ⁻¹)	176 \pm 8.2	174 \pm 5.8	157 \pm 8.3	140 \pm 11.5
N-NH ₄ ⁺ (mg.L ⁻¹)	152 \pm 1.5	165 \pm 3.1	136 \pm 14.7	138 \pm 12.8
N-NO ₂ ⁻	-	-	21 \pm 13	3.5 \pm 1.6
N-NO ₃ ⁻	-	-	4 \pm 1.6	0.4 \pm 0.08
PT (mg.L ⁻¹)	9.5 \pm 1.8	8.9 \pm 0.9	7.5 \pm 0.3	7.3 \pm 0.7
P-PO ₄ ³⁻ (mg.L ⁻¹)	6.7 \pm 0.2	6.6 \pm 0.5	5.75 \pm 0.8	5.5 \pm 1.1

UASB: *upflow* anaerobic sludge blanket; PBF: percolator biological filter; AR: anoxic reactor; VFA: volatile fatty acids; COD_T: total chemical oxygen demand; COD_F: filtered chemical oxygen demand; TSS: total suspended solids; VSS: volatile suspended solids; TKN: total Kjeldahl nitrogen.

The heterotrophic denitrification process causes the release of hydroxyl ions, consequently generating an increase in the alkalinity of the system, which can cause an increase in pH. Analyzing the data obtained over the monitoring period, it can be seen that the average VFA concentration in the substrate was 226 mg H_{AC}.L⁻¹, ranging from 198 to 241 mg H_{AC}.L⁻¹. The UASB reactor consumed 60% VFA, presenting an effluent with an average VFA concentration of 87 mg H_{AC}.L⁻¹. In the effluent from the UASB reactor, this decrease in VFA concentration is associated with the anaerobic process, in which the assimilation of volatile fatty acids occurs, carried out by bacteria and methanogenic archaea (van Haandel, 1994).

It is observed in the UASB reactor that the VFA/Alkalinity ratio was 0.09. This value indicates that there was sufficient alkalinity in the system to neutralize the acids formed, buffering the medium and thus avoiding acidification of the reactor, which would compromise its performance. The VFA/Alkalinity ratio can be used as a measure of the stability of the anaerobic process (Raposo *et al.*, 2009). According to Luque *et al.* (2013), when this ratio is greater than 0.3 it suggests the presence of disturbances in the digestion process.

In the FBP effluent, the average VFA concentration was 69 mg H_{AC}.L⁻¹. This decrease in VFA concentration in PBF is associated with the consumption of material organic by the microorganisms present.

In the anoxic reactor, a small reduction in VFA concentration was observed, producing effluent with an average concentration of 63 mg H_{AC}.L⁻¹. This reduction is related to the consumption of VFA by denitrifying microorganisms in the reduction of nitrate, which occurs in an anoxic environment.

Analyzing the data in **Table 3**, it is observed that the concentrations of COD_T in the substrate varied in the range of 889 to 980 mg.L⁻¹, reaching average

concentration of 933 mg.L⁻¹. In the effluent from the UASB reactor, the average total COD concentration was 331 mg.L⁻¹, reaching average efficiency of removing 64%. Behavior similar to that found in this study was found by Miorim (2017), obtaining a total COD removal of 63% when evaluating the combined treatment of LL (3%) with domestic sewage in a UASB reactor. It is observed that the removal of organic matter in terms of total COD was more significant in the UASB reactor, the first stage of the process, with removal efficiencies above 60%, corroborating with studies carried out by Oliveira *et al.* (2015); Miorim (2018); Araújo (2018). The PBF and AR effluents showed an average COD_T concentration of 226 e 161 mg.L⁻¹, respectively. It is observed that the combination of the UASB-PBF-AR system provided an 82% reduction in organic matter in terms of COD_T, a very significant result of removing carbonaceous material. The UASB reactor substrate and effluent showed an average COD_F concentration of 368 mg.L⁻¹ and 218 mg.L⁻¹, respectively. The UASB reactor provided removal efficiency of 41% of the DQO_F present in the substrate. In PBF and AR effluents, COD_F concentrations were 152 e 130 mg.L⁻¹, respectively. The efficiency of removing COD_F in the treatment system was 64%.

Regarding the removal of solids, measured in terms of TSS and VSS, variations in concentrations in the effluent were observed throughout the monitoring period. As can be seen in **Table 3**, the average values of total and volatile suspended solids obtained in the substrate were 457 and 420.6 mg.L⁻¹, respectively. In the effluent of the UASB reactor there is a significant reduction in suspended solids present in the substrate, with concentrations of 84.26 mg TSS.L⁻¹ and 69 mg VSS.L⁻¹, which demonstrates that the UASB reactor was able to significantly remove suspended solids, providing

TSS and VSS removal efficiency of 82 and 84%, respectively.

In the PBF and AR effluents, the average TSS concentrations were 67.6 and 52.7 mg.L⁻¹, respectively. The combination of the three processes made it possible to remove TSS and VSS by 88%. Ferraz *et al.* (2014), operating a submerged aerated biofilter (2% LL and 98% DS), obtained similar results, achieving removal of 90% of total suspended solids.

Analyzing the data obtained during the monitoring of this experimental system (Table 3), it is observed that the concentrations of TKN in the substrate and in the effluents of the UASB, PBF and AR reactor were, respectively, 176, 174, 157 and 140 mg.L⁻¹. In the substrate, it was found that organic nitrogen corresponded to 13.4%, being mostly constituted by ammoniacal nitrogen (86.6%). In the effluent from the UASB reactor, the TKN concentration remains constant, but a small fraction of organic nitrogen is converted to ammoniacal nitrogen through the ammonification process, and then approximately 8% of the nitrogenous organic fraction is converted, thus increasing the nitrogen concentration ammonia in the UASB effluent, corresponding to 95% NH₄⁺ and 5% organic nitrogen present in the effluent. In the effluent of the PBF there is a reduction in the concentration of TKN, which is associated with the nitrification process, in which the oxidation of ammoniacal nitrogen to nitrite and nitrate occurs. The reduction in the concentration of ammoniacal nitrogen present in the UASB reactor occurs in the PBF, thus decreasing the concentration of TKN. Ammoniacal nitrogen (21 mg.L⁻¹) was oxidized, corresponding to a reduction of 13%.

The average concentration of ammoniacal nitrogen in the substrate was 152.4 mg N-NH₄⁺.L⁻¹. In the effluent of the UASB reactor, there is an increase in the average concentration of ammoniacal nitrogen, which may result from the biological activity of hydrolysis and deamination of nitrogenous organic matter that occurred in the UASB reactor, the ammonification process. In this effluent, the average concentration was 165.3 mg N-NH₄⁺.L⁻¹, with an 8% percentage increase in N-NH₄⁺ concentrations.

In the PBF effluent there are high concentrations of ammoniacal nitrogen, in which nitrification did not occur effectively and only a small part of NH₄⁺ was converted to nitrite and nitrate, possibly due to the limitation of dissolved oxygen in the medium. The PBF provided an average removal efficiency of 16%, producing effluent with a concentration of 136 mg N-NH₄⁺.L⁻¹. Despite the low DO/NH₄⁺ ratios, the nitrification process in the FBP occurred, which could be increased with greater oxygen supply to the environment, so that the conditions in the PBF could be optimized and an increase in specific biomass for the nitrification process. According to Gonçalves *et al.* (2001), for values in which the DO and NH₄⁺ ratio are

very low, the aerobic compartment is dominated by heterotrophic bacteria and nitrification occurs very slowly.

Analyzing the data, it can be seen that the average concentrations of nitrite (NO₂⁻) and nitrate (NO₃⁻) in the effluent of the percolating biological filter were 21 and 4 mg.L⁻¹, respectively. The high concentration of nitrite and the low conversion to nitrate indicates that the percolating biological filter did not present satisfactory conditions in the oxidation process of ammoniacal nitrogen. Ammonia nitrogen concentrations are still high, requiring a greater amount of dissolved oxygen to promote and optimize the nitrification process (Zoppas *et al.*, 2016). Another important factor, according to Yusof *et al.* (2010), is that ammoniacal nitrogen oxidizing bacteria can be inhibited by the nitrite ion and, in order for this inhibition not to occur, nitrite oxidizing bacteria must live in syntrophy with ammoniacal nitrogen oxidants. In addition, the pH must remain neutral to avoid the formation of nitrous acid during the process. Nitrous acid is one of the main responsible for the inhibition of oxidizing bacteria of ammonia and nitrite, and can also be the cause of low nitrification in the percolating biological filter.

The accumulation of nitrite in reactors with biofilm, such as PBF, is usually considered an indication that the rate of oxygen transfer or aeration is insufficient. As nitrite oxidizing bacteria have less affinity for oxygen, they require a higher transfer rate than ammoniacal nitrogen oxidators, being the first to be inhibited when it becomes deficient. Based on this premise, nitrite oxidizers would have reduced their activity and nitrite was predominant in the PBF effluent. Another possible argument is that the nitrite oxidizer population was not sufficient to convert the entire nitrite load produced, thus becoming the limiting factor for nitrification in the system (Yusof *et al.*, 2010)

The introduction of oxygen through forced aeration provided a considerable increase in the production of nitrite and nitrate in some studies. Neto and Costa (2011) and Fulazzaky *et al.* (2015) reported that controlled aeration units have considerably increased the efficiency of nitrogen removal in biological treatment systems.

In the anoxic reactor, there was a reduction of nitrate present in the effluent in the percolating biological filter, reaching an average nitrate concentration of 0.42 mg.L⁻¹. The amount of organic carbon in the medium was sufficient to promote the denitrification process, since the occurrence of this process is directly related to the amount of biodegradable organic matter present. In conventional biological treatments, the presence of easily biodegradable substrate is generally low, being removed in the previous steps, and for this reason, it is necessary to add an external carbon source to perform the denitrification process.

The average concentrations of total phosphorus in the substrate, effluent UASB, effluent PBF and effluent AR were: 9.47, 8.53, 7.56 and 7.34 mg.L⁻¹, respectively. It is also possible to notice a low phosphorus removal in the UASB reactor, reaching an efficiency of 9.8%. The occurrence of this low removal is justified by the fact that anaerobic reactors do not have the objective of removing nutrients, but the removal of carbonaceous material by heterotrophic microorganisms. Nutrients can be removed in anaerobic systems through the processes of sedimentation and precipitation in the sludge, and by the assimilation of microorganisms. The total system showed a total phosphorus removal efficiency of 22%. In a study carried out by Santos (2014), the average values of phosphorus removal efficiency obtained were similar, which obtained removal efficiency of 26%.

The average concentration of orthophosphate in the tributary was 6.76 mg.L⁻¹. In the effluent of the UASB reactor, the concentration was similar to that found in the substrate, with 6.6 mg.L⁻¹ of orthophosphate. In the PBF, there was a 10.2% reduction in the orthophosphate present in the UASB effluent, with an average concentration of 5.93 mg.L⁻¹. In the effluent of the anoxic reactor the average concentration of orthophosphate was 5.57 mg.L⁻¹.

CONCLUSIONS

Based on the results presented, it can be concluded that the combined treatment of landfill leachate and domestic sewage in the UASB reactor did not present significant interferences in the operational stability of the reactor. The efficiency of the UASB reactor was 64 and 63% of carbonaceous material in terms of total and filtered COD, respectively.

The combination of the anaerobic, aerobic and anoxic processes enabled a significant increase in the efficiency of removing carbonaceous material during the monitoring period. The treatment system provided removal efficiency of 82% of total COD and 88% of TSS and VSS.

The availability of alkalinity in the medium, throughout the experimental period, has always remained greater than the required quantity, providing favorable conditions for the nitrification and denitrification processes.

During the experiment, the PBF was naturally aerated and most of the ammoniacal nitrogen was converted to nitrite, resulting in partial nitrification of the medium, with ammoniacal nitrogen concentrations in the effluent still high. The low oxidation to nitrate is indicative of the lack of oxygen, because the nitrite oxidizing bacteria are more sensitive to DO variations, and to meet the oxygenation needs and improve the nitrification process, it would be necessary to add DO.

The average efficiency of removing ammoniacal nitrogen from the effluent was 16%. The low

concentration of dissolved oxygen in the PBF hampered the nitrification process during the first months of monitoring. In the anoxic reactor, the reduction of nitrate present in the effluent of the percolating biological filter was observed, producing final effluent with a concentration of 0.42 mg NO₃⁻.L⁻¹. The results obtained confirmed the effective potential of polyethylene rings as an alternative support material in the biological treatment of effluents. In addition, its use allows cost reduction in the acquisition of the material, when compared to materials such as gravel, facilitates the maintenance and control of the biological treatment unit, due to its spatial conformation and constitution of the rings, and substantially reduces its mass per area occupied inside the anoxic reactor.

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