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AMMONIACAL NITROGEN REMOVAL FROM SANITARY LANDFILL LEACHATE BY STRIPPING PROCESS USING A BAFFLED REACTOR

*Luciana Paulo Gomes[1]
Marcelo Oliveira Caetano[1]
Luis Alcides Schiavo Miranda[1]

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Abstract
Ammoniacal nitrogen in Sanitary Landfill Leachate may reach concentrations up to 2000 mg/L, which, if discharged into the environment under such concentrations, may cause severe environmental and public health impacts. The stripping process is a technical highlight among the alternatives for leachate ammoniacal nitrogen removal employed worldwide. The comparison of the analyses performed at inflow and outflow, at the São Leopoldo/Brazil Leachate Treatment Plant wastewater (lagoons), showed an ammoniacal nitrogen removal rate that ranged between 38% and 65% in 90 days of HRT. On the other hand, the Baffled Reactor yielded a 73% removal rate in 12 days. Statistically, the "temperature" variable affected Ammoniacal nitrogen removal, such that the higher removal rates were associated to environmental temperatures above 20ºC, thus rendering this technology as useful in tropical countries. The Baffled Reactor demonstrated to be applicable for use in sanitary landfills that produce 0.33 m³ of leachate per day. This value corresponds to service provided to a small scale municipality with a population of up to 10.000 inhabitants. Treatment operational cost using the reactor was estimated to be US$ 30.25/m3 of treated leachate, which is an interesting result if compared with other ammoniacal nitrogen removalunits, as well as with ex situ treatment processes.

Key Words: Landfill, Leachate treatment, Ammoniacal nitrogen removal.

[1] Universidade do Vale do Rio dos Sinos – UNISINOS, Brasil
**Autor corresponsal:* Programa de Pós Graduação em Engenharia Civil / Unisinos. Avenida Unisinos, 950. CEP 93022-000 - São Leopoldo – RS – Brasil. Email: lugomes@unisinos.br

Resumo

Nitrogênio amoniacal em lixiviados pode atingir concentrações que ultrapassam 2.000 mg/L, o que, se lançado para o meio ambiente com tais concentrações, pode causar graves impactos ambientais e de saúde pública. O processo de stripping é uma das técnicas que se destaca entre as alternativas para remoção de nitrogênio amoniacal de lixiviados empregados em todo o mundo. A comparação das análises realizadas na Estação de Tratamento de Lixiviado de São Leopoldo/Brasil, na entrada e saída, mostrou que o tratamento biológico utilizado atualmente no local (lagoas) para o tempo de retenção hidráulica de 90 dias, produziu uma taxa de remoção de nitrogênio amoniacal, que variou entre 38% e 65%. Por outro lado, o reator de chicanas (reator compartimentado) rendeu uma taxa de remoção de 73% em 12 dias. Estatisticamente, a variável "temperatura" afetou a remoção de nitrogênio amoniacal, de tal forma que as maiores taxas de remoção foram associadas a temperaturas ambientais acima de 20 ºC, tornando, assim, essa tecnologia tão útil em países tropicais. O reator de chicanas demonstrou ser aplicável para uso em aterros sanitários que produzem 0,33 m³ de lixiviado por dia. Este valor corresponde ao serviço prestado em um município de pequeno porte, ou seja, com uma população de até 10.000 habitantes. O custo operacional do tratamento usando o reator de chicanas estudado foi estimado em US$ 30,25/m^3 de lixiviado tratado, o qual é um resultado interessante, se comparado com outras unidades de remoção de nitrogênio amoniacal, bem como com os processos de tratamento ex situ.

Palavras chaves: Aterro Sanitário, Lixiviado, stripping.

Introduction

In Brazil, sanitary landfills are the main municipal solid waste final disposal method. If adequately engineered and operated, this treatment system is both a safe and economically viable technical solution. It may be noted, however, that in the majority of the municipalities in the country such control does not occur, thus potentially causing a serious environmental contamination of water, soil and air resources as a result of landfill leachate and gas toxicity, as they are discharged and spewed intod the environment without any treatment.

Marttinen *et al*. (2002) mention that leachate treatment focus is on organic and nitrogenated matter removal. Souto e Povinelli (2006) confirm this point of view, since a high concentration of these pollutants is found in Brazilian Sanitary Landfill leachate (the authors indicate that the total nitrogen concentration may reach up to 3.100 mg/L. Such characteristics may cause systemic effects such as: (1) dissolved oxygen level depletion (due to oxygen demand), (2) it is the main cause of the process of eutrophication, thus affecting water quality and aquatic life; (3) it is toxic to both fish and population health, potentially causing diseases that affect the central nervous system, breathing and the digestion of human beings and (4) it may inhibit wastewater biological treatment processes, thus affecting the efficacy of the system. The incidence of such effects as related to nitrogen in the water was noted by several authors such as Aziz *et al.* (2004), WEF, ASCE, EWRI (2005), Pelkonen *et al.* (1999), Jokela *et al*. (2002) and Iamamoto (2006).

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Burton e Watson-Craik (1998) mention that the main organic nitrogen component in Municipal Solid Wastes (MSW) landfills is protein, although smaller quantities may be found in nucleic acids, urea, chitin, phospholipids and adenosine triphosphate (ATP) derived from the organic fraction of the wastes. These components may be found in wastes such as: plant and animal remains, food-waste, used cloth diapers, animal feces, slaughterhouse wastes, sewer wastewater treatment plant sludge and soil.

In spite of recognizing the limitations of biological lagoons in sanitary landfill leachate treatment as they relate to the need for a physical area in addition to low nitrogen removal efficiency, their use is widespread in Brazil. As an alternative, Aziz *et al.* (2004) mentions both physico-chemical treatments as interesting and outstanding processes when compared to other methods. The motivation to study the ammonia stripping process for leachate treatment among the several existing processes is due to its proven worldwide efficiency in removing wastewater ammoniacal nitrogen, as demonstrated in the works by Campos *et al*. (2006), Leite *et al*. (2006), Cheung *et al*. (1997), Marttinen *et al*. (2002), Ozturk *et al*. (2003), Collivignarelli *et al*. (1998), Silva *et al*. (2004), Calli *et al*. (2005). Marttinen *et al*. (2002) and Renou *et al*. (2008), in which stripping is highlighted as the most widespread treatment method. Bench scale experiment that resulted in over 90% ammoniacal nitrogen removal rate, including high initial concentrations for this variable.

The essence of the Baffled Reactor project presented in this work is to take the reality of a leachate treatment plant and its variables such as temperature, climate, flow and leachate variability into consideration. In addition, the goal was to use an efficient ammoniacal nitrogen removal process by stripping, with low operational costs and lower utilization of natural resources; thus consisting in a technology that may be used even in municipalities with limited financial resources.

Methodology

Characteristics of the Studied Leachate

The treated leachate in the proposed system originated from the São Leopoldo Sanitary Landfill Leachate Treatment Plant, which is operated by SL Ambiental. The landfill receives all of the Municipal Solid Wastes (MSW) generated in the municipality, although the potentially recyclable wastes are previously segregated at the Recycling Plant, which is also operated near the sanitary landfill. The wastes generated in São Leopoldo and later discarded into the landfill have the following characteristics: 59% organic matter, 13% plastic, 13% paper/cardboard, 2% glass, 2% metal, 11% chemical and biological contaminants as well as other wastes (SEMMAM, 2009).

The wastes discarded in the São Leopoldo Sanitary Landfill thus produced the leachate used in this research. Nowadays, the current treatment has an equalization tank followed by one anaerobic lagoon, four optional lagoons and two maturation lagoons. The total mean Hydraulic Retention Time was of 90 days.

Experimental Unit Set Up (Baffled Reactor)
The experimental unit has a Baffled Reactor built with solid brick walls and a reinforced concrete floor. The internal dimensions of the reactor are as follows: 10 (ten) meters long, 1 (one) meter wide and 0.5 meters deep and a usable volume of 5m³.

Internally, the reactor has twenty-two movable parts (baffles), transversely arranged lengthwise, made of 6 mm thick polyethylene measuring 0.50 x 1.00 m with a hollow rim measuring 10 x 10 cm, which will serve as wastewater passageway (Figure 1).

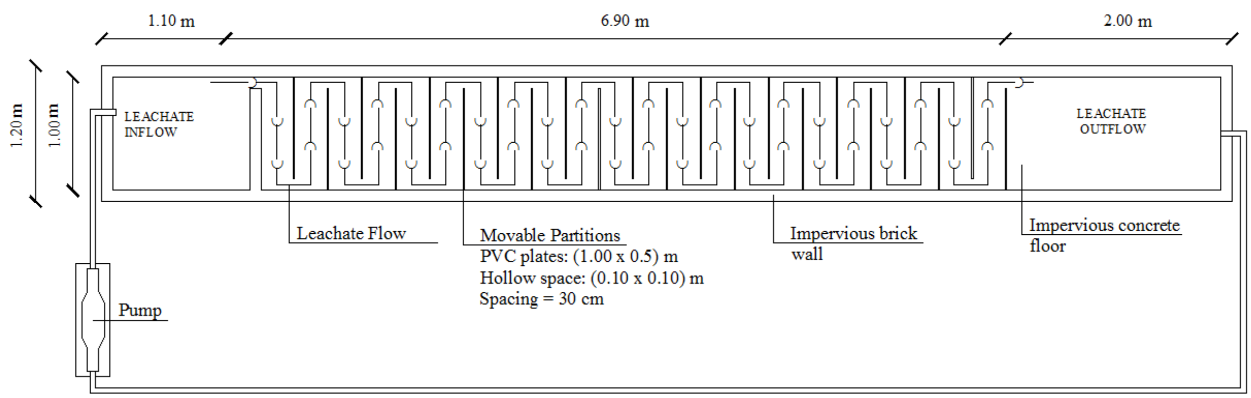

Figure 1. Studied Baffled Reactor Scheme

The tests were made in batches, preceded by preliminary experimental tests performed in bench testing scale using Jar Test equipment in order to simulate the Baffled Reactor's operation. The studied variables and the monitoring parameters of these tests are described below:

Bench Tests (Jar Test) – performed with and without aeration and added alkaline agent concentration variation, leading to leachate behavior assessment with different pH values. Both ammoniacal nitrogen concentration and pH were monitored.

Baffled Reactor Preliminary Tests: ammoniacal nitrogen initial concentration and recirculation pump flow variation. The monitored parameters were: pH, ammoniacal nitrogen and COD.

The Jar Tests revealed that the increase in pH contributes to ammonia removal efficiency in the stripping process, such that leachate aeration with air diffusion (flow of 0.33 L/minute) also aided in such improvement, although not significantly. The degree of agitation used in the Jar Test did not correspond to that which was used in the Baffled Reactor, although the results were useful in the extrapolations and necessary applications carried forth in the subsequent Baffled Reactor tests. The lack of feasibility of this treatment alternative on a real scale using added chemical products was also noted, considering both the product quantity to be used and the operational cost, as well as the sludge volume that would be produced as a result of the added NaOH. In accordance with the conclusions set forth by the works of Collivignarelli *et al*. (1998), Ozturk *et al*. (2003) and Cheung *et al*. (1997) the final Jar Tests' analysis showed that the most feasible cost-benefit option for Baffled Reactor sanitary landfill leachate treatment would have a leachate pH ranging between 7.7 and 8.6 without using any chemical products, mechanical agitation or aeration.

On the preliminary Baffled Reactor tests it was noted that: a) longer hydraulic retention time improved ammoniacal nitrogen removal; b) there may be an ammoniacal nitrogen initial concentration effect on nutrient removal; c) there is a possibility that the increase in leachate recirculation flow may affect ammoniacal nitrogen removal; d) Baffled Reactor solids' sedimentation between tests did not affect ammoniacal nitrogen removal results; thus, it was not necessary to filter the samples prior to the analyses.

Therefore, based on these results, the Baffled Reactor batch tests were planned and performed with the following characteristics: leachate recirculation flow (0.0 m^3/h; 1.7 m^3/h and 3.5 m^3/h) and ammoniacal nitrogen initial concentration (greater and smaller than 600mg/L), without the use of chemical products or aeration. As for the hydraulic retention time, the value corresponding to 12 days was used.

Fifteen batch tests were performed on the Baffled Reactor, divided into 5 tests with different characteristics in order to assess the performance of the leachate treatment unit, mainly regarding ammoniacal nitrogen removal. Tests 1, 2, 3 and 4 included leachate recirculation aiming at the intensification of the ammonia stripping process and a recirculation pump, whereas test 5 was conducted without the aid of recirculation in order to simulate ammonia's natural volatilization.

Table 1 shows the characteristics of each Baffled Reactor test and trial. In these trials the treated leachate volume ranged from 2 to 3 m^3. The monitored variables were: pH, ammoniacal nitrogen and environmental temperature (on a daily basis); series of solids, COD, nitrite and nitrate (measured both in the beginning and in the end of each trial) and alkalinity (measured every two days). The trial methodology followed APHA, AWWA, WEF (1995) guidelines.

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Table 1. Specification data for the trials performed on the Baffled Reactor

TESTS	PARAMETERS – VARIABLES	TRIALS
Test 1	Initial AN concentration range < 600 mg/L Recirculation Pump Flow = 1.7 m³/h	RC1, RC4, RC13
Test 2	Initial AN concentration range < 600 mg/L Recirculation Pump Flow = 3.5 m³/h	RC10, RC11, RC14
Test 3	Initial AN concentration range > 600 mg/L Recirculation Pump Flow = 1.7 m³/h	RC2, RC3, RC7 e RC8
Test 4	Initial AN concentration range > 600 mg/L Recirculation Pump Flow = 3.5 m³/h	RC5, RC6, RC9
Test 5	Initial AN concentration range < 600 mg/L Without recirculation pump	RC12, RC15

AN – ammoniacal nitrogen

Statistical Analysis

The following characteristics were taken into account when conducting the statistical analyses: Data Variability – the initial data analysis always corresponded to the obtained median and standard deviation, in addition to the variation coefficient (VC). The objective of this research was to present the median results obtained with values where VC ≤ 20%; Environmental temperature range definition – even though temperature influence in the stripping process was corroborated in the references' review, the statistical analysis for this variable was used in this work and has become essential, given the fact that the Baffled Reactor study was developed in an experimental scale, as opposed to the previous works, which were conducted on a bench scale. Thus, three environmental temperature ranges were defined, which were obtained from the temperature values measured onsite (Baffled Reactor trial) and based upon the work of Emerson *et al*. (1975) and Von Sperling (2007). The trials were divided into three temperature ranges: below 20ºC (range 1); above or equal to 20ºC and below or equal to 25ºC (range 2); above 25ºC (range 3); Precipitation ranges' definition – Precipitation ranges were defined as greater than and lower than 51mm. The total precipitation mean value of 51mm in the trials corresponds to a monthly precipitation of 127.5mm, which is equivalent to the pluviometric mean value of the city of São Leopoldo, Rio Grande do Sul, Brazil.

The similarity among the Baffled Reactor trials on the same test was analyzed using the mean, standard deviation and the variation coefficient. Subsequently, temperature influence, leachate solids precipitation, initial ammoniacal nitrogen concentration, leachate recirculation flow in ammoniacal nitrogen removal and alkalinity were analyzed, in addition to the decrease in COD and total solids. In order to do so, the software SPSS 1.5 for Windows was used to perform the ANOVA test with a 95% confidence level.

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Results and Discussion

Characteristics of the Studied Leachate

The results of the physico-chemical monitoring performed at the São Leopoldo Sanitary Landfill Leachate Treatment Plant showed great variability in wastewater characteristics. The concentration of ammoniacal nitrogen verified at the plant's wastewater inflow, for instance, varied between 219.0 mg/L and 1802.9 mg/L. In terms of efficiency, the conventional São Leopoldo landfill leachate treatment through the lagoon succession system showed an ammoniacal nitrogen removal rate that varied between 38% and 65% for a 90-day hydraulic retention time period. Table 2 illustrates removal efficiency for the analyzed variables.

Table 2. Physico-chemical variables' removal efficiency – Leachate Treatment Plant

Variable	Removal Efficiency Range (%)
Phosphorus	28 – 62
Volatile Acidity	52 – 78
Total Alkalinity	65 – 42
BOD	70 – 84
COD	0 – 58
Ammoniacal Nitrogen	38 – 65
Organic Nitrogen	0 – 4
Total Nitrogen	17 – 25
Nitrites	0 – 60
Nitrates	0 – 55

Baffled Reactor Tests

According to the performed trials, the ammoniacal nitrogen removal rate varied from 6% to 73%, given that these limits are associated to test 3, trial RC8 (mean environmental temperature of 14ºC) and trial RC2 (mean environmental temperature of 30ºC), respectively. Other works addressing leachate ammoniacal nitrogen removal through the stripping process modifying variables such as pH, aeration flow, hydraulic retention time and temperature obtained removal rates such as: 79% (Silva *et al*., 2006); 7% to 96% (Campos *et al*. 2006); 92% (Leite *et al*. 2006); 14% to 68% (Collivignarelli *et al*. 1998); 64% to 89% (Marttinen *et al.* 2002); 45% to 95% (Ozturk *et al.* 2003); 65% to 93% (Cheung *et al.* 1997); 80% to 99,5% (Silva *et al.* 2004) and 94% (Calli *et al.* 2005).

The alkalinity variable decreased in all trials, showing a similar profile regarding ammoniacal nitrogen removal, as illustrated in Figure 2. This close association between the ammoniacal nitrogen and alkalinity variables is reported by Silva *et al*. (2006) as a result of the chemical balance between ammonium and free ammonia ions and the consequent removal of the latter via stripping process. Similarly, Campos *et al*. (2006) suggests that a secondary effect, which can

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be combined with the first, may occur. This refers to the transformation of bicarbonates into carbonates, and the latter into CO_2, which is eliminated through entrainment, since the CO_2 stripping speed is greater than the ammonia's counterpart. The result of this physico-chemical dynamics reflects upon the combined decrease in ammoniacal nitrogen content and alkalinity, as the stripping process is finalized.

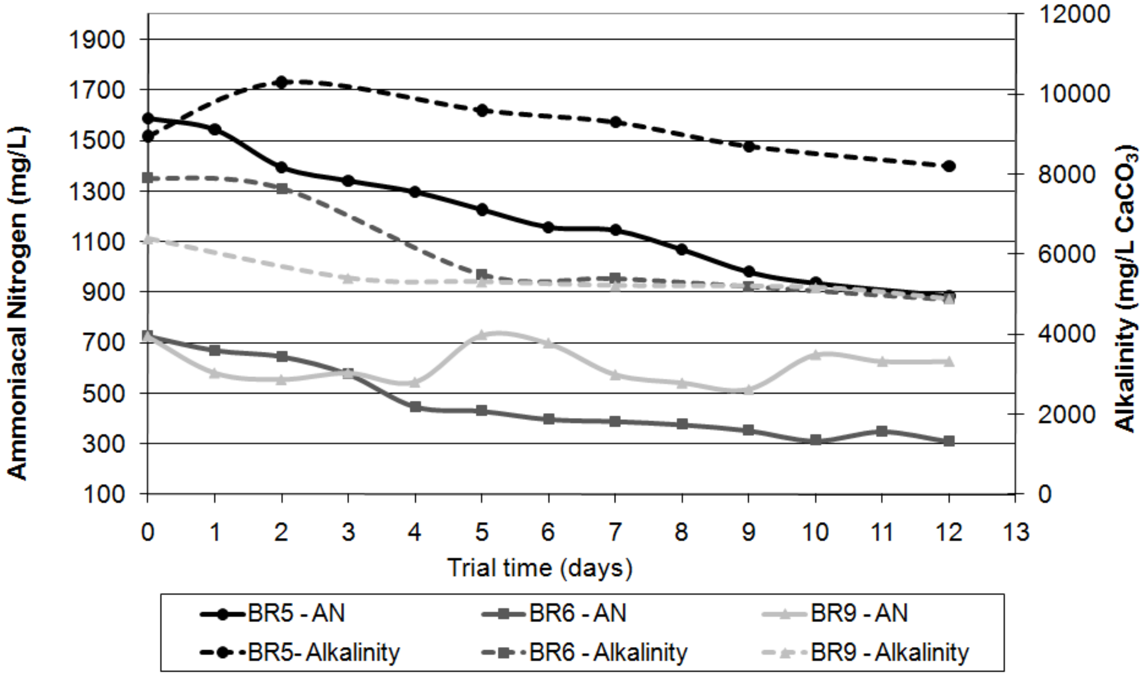

Figure 2. Ammoniacal Nitrogen and Alkalinity Result Analysis for Test 4: Initial AN >600mg/L and Recirculation Flow = 3.5 m^3/h

The Baffled Reactor trials confirmed the dependence of ammoniacal nitrogen removal upon environmental temperature, reinforcing the results obtained by Emerson *et al*. (1975), Collivignarelli *et al*. (1998), Marttinen *et al*. (2002), Calli *et al*. (2005) and Campos *et al*. (2006).

Statistical Analysis

The statistical analysis showed great variability among the results obtained considering the same test, such that there is no similarity among them. In addition, the influence of other variables such as initial ammoniacal nitrogen concentration, leachate recirculation flow and temperature was evidenced. Table 3 shows the results obtained in the different trials, as well as the calculated mean, standard deviation and variation coefficient.

Table 3. Obtained results for sanitary landfill leachate Ammoniacal Nitrogen removal in the BR trials

Test	Trial	Mean Temperature (ºC)	Initial AN (mg/L)	Final AN (mg/L)	AN Removal (%)	Mean Removal	Standard Deviation
1	BR 1	24.0	539.3	229.0	58	51	13
	BR 4	25.0	357.4	169.4	63		
	BR 13	20.3	513.4	344.9	33		
2	BR 10	19.0	512.0	361.6	29	18	8
	BR 11	18.0	301.8	268.0	11		
	BR 14	22.1	233.7	200.7	14		
3	BR 2	30.7	898.4	289.8	73	36	25
	BR 3	25.4	1213.0	696.1	43		
	BR 7	17.4	1802.9	1361.0	25		
	BR 8	13.3	877.5	828.6	6		
4	BR 5	26.4	1588.3	885.9	44	39	13
	BR 6	22.4	727.3	346.2	52		
	BR 9	15.5	724.4	574.1	21		
5	BR 12	15.8	220.05	146.7	33	20	13
	BR 15	25.6	172.75	160.1	7		

Through the statistical analysis' results, the influence of the variables (initial ammoniacal nitrogen concentration, recirculation flow, temperature and pluviometric precipitation) was assessed without taking the characteristic of the test into consideration. The results showed that environmental temperature (significance equal to 0.022; thus, smaller than 0.05 and 95% confidence interval) and pluviometric precipitation (significance equal to 0.012; thus, smaller than 0.05 and 95% confidence interval) variables had a significant influence in ammoniacal nitrogen removal in the studied leachate. However, studies addressing the influence of precipitation must be amplified, aiming at confirming the obtained results, whereas the influence of the temperature variable showed similar results to those obtained by several authors who researched ammoniacal nitrogen removal from sanitary landfill leachate through the stripping process.

In analyzing the ammoniacal nitrogen initial concentration and recirculation flow variables, the significant influence of the recirculation flow factor alone was noted, highlighting ammoniacal nitrogen removal in temperatures above 20ºC and recirculation flow of 1.7 m^3/h. Figures 3 and 4 illustrate ammoniacal nitrogen removal comparison graphs, taking temperature, recirculation flow and initial concentration into consideration.

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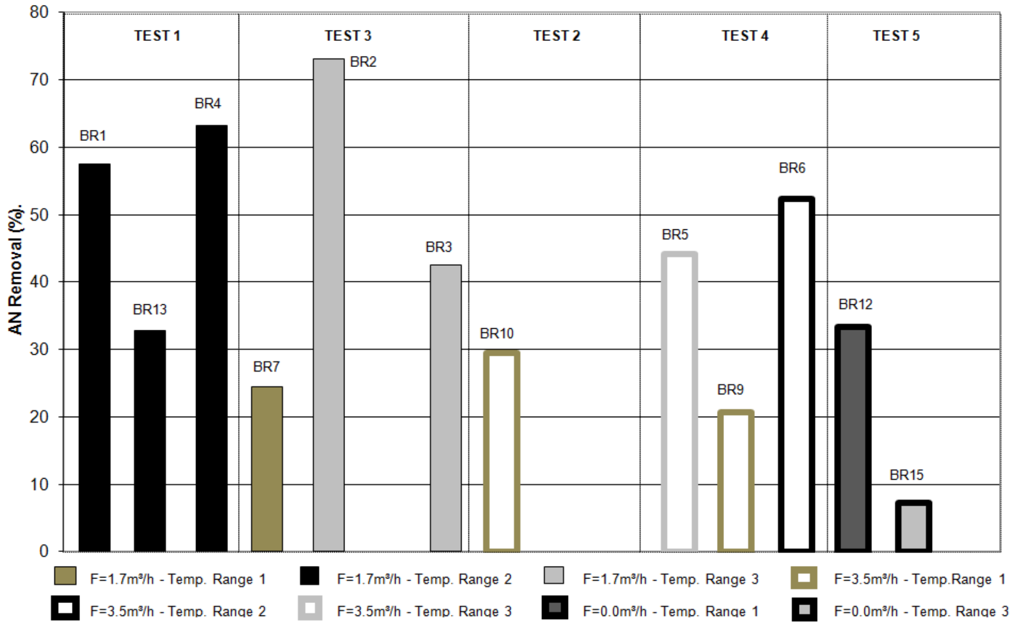

Figure 3. BR Ammoniacal Nitrogen removal comparison under different recirculation flows

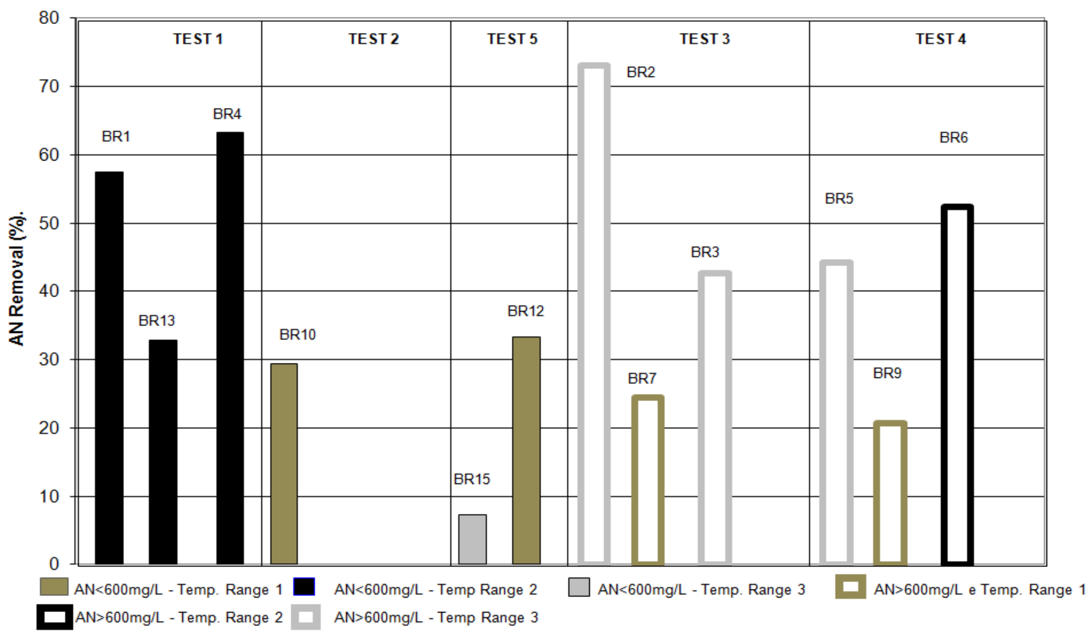

Figure 4. BR Ammoniacal Nitrogen removal percentage during trials using Ammoniacal Nitrogen concentrations lower than and greater than 600 mg/L

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Economic and Operational Analysis

Cost make-up associated to the ammonia stripping process preformed on the Baffled Reactor took only electrical energy use and recirculation pump operation into consideration. In this case, costs associated to chemical products (since the system was operated with the original pH without the need to add an alkaline agent), human resources (since the system does not need a dedicated and continuous operational monitoring, thus enabling the actual landfill operating team to run it as its duty), and reactor maintenance costs, such as cleaning painting and baffle replacement (since these are non-significant due to low maintenance) were not taken into consideration.

The characteristics of the used pump (Pump NM0310--1L by Nietzsche) were: operation with maximum flow of 4.2 m^3/h, nominal rotation of 510 rpm and maximum frequency of 60 Hz. Thus, for a recirculation flow of 1.7 m^3/h, batch treatment, hydraulic retention time of 12 days and Baffled Reactor with a volume of 4 m^3, the total energy consumption will be US$ 121 (US$ 30.25/m^3 of treated leachate). This composition may be applied to small scale municipalities (up to 10,000 inhabitants), which represent nearly 75% of the municipalities in the country.

This exact analysis and cost make-up was performed by Leite *et al*. (2009) considering ammoniacal nitrogen removal tests via stripping using Filling Tower in bench testing scale using leachate from the João Pessoa/Paraíba Brazil sanitary landfill. The tests considered the use of a recirculation pump and chemical products to increase leachate pH to 8, 9 and 10. According to the results, the best efficiency in ammoniacal nitrogen removal occurred with pH equal to 10, with an operational cost of US$ 89.90/m^3 of treated leachate. With a pH equal to 8, considering pump and electricity costs without the use of chemical products, treatment cost lowered to US$ 44.10/m^3 of treated leachate.

In Brazil there is also the possibility of ex situ leachate treatment, thus, outside the landfill area. The approximate price charged by the Waterworks Agency of the State of Rio Grande do Sul is US$ 12.00/m^3 of treated leachate (Souza, 2011). Private companies charge approximately US$ 85.00/m^3 of treated leachate for leachate treatment in Rio Grande do Sul. Nowadays, the mean cost of transportation from the landfill to the treatment location is estimated to be US$ 75.00/m^3 (considering a mean distance of 20 km between the two locations), which are much higher costs than those charged for in situ treatment.

Conclusions

The comparison between the analyses performed at the leachate treatment plant's wastewater inflow and outflow showed that the biological treatment currently used onsite yielded an ammoniacal nitrogen removal that varied from 38% to 65% in a 90-day hydraulic retention time period. Conversely, the Baffled Reactor yielded an ammoniacal nitrogen removal that varied from 6% to 73% in a 12-day hydraulic retention time period. The use of the Baffled Reactor is considered to be promising, mainly in what refers to hydraulic retention time reduction and also due to the fact that in 40% of the performed trials ammoniacal nitrogen removal was greater than 40%.

Nevertheless, as was the case of the plant's current treatment, it was noted that none of the performed trials (Table 4) yielded ammoniacal nitrogen concentrations that could be discharged into water bodies in compliance with the country's established laws and regulations (lower than 20mg/L - CONAMA nº 357/05 (BRASIL, 2005). Accordingly, some kind of treatment after the use of the Baffled Reactor must be contemplated.

The statistical analysis showed a significant influence of the temperature variable, thus confirming the various studies addressing this subject. Regarding the influence of the recirculation flow and ammoniacal nitrogen initial concentration, it was noted that for temperatures above 20ºC (ranges 2 e 3) the best sanitary landfill leachate treatment option from an environmental and technical stance is the use of leachate recirculation flow of 1.7 m^3/h, regardless of the initial ammoniacal nitrogen concentration. For temperatures below 20ºC, the best Baffled Reactor performance occurred with recirculation flow equal to 0.0m^3/h; thus, without the use of a pump, also regardless of the initial ammoniacal nitrogen concentration. However, it is suggested that for temperatures below 20ºC a higher hydraulic retention time be used in order to obtain an adequate ammoniacal nitrogen removal efficiency.

The Baffled Reactor proved to be applicable to sanitary landfills that produce 0.33 m^3 of leachate daily. This value corresponds to service provided to a small scale municipality with a population of up to 10.000 inhabitants. Treatment operational cost using the reactor was estimated to be US$ 30.25/ m^3 of treated leachate, which is an interesting result if compared with other ammoniacal nitrogen removal units, as well as with ex situ treatment processes..

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