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Organic compounds removal and toxicity reduction of landfill leachate by commercial bakers' yeast and conventional bacteria based membrane bioreactor integrated with nanofiltration

Beatriz Gasparini Reis [a], Amanda Lemes Silveira [b], Luiza Procópio Tostes Teixeira [a], Adriana Akemi Okuma [b], Liséte Celina Lange [a], Miriam Cristina Santos Amaral [a,*]

[a] Dept. of Sanitary and Environmental Engeneering, Federal University Of Minas Gerais, Presidente Antônio Carlos Avenue, 6627, Engeneering School – 4th flloor, Pampulha, Belo Horizonte/MG CEP: 31.270-901, Brazil

[b] Dept. of Chemistry, Federal Center of Technological Education of Minas Gerais, Campus I, Amazonas Avenue, 5253, Belo Horizonte/MG CEP: 30.421-169, Brazil

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A B S T R A C T

This study aimed to compare the performance of a commercial bakers' yeast (MBRy) and conventional bacteria (MBRb) based membrane bioreactor integrated with nanofiltration (NF) in the removal of landfill leachate toxicity. Performances were evaluated using physicochemical analyses, toxicity tests and identification of organic compounds. The MBR_b and MBR_y were operated with a hydraulic retention time (HRT) of 48 h and solids retention time (SRT) of 60 d. The MBR_y demonstrated better removal efficiencies for COD (69 ± 7%), color (54 ± 11%) and ammoniacal nitrogen (34 ± 7%) compared to MBR_b, which showed removal efficiencies of 27 ± 5%, 33 ± 4% and 27 ± 7%, for COD, color and ammoniacal nitrogen. Although the MBR_y seems to be the configuration that presented the highest efficiency; it generated toxic permeate whose toxicity cannot be explained by physicochemical results. The identification of compounds shows that there is a wide range of compounds in the landfill leachate in addition to others that are produced in the biological treatment steps. The NF plays a crucial role in the polishing of the final effluents by the either complete or partial retention of compounds, that attribute toxicity to the leachate, and inorganic contaminants.

1. Introduction

Landfill leachates (LFL) contain high loads of refractory organic matter, inorganic salts (sulfates, carbonates and sodium chloride), ammonia, halogenated and heavy metals that contribute to high LFL toxicity (Renou et al., 2008; Kjeldsen et al., 2002; Zhou et al., 2016). The presence of toxic substances can be indirectly detected using ecotoxicity bioassays (Thomas et al., 2009; Tigini et al., 2010).

Ecotoxicity tests applied to wastewater treatment method development could provide a rapid and low-cost means of evaluating the efficiency and safety of new treatment methods, since the toxicity of an effluent does not always follow the pattern of removal of the physical-chemical parameters. This is particularly valuable when treating wastewaters with a complex contaminant matrix, such as landfill leachates, where the toxicity can vary greatly between different types of leachates (Thomas et al., 2009).

In the report "Handbook for leachate characterization," published by the Swedish Environmental Research Institute, it is recommended that toxicity testing of leachates with elevated levels of ammonium and chlorides is performed with organisms which are less sensitive to these contaminants, e.g. *Aliivibrio fischeri* (Öman et al., 2000).

The most common systems used in the treatment of landfill leachate are based on biological processes. Biological processes are very effective when applied to young leachates, but their efficiency decreases with increased leachate age (Bashir et al., 2013). In particular, conventional biological systems cannot efficiently treat old leachates, which contain contaminants resistant to biodegradation. Thus, the option of combined treatments must be considered.

Membrane bioreactors (MBR), which consist of the association of biological processes combined with membrane separation processes, have been considered one of the most promising methods for treating LFL. MBR are modular systems that can operate with a high concentration of biomass and sludge retention time, resulting in a more efficient biological degradation system compared to conventional bioreactors (Judd, 2010; Renou et al., 2008; Ahmed

* Corresponding author.
E-mail address: miriam@desa.ufmg.br (M.C.S. Amaral).

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and Lan, 2012), besides eliminating perceived drastic fluctuations in suspended solids concentration of effluents treated by bioreactors without membranes (Laitinen et al., 2006).

However, bacterial sludge, commonly used in MBR processes, has limitations on the degradation of recalcitrant compounds from leachate that tend to increase with increasing leachate age. In this way, the use of other groups of microorganisms can be promising. The fungi and yeasts present high capacity of degradation and assimilation of pollutants of difficult degradation (Harms et al., 2011) and may be promising in leachate treatment (Wichitsathian et al., 2004).

Yeasts present a lower tendency towards adhesion in surfaces than bacteria (Douglas, 1987), making their application in MBR able to bring benefits in relation to systems operation. The lower adhesion of the yeast cells to the membranes causes a decrease in membrane fouling and, consequently, an increase in the lifespan of the membranes. Wichitsathian et al. (2004) compared the performance of two MBR, one containing bacterial sludge and one containing a yeast mix, and observed similar COD removal efficiency, but notable operational advantages in the yeast-containing sludge system.

Saccharomyces cerevisiae is a model species of yeast, widely used by industry in fermentation processes. In these environments, they grow under high concentrations of sugars and ethanol, supporting the stress imposed by osmotic pressure, lack of water and harmful effect of ethanol (Tanghe et al., 2005). Raspor and Jure (2005) also describe the tolerance presented by this species at high concentrations of metals such as Zn, Cr (VI), Co, Ni, Hg, Sr, Mo and Cu.

Brito et al. (2012) carried out a study of the inert COD fraction of leachate for bacterial sludge and yeast sludge from *Saccharomyces cerevisiae* under aerobic conditions, noting that not only this fraction is variable for different bacterial groups, but inert COD for bacterial sludge is 13% higher than for yeast sludge. Thus, *S. cerevisiae* is a promising species in the treatment of effluents containing high concentrations of organic matter, solids and salts (Wichitsathian et al., 2004), such as LFL.

However, with progressively more strict discharge standards being implemented in most countries, MBR effluents may still require post-treatment. (Sadri et al., 2008; Aloui et al., 2009; Zhou et al., 2016). A combination of nanofiltration (NF) as a polishing step for MBR effluent allows for greater efficiency in pollutant removal. The NF technology offers a versatile approach to meet multiple water quality objectives such as control of organic, inorganic, and microbial contaminants and, when used as post-treatment, it has the capacity of approximately 98% and 100% of COD and N-NH3 removal respectively (Renou et al., 2008; Robinson, 2007).

In this context, the aim of this work is to compare the performance of a commercial bakers' yeast (MBR_y) and conventional bacteria (MBR_b) based membrane bioreactor associated with nanofiltration in the removal of LFL toxicity.

2. Materials and methods

2.1. Landfill leachate sampling and characterization

For this work, the leachate from the Macaúbas Sanitary Landfill was used, located in the municipality of Sabará (Minas Gerais, Brazil), in operation since 2007. Raw leachate was collected from the equalization tank. The collected samples were kept refrigerated at 4 °C for physicochemical analysis and frozen at −20 °C for toxicity tests. The characteristics of leachate used in this study are given in Table 1.

The leachate used shows high organic matter concentration and toxicity. The average ammonium concentration found was 1,552 mg L^{-1}, which indicates that pre-treatment requires ammonium removal. According to Ahmed and Lan (2012) this LFL can be classified as stabilized due to COD being less than 4,000 mg L^{-1}, ammonium concentration being higher than 400 mg L^{-1} and low heavy metal concentration. Nitrate in leachate may be considered as partial nitrification resulting from leachate flow in an uncovered outdoor disposal area.

2.2. Experimental setup and operational conditions

The pilot plant consists of an air-stripping reactor for ammonia removal, a commercial bakers' yeast (route 1) and conventional bacteria (route 2) based submerged membrane bioreactor and a nanofiltration system for polishing (organic and inorganic pollutant removal).

The air stripping process, used as pretreatment of the treated leachate, was carried out in a tank with aeration (air flow of 60 m^3 h^{-1}) installed in the pilot plant of the landfill, at room temperature, without pH adjustment, with residence time of 48 h.

The MBR had a submerged hollow fiber microfiltration (MF) membrane module made of poly(etherimide) with an average pore size of 0.5 μm, packing density of 500 m^2 m^{-3}, and membrane area of 14 and 0.04 m^2 for the MBR_b (MBR inoculated with bacterial sludge) and MBR_y (MBR inoculated with baker's yeast sludge), respectively. The MBR_b had four tanks: a feed tank and a biological tank, both operated with an effective volume of 3,000 L, a 200 L membrane tank, and a 10,000 L storage tank for permeate. The MBR_y had three tanks: a feed tank that operated with an effective volume of 30 L, a 10 L biological and membrane tank, and a 20 L storage tank for permeate. For both MBRs, a diaphragm pump was used to promote both the MF and backwash. There were also three-way solenoid valves; level sensors; needle valves for flow adjustment; rotameters to indicate permeation, backwash, and air flows; a manometer to indicate pressure; and a skid with an

Table 1
Descriptive statistics of the physicochemical parameters of the landfill leachate.

Parameters	N	Median	Average and Standard deviation	Minimum	Maximum	Percentile 10	Percentile 90
pH	11	8,5	8,6 ± 0,3	8,4	9,4	8,4	8,7
Apparent color (uH)	11	1126	1147 ± 334	643	1909	711	1311
Electrical Conductivity (μS cm^{-2})	11	21,5	20,3 ± 2,7	13,3	22,6	18,4	22,3
COD (mg O_2 L^{-1})	11	4032	4184 ± 651	3526	5429	3571	5265
Total Nitrogen (mg N L^{-1})	11	1928	1925 ± 305	1473	2336	1537	2316
Ammonia Nitrogen (mg N L^{-1})	11	1552	1476 ± 260	953	1709	1041	1704
Nitrite (mg N L^{-1})	10	0,20	0,21 ± 0,03	0,16	0,28	0,17	0,25
Nitrate (mg N L^{-1})	10	2,64	2,65 ± 1,20	1,13	5,03	1,34	4,45
Total phosphorus (mg P L^{-1})	9	25,7	26,6 ± 5,9	17,3	35,7	17,3	35,7
Chloride (mg Cl L^{-1})	9	2466	2503 ± 56	2433	2599	2433	2599
Alkalinity (mg $CaCo_3$ L^{-1})	9	7043	7370 ± 1085	6021	8941	6021	8941
Toxicity(EC50 30 min)	9	5	5 ± 1	3	6	3	6

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