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Recirculation as the form of destination of the Concentrate originated from the Treatment of leachate in landfills by Membrane Processes

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ABSTRACT

The different methodologies of leachate treatment are widely debated in the literature, promoting a great discussion among the scientific and academic community on the most efficient and propitious methods. Membrane treatment processes, especially Reverse Osmosis (RO), stand out as the best solution. The RO has pollutant removal rates higher than 99%, with operational cost and complexity competitive with other technologies. Its main disadvantage is the concentrated residue generated in the process that covers about 30% of the volume of leachate entering the system. Its recirculation in the body of the landfill arises as an alternative of low destination cost. Its effectiveness is directly related to the method of recirculation along the geological, climatological, technical and operational conditions of the landfills. Although already widespread, the treatment or destination of the concentrate requires a greater technological assertion. Further research is needed on the recirculation methods of the concentrate and its medium and long-term effects on leachate, settlement and landfills after care period. It is important to make a comparative analysis of landfills with similar characteristics, one with and another without recirculation of the concentrate. Alternatives to treat the concentrate are also of great interest whether they are economically viable in real scale.

Keywords: Reverse Osmosis; Leachate Treatment; Membrane Technologies

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RESUMO

As metodologias de tratamento do lixiviado são amplamente debatidas na literatura, promovendo discussão entre a comunidade científica e acadêmica sobre os métodos mais eficientes e propícios. Os processos de tratamento por membranas, com destaque para Osmose Reversa (OR), sobressaem como melhor solução. A OR possui índices de remoção de poluentes superiores a 99%, com custo e complexidade operacional competitivas. Sua principal desvantagem é o rejeito concentrado gerado no processo, que abrange cerca de 30% do volume de lixiviado ingressante no sistema. Sua recirculação no corpo do aterro surge como uma alternativa de destinação de baixo custo, apesar de riscos de aumento de volume e poluentes no lixiviado. Sua eficácia está diretamente relacionada com o método de recirculação junto as condições geológicas, climatológicas, técnicas e operacionais dos aterros sanitários. Apesar de já difundida, o tratamento ou destinação do concentrado dos sistemas OR precisam de maior afirmação tecnológica, para isso são necessárias pesquisas mais profundas sobre os métodos de recirculação e seus efeitos a médio e longo prazo sobre o lixiviado, assentamento e período de pós encerramento dos aterros. Salienta-se a importância de uma análise comparativa entre aterros sanitários com características semelhantes, contemplando um com e outro sem recirculação do concentrado.

Palavras-chave: Osmose Reversa; Tratamento de Lixiviado; Tecnologias membranares

1 INTRODUCTION

With the tightening of environmental legislation and checks in patterns of leachate from landfills, conventional biological systems have proven ineffective in achieving such levels of removal. Due to this, membrane processes emerge to optimize and increase the quality of leachate treatment. These have been shown to be more efficient, adaptable and indispensable. (RENOU et al., 2008).

Membrane treatments are characterized by the action of membranes, of different types, with different porosities and compositions. These membranes act as a fine filter which, through external pressures, provide a selective barrier to particles of different sizes, which vary according to the selectivity of the membranes used in the treatment. (BIDONE, 2008; HURD, 1999).

The landfill leachate subjected to membrane processes generates:

1)Concentrate: is the reject of the treatment.

2)Permeate: is the result of the treatment.

Table 1 compares the porosities and material types retained in the different membrane treatment processes.

Table 1 - Porosities and material types retained according to membrane processes

Membrane	Porosity	Material retained
Microfiltration (MF)	0.1μm - 0.2μm	Protozoa, bacteria, virus (most), particles
Ultrafiltration (UF)	1,000 - 100,000 Da	Materials removed on MF + colloids + virus totality
Nanofiltration (NF)	200 - 1,000 Da	Divalent and trivalent ions, organic molecules larger than average membrane porosity
Reverse Osmosis (RO)	< 200 Da	Ions, basically all organic matter

According to studies by Jamaly et al. (2014), the potential of using a Membrane Biological Reactor (MBR) system upstream of a membrane process unit for purification is interesting in reducing the frequency of clogging of RO membranes and membrane processes and producing a very high-quality effluent.

MBR treatment includes a biological pretreatment for a subsequent MF or UF membrane system. Its purpose is the complete removal of suspended solids as well as Chemical Oxygen Degradation (COD), through the retaining of high molecular weight compounds and biodegradation. RO is a consolidated technology that produces a high-quality final effluent with removal rates of 99% of pollutants. Concentrated tailings in the order of 20-30% of the system input volume are generated, being the technology of greatest application in the global scenario (RENOU et al. 2008).

It is understood that membrane treatments are best suited for the treatment of leachate by factors such as operational stability, tolerance to leachate variations, competitive CAPEX and OPEX, as well as a high-quality effluent.

The present work aims to evaluate recirculation in the landfill as a form of destination of the concentrate, resulting from the treatment of landfill leachate by membrane processes. Thereby, methods and operational precautions to be adopted with the implementation of these systems will be exposed. In addition, the technical feasibility of this procedure will be analyzed by compiling several countries real cases, both at pilot and operational scale.

2 METHODOLOGY

The present work was developed from a bibliographical research of technical and academic references such as scientific articles, papers presented at international conferences and technical documents issued by companies. Documents published in the last ten years were prioritized, but the oldest works with great relevance to the currently analyzed subject were not discarded.

The platforms explored were Scopus, Science Direct and Mendeley. Also, consultations with professionals of the area were made. The research used keywords such as: Leachate, Leachate Treatment, Reverse Osmosis, Concentrate and Sanitary Landfill.

3 BIBLIOGRAPHIC REVIEW (CONCEPTS)

3.1 Concentrate Characteristics

Concentrate is the major disadvantage of membrane processes. Volumes are of considerable concern in any membrane treatment process, especially in reverse osmosis (RO), ranging from 13-30% of the leachate input volume (ZHANG et al., 2013).

The concentrate is a brownish-colored liquid with high pollutant loads. As the name suggests, it is composed of the substances present in the leachate in a concentrated and smaller volume due to physical membrane separation. It has substances that are difficult to biodegrade due to the high concentration of recalcitrant organic substances such as aromatic compounds and long chain hydrocarbons. As well as high toxicity with the presence of toluenes, ethylbenzenes and chlorobenzene, substances considered by the United States Environment

Protection Agency (USEPA) as the main toxic substances for the environment (ZHANG et al., 2013). Table 2 comes from the comparative laboratory analysis of 3 parallel samples of leachate and concentrate generated in a UF process with subsequent treatment by RO.

Table 2 - Comparison of some chemical characteristics of leachate and concentrate from a RO process in 3 samples

Chemical characteristics of landfill leachate and concentrated leachate from membrane treatments.

Item	Landfill leachate			Concentrated leachate		
	X	S	N	X	S	N
pH	8.01*	7.75	7.66	5.56	7.58	5.58
BOD_5 (mg L^{-1})	1000.7	875.7	834.3	70.7	95.7	101
COD (mg L^{-1})	1491	1105	1906	1158	400	1164.5
VFA (mg L^{-1})	802.8	638.3	1051.3	275.7	77.6	457.0
BOD/COD	0.67	0.79	0.44	0.06	0.24	0.09
VFA/COD	0.54	0.58	0.55	0.24	0.24	0.39
TP (mg L^{-1})	15.43	13.53	19.93	11.44	1.64	5.14
TN (mg L^{-1})	775.3	955.7	1162.8	1051.3	244.5	1417.5
NO_3^-—N (mg L^{-1})	9.4	9.7	21.2	641.3	22.5	1044.6
NH_4^+—N (mg L^{-1})	467.5	667.0	676.5	46.3	77.9	298.1
Cl^- (mg L^{-1})	1429.6	819.7	3154.0	1779.4	999.7	3998.8
SO_4^{2-} (mg L^{-1})	54.95	270.4	73.02	164.76	298.2	253.72
Cr (mg L^{-1})	0.17	0.31	0.78	0.06	1.56	3.9
Mn (mg L^{-1})	0.54	2.39	5.98	0.48	11.97	29.91
Fe (mg L^{-1})	1.94	15.47	38.67	3.09	77.34	193.34
Co (mg L^{-1})	0.02	0.04	0.1	0.01	0.2	0.512
Ni (mg L^{-1})	0.06	0.2	0.512	0.04	1.02	2.56
Cu (mg L^{-1})	0.18	0.74	1.85	0.15	3.71	9.26
Zn (mg L^{-1})	17.21	532.5	1331.25	106.5	2662.5	6656.25
As (mg L^{-1})	0.05	0.3	0.74	0.06	1.48	3.71
Mo (mg L^{-1})	0.03	0.16	0.39	0.03	0.78	1.96
Cd (mg L^{-1})	0.01	0.24	0.6	0.05	1.2	3.01
Pb (mg L^{-1})	0.23	4.56	11.39	0.91	22.79	56.97

Source: ZHANG et al., 2013

Concentrates can also contain considerable levels of emerging contaminants such as drugs, pesticides, phenols and disinfectants, consisting in high risk to ecosystems and society (JOO & TANSEL, 2015).

The difficult treatability of the concentrate is indeed a problem for waste managers. Alternatives such as incineration, evaporation with disposal of the remaining solid in hazardous waste landfills or a reinsertion into the RO system itself with a reduction of 50% of the original volume have high operating costs (LOBLICH, 2005; STEGMANN & SCHELLERDAMM, 2007; RENOU et al., 2008; SCANTAMBURLO, 2015).

According to laboratory scale research by Labiadh et al. (2016), the anodic oxidation treatment process followed by an Electro-Fenton system is an efficient technology for treating concentrate from RO systems for leachate treatment.

A study by Joo & Tansel (2015) concludes that if there is a renewable energy source within the landfill such as biogas conversion, the electrodialysis process is effective in treating the concentrate with subsequent reinsertion in the RO or UF system itself.

Recirculation in the mass of waste from the landfill itself is the most widely used and debated destination (RENOU et al., 2008). According to Calabrò et al. (2018) is the most economically viable. However, there are controversies in the literature and differences of opinion about the effects of this method (TALALAJ & BIEDKA, 2015).

3.2 Concentrate Recirculation

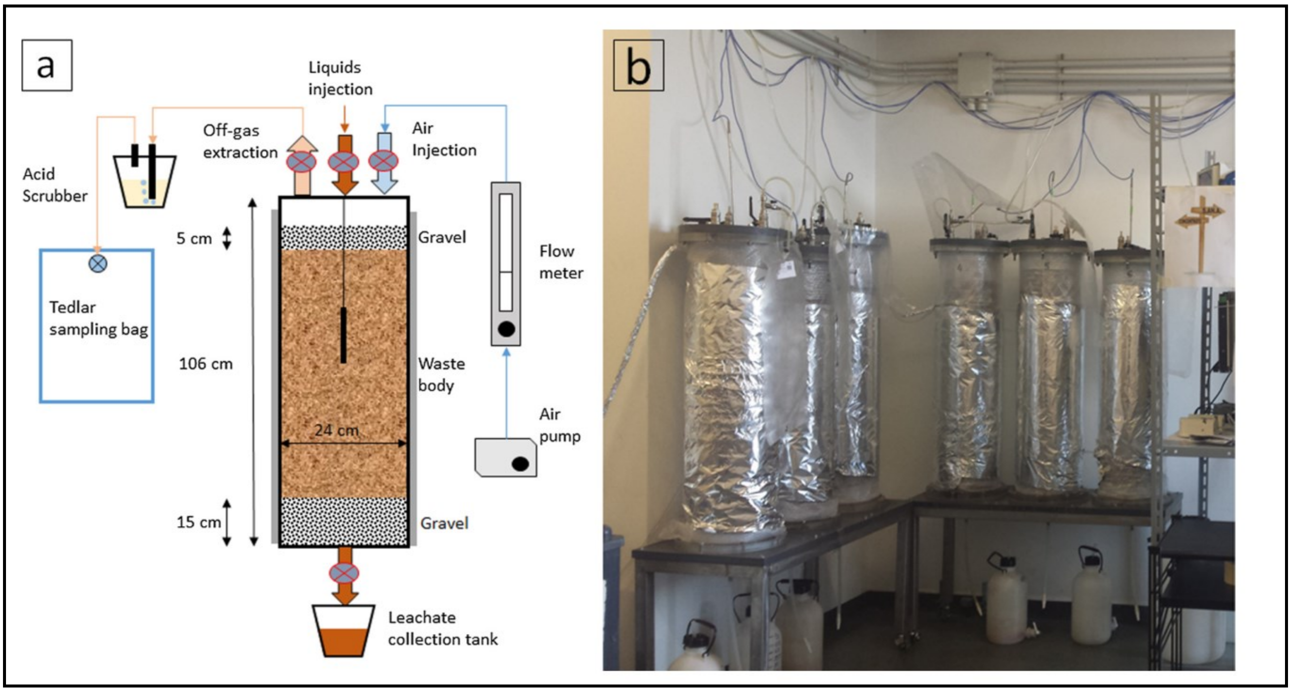
The recirculation of the concentrate arises from the practice of a new injection of the leachate itself to reduce the volume to be treated, increasing the production and quality of biogas, increasing the humidity and microbiological activity with consequent increase in the degradation of organic matter and stabilization of the leachate landfill with reduced post-closure period (BARINA et al., 2001; ONSTANTAKOPOULOSX et al., 2001)

This technique takes into account the concept of the landfill as a biochemical reactor rather than a tomb for mummification, the chemical reactions and microbiological activity are intense inside. Concentration recirculation is of paramount importance to accelerate the biodegradation process and promote the early inertization of the waste mass, shortening the stabilization period after the landfill closure (CABEÇAS, 2008).

According to Stegmann & Schellerdamm (2007), recirculation does not present a major problem for German landfills. In England, the environmental agency approves recirculation and emphasizes the suitability of the method as long as the landfill is properly designed and the RO plant is capable of treating any changes in the leachate.

Studies by Morello et al. (2016), analyzed laboratory scale landfill simulators systems, with and without air injection, and the concentrate from a RO system was recirculated. Figure 1 shows schematically the studied system. This author compared the effects of recirculation on two air injection systems and two anaerobic systems, having two other systems, aerobic and anaerobic, without recirculation for comparative purposes. There was an increase in ion ammonium concentration in the leachate of anaerobic reactor, while in the aerobic reactor no significant change was found. In conclusion, the injection of air into the landfill waste mass together with the recirculation of the concentrate is a sustainable alternative in waste management, promoting a technological symbiosis, however, it is worth weighing the energy expenditure for landfill air recirculation.

Figure 1 - Schematic of a system that simulates a cell from an aerated landfill with concentrate recirculation



Source: MORELLO et al., 2016

The real scale study by Calabrò et al. (2018), was based on the fifteen-year data collection of the Il Fossetto Landfill, in Tuscany (Italy). In the first four years, the leachate analysis was observed without recirculation for later comparison. After the end of this period, a RO system was implanted and concentrate recirculation began with continuous observation through leachate sampling. The author's conclusions state that there was an increase in annual leachate volume only after 10 years of recirculation. Also, ammonia, chloride and sulfate parameters were slightly higher after recirculation onset, not significantly compromising the efficiency of the RO system. Table 3 shows the average leachate parameters before and after recirculation. The author states that this methodology is sustainable in the management of leachate in landfills.

Table 3 - Comparison of mean values + standard deviation of some leachate parameters in the period before and after recirculation

Parameter	Before Recirculation (n = 8)	After Recirculation (n = 40)
pH	7.80 ± 0.68^A	7.82 ± 0.34^A
COD	3490 ± 1540^A	3700 ± 1000^A
NH_4^+	1900 ± 621^A	2240 ± 1040^A
Pb	0.74 ± 1.0^A	0.18 ± 0.23^B
Cr_{tot}	6.3 ± 2.4^A	3.7 ± 4.9^A
Cu	0.26 ± 0.15^A	0.24 ± 0.29^A
Ni	0.68 ± 0.25^A	0.77 ± 0.42^A
Zn	0.99 ± 1.15^A	1.23 ± 1.35^A
As	0.043 ± 0.05^A	0.17 ± 0.23^A
Hg	0.0162 ± 0.042^A	0.033 ± 0.073^A
Cl	2320 ± 658^A	3170 ± 1328^A

Source: CALABRÒ et al., 2018

The laboratory experiment by Scantamburlo (2015) simulated 6 landfill cells, 3 anaerobic and 3 aerobic, with 100% recirculation, 50% and 0% concentrate from an OI system, with the remaining percentages composed of water. The author concludes that the larger the volume of concentrate injected, the greater the accumulation of hazardous substances in the waste mass. In addition, the concentrate did not inhibit methanogenic bacteria, contributed to the increase in biogas generation and promoted an increase in the biological stability of the leachate. In addition, concentrate recirculation encourages biological activity by reducing the post-closure period and does not affect waste hydraulic performance. However, an accumulation of salts and chlorides in the leachate was noted.

According to Peters (2001), concentrate recirculation has been used in Germany since 1986. The concept of landfill as a bioreactor is solid, the biodegradation of its organic part is accelerated by the recirculation process, generating an increase in biogas production and reduction of post-closure period, especially in low humidity landfills. The decomposition of organic and inorganic materials in the form of oxides, sulfates and carbonates is also established. In addition, the adsorption of heavy metals on different surfaces of the waste, such as mineral clay and humic compounds, and the crystallization processes of insoluble salts forming minerals, are also benefits of recirculation. The author states that to achieve these aspects successfully, it is necessary to analyze the characteristics of the landfill and the volume and parameters of the concentrate to then adopt a reinfiltration method, the location of the reinjection wells and when to change locations. The author also states that by 2001 there were 15 German landfills that successfully recirculated RO concentrate, where some were observed for 15 years and there was no significant evidence of increased concentration of leachate parameters.

The PhD thesis developed by Henigin (1999) studied in depth the recirculation of the real scale concentrate in several German landfills for 12 years and performed bench experiments on reactors with reinjection systems. The study describes that there is no significant change in the concentration of leachate parameters when recirculation is well performed, and that its volume may increase by a maximum of 33% of the projected, in unfavorable situations. As a conclusion of the study, the author states that there are no technical, ecological and economic reasons for the prohibition of concentrate recirculation. The reflections, based on the knowledge of physics, chemistry, biochemistry and soil science made by this author, underline the following processes responsible for the success of the method:

●Biochemical decomposition of biochemically degradable substances;

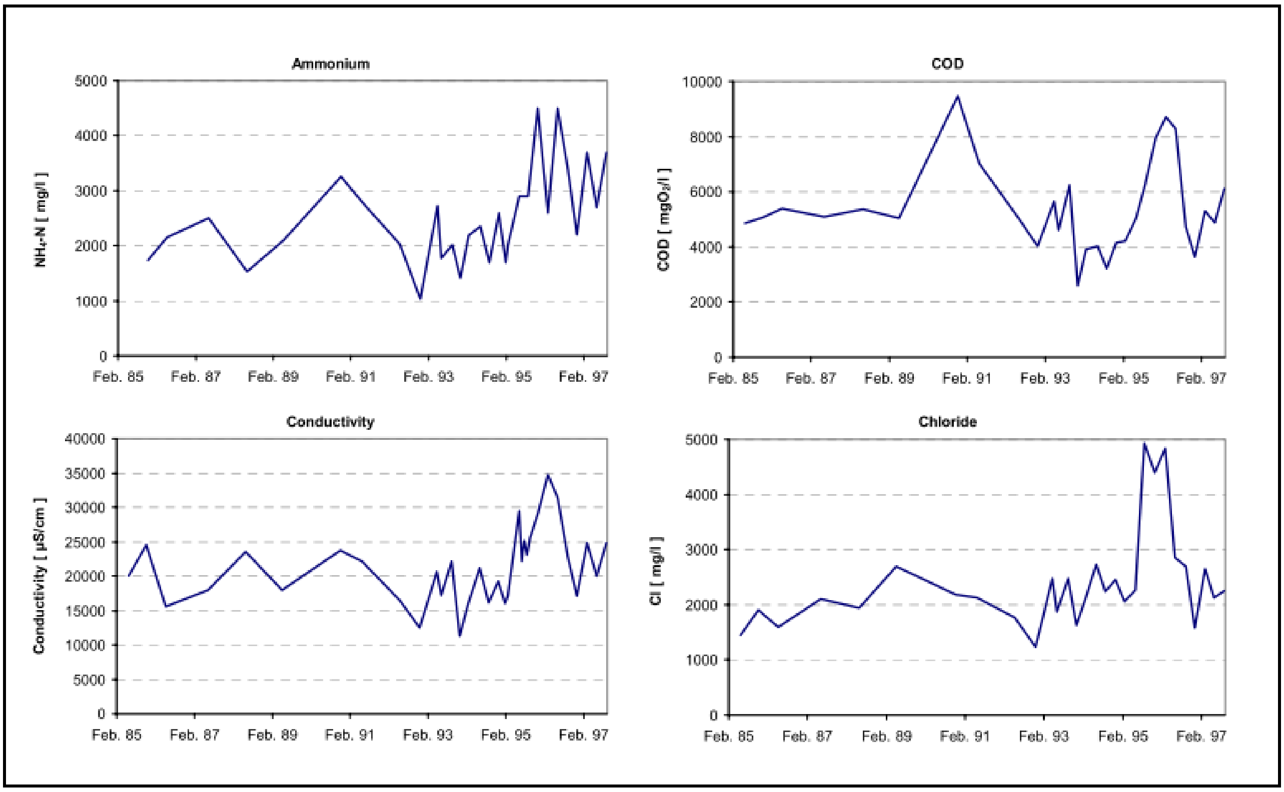
●Mechanical filtration of solids exceeding 10 μm;

●Adsorption of organic and inorganic compounds as well as metals;

●Determination of inorganic compounds due to excess solubility balance (crystallization) and biochemical decomposition processes.

Figure 2 shows the result of one of the longest and highest quality concentrate recirculation monitoring at the Oberweier Landfill, Germany. Over the years, there has been no significant impact on leachate quality, except for 1995, when two reinfiltration points directed the concentrate to saturated sites in the landfill body, shortening the system and increasing the leachate concentrations. After identifying the problem, the reinfiltration points were changed according to the graphs below, the leachate concentrations dropped and normalized.

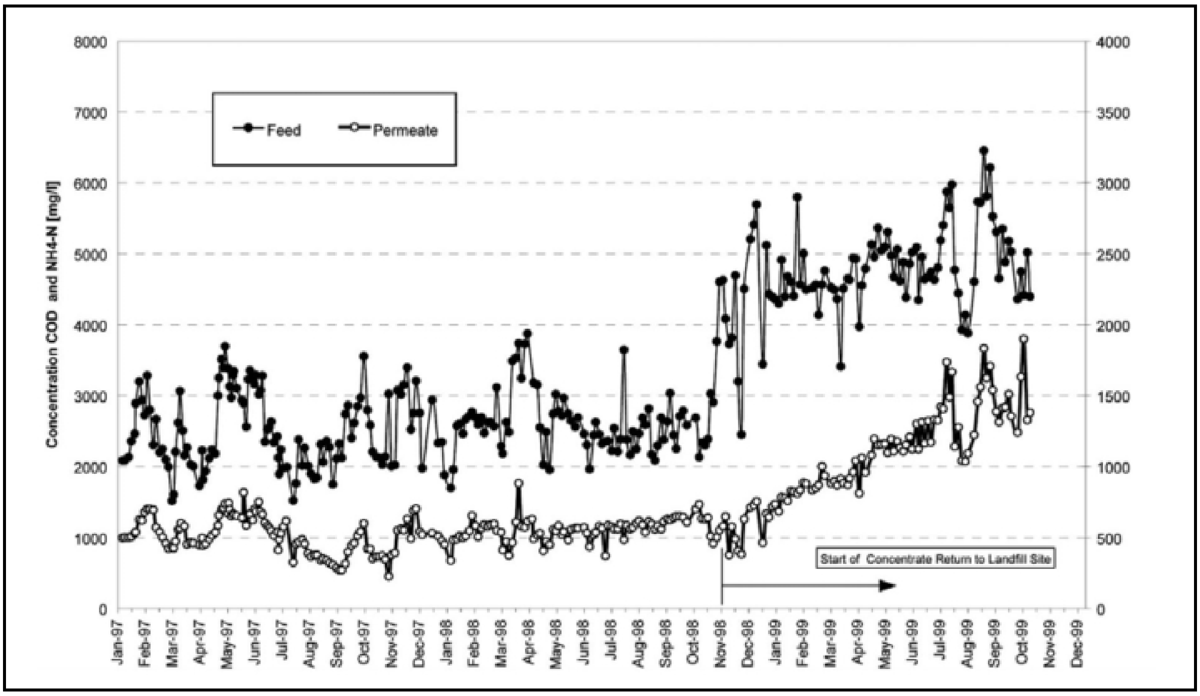
Figure 2 - Composition of leachate during recirculation period at the Oberweier landfill, Germany, 1986-1997



Source: HENIGIN, 1999; STEGMANN & SCHELLERDAMM, 2007

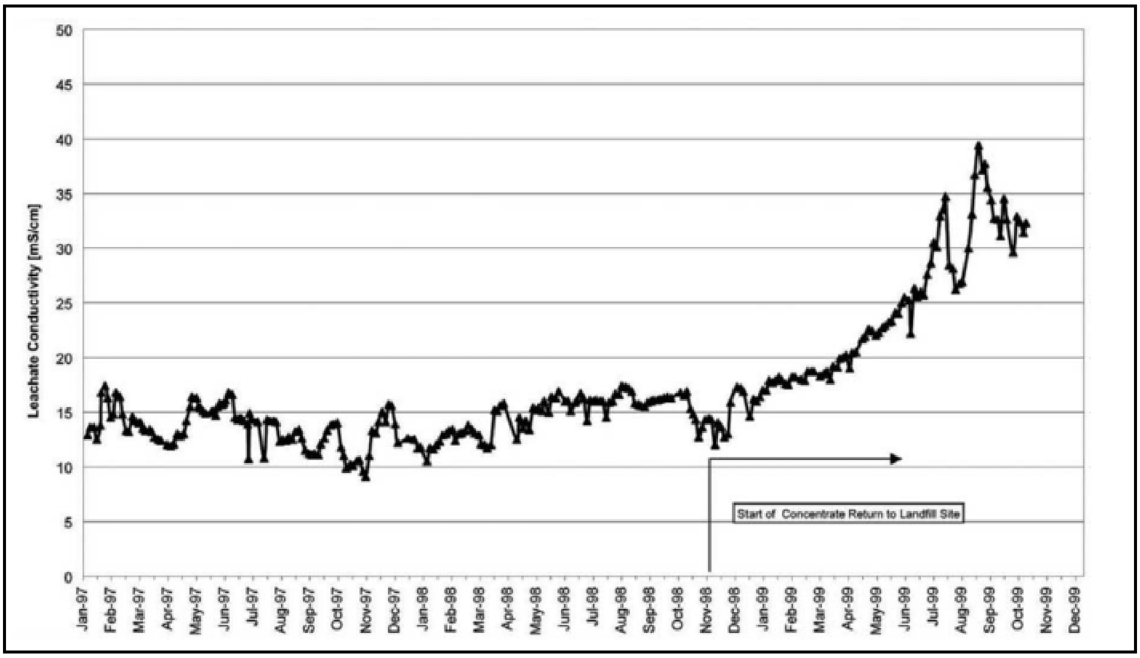
A two-year continuous analytical observation at a German landfill in Wischhafen of RO concentrate recirculation by Robinson (2005) points to a growth in ammonia concentration, COD and leachate conductivity, which directly affects the efficiency and operating costs of RO leachate treatment plant. Figure 3 and Figure 4 graphically present the survey results.

Figure 3 - Effects of concentrate recirculation on COD and NH_4 parameters in the permeate and leachate generated



Source: ROBINSON, 2005

Figure 4 - Effects of RO concentrate recirculation on the conductivity parameters of the generated leachate



Source: ROBINSON, 2005

Real scale studies by Talalaj & Bieka (2015) analyzed the effects of recirculation on the leachate over a period of one year. An increase in conductivity, COD, ammonia and sulphates was found in the leachate. After one year of recirculation, the stabilization of the methanogenic phase was verified by the increase in pH and decrease in the BOD / COD ratio. The attenuating capacity of pollutants such as chlorides and ammonia nitrogen were observed. It was concluded that after the sorption capacity of the waste is depleted, the concentration of pollutants in the leachate will increase. According to Stegmann & Schellerdamm (2007), the positive and negative points of recirculation fall as follows according to Table 4.

Table 4 - Summary of the advantages and disadvantages of Concentrate Recirculation in landfills

Advantages	**Disadvantages**
Increased biogas generation up to three times.	Hydraulic disturbance induced by settlements or clogging.
Acceleration in the landfill stabilization process.	A few cases of short- and long-term accumulation of non-degradable components in the leachate.
Reduction of organic components in leachate.	Short circuit of the concentrate, where preferential paths in the waste / soil mass originate, promoting saturation in some places of the landfill body and consequent concentration of the leachate.
Toxic effects on the concentrate are not induced to the leachate.	Flooding of biogas wells.
In concrete cases of recirculation there is no significant evidence of increased concentration in the leachate. When there is an increase, it is due to climate or operating factors of the landfill, when the reinjection system is adequate.	Odor problems.
Reduces the time of the biological reaction process due to the absence of moisture and may lead to mummification (in drier places or landfills with broad surface coverage).	Clogging of leachate collection and drainage system due to precipitation of inorganic materials.
It is a cost-effective method of treating leachate by RO systems.	Clogging and fouling of the reinfiltration system tubing when not properly used.

It is a fact that recirculation can generate as many benefits as damages to landfills, being a complex method that does not have several conclusive and consistent studies about it. However, the technique or methodology used in the reinjection of the concentrate is the most relevant to block the success of RO and other membrane treatments. Recirculation planning should take into account the important aspect of the landfill moisture content and avoid preferred soil infiltration paths through control measures. In addition, the minimum criteria for a landfill to have a successful recirculation system should be considered. These include adequate bottom waterproofing and drainage system, static landfill stability, gas collection system, concentrate infiltration control system and a gas, water balance and settlement monitoring program (STEGMANN & SCHELLERDAMM , 2007).

Restrictions also reach the sphere of biological activity and water storage capacity, non-saturation, of landfill body regions. Already the amount of concentrate infiltrated in a given time is directly dependent on the height, geometry and degree of compaction of the landfill, weather conditions, waste gravimetry and the recirculation technique are also relevant aspects. (STEGMANN & SCHELLERDAMM, 2007). Therefore, Peters (2001) states that it is not possible to obtain a generalized and approximate prognosis due to the large number of variables, requiring an efficient monitoring program for better control and adjustment of the reinfiltration system. Table 5 presents a recirculation monitoring plan.

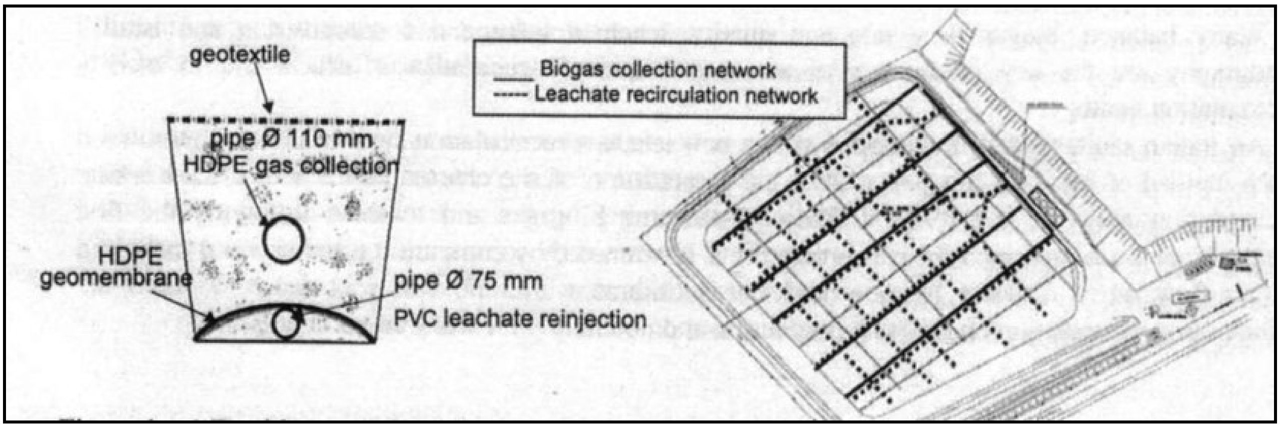
There are two commonly used recirculation methods: periodically alternating wells, both dug and existing from the biogas collection system, similar to an injection into the landfill body, tending to choose the highest points (PETERS, 2001; STEGMANN & SCHELLERDAMM, 2007). The other method is more sophisticated, where a horizontal insertion system is composed of specific pipes to support the concentrate that are symmetrically arranged, being buried at three meters from the surface, with superior geomembrane coverage, in the highest places, aiming at a homogeneous dispersion of the concentrate in the landfill (BARINA et al., 2001; PETERS, 2001; STEGMANN & SCHELLERDAMM, 2007). Figure 5 shows an example of a horizontal recirculation system at the Busta landfill, Italy.

Table 5 - Synthesized leachate recirculation monitoring plan in landfills

	Parameter	**Frequency**	**Instrumentation**
Leachate quality	pH, Conductivity and TSS	Quarterly or monthly (if there is a change in the recirculation strategy)	Laboratory analysis
	CDO, BOD_5 and Volatile Fatty Acids		
	Ammonia	Quarterly or monthly	
	Nitrate	Quarterly	
	Nitrite	Quarterly	
	Total Phosphorus, Sulphate, Sulfide, Chloride, Calcium, Magnesium, Potassium and Sodium	Quarterly or Monthly	
	Iron, Manganese, Lead, Copper and Zinc	Quarterly	
Leachate volume	Volume collected	Regular	Electromagnetic or mechanical meters
	Recirculated volume		
Biogas quality	Measure methane, carbon dioxide, oxygen and hydrogen sulfide. Measure on main pipe and all horizontal sections	Twice a week	Portable IR analysis
	Nitrogen, hydrogen, carbon monoxide, Volatile Organic Compounds (VOC), metals and moisture	Quarterly	Gas chromatography and laboratory analysis of atomic absorption
Biogas flow (main tube)	Speed	Daily control	Fixed analysis or portable anemometers and barometers
	Temperature		
	Pressure		

Source: Adapted from BARINA et al., 2001

Figure 5 - Simplified schematic of a horizontal concentrate recirculation system



Source: BARINA et al., 2001

4 FINAL CONSIDERATIONS AND CONCLUSIONS

The treatment of landfill leachate is one of the costliest activities within the operation of a landfill, with difficulties in achieving the parameters provided for in the environmental standardization. The peculiarities of each landfill (climate, water balance, operation and waste characteristics) influence the quality and quantity of leachate, making the situation even more critical.

Different leachate treatment techniques have been widely and thoroughly debated in the literature, through experiments and practical analysis of operating leachate treatment plants. All technologies have their advantages and disadvantages, dealing with aspects such as efficiency, effectiveness, economy and operational viability and logistics, making the choice of the best technology a challenge. Because of this, the importance of in-depth analysis of the scenario in which a leachate treatment plant is planned to be built is crucial to the completion of the treatment goal to the satisfaction of all stakeholders.

RO's membrane leachate treatment technology is consolidated worldwide, is the most economically viable, efficient, effective alternative and, although already widespread in many countries, still has great application potential in the municipal solid waste (MSW) management market. Permeate (resulting from membrane treatments that is intended for recipient bodies) generally meets the discharge requirements of environmental organs due to its high rates of pollutant removal. The technology has maturity and its development is constant, being periodically improved to reduce operating costs, especially through the technological development of membranes.

The resulting concentrate from the RO process is the major disadvantage of the technology. The considerable volumes generated, and their treatment methodologies have high costs, which in turn may compromise the decision to acquire this technology for the treatment of leachate. The recirculation method appears as a solution that promotes technological symbiosis within a landfill system, bringing benefits such as increased biogas generation and decreased post-closure period, avoiding waste mummification through the acceleration its degradation, besides being a low-cost solution for the concentrate. In fact, there are a few bad experiences and reports where the RO system has been stifled by increased leachate parameters. However, recirculation methods stand out as the main aspects that influence short, medium- and long-term results. The geological, climatological, technical and operational conditions of landfills are also key factors for decision making when adopting a recirculation method.

Having made a bibliographic review of the subjects, it is remarkable that there are still several studies to be carried out to increase the certainties of the different optics and particularities of the theme, considering that each case is specific and the variables involved in the process must be observed individually. The concentrate recirculation project will differ according to the technical, environmental and operational configurations of the landfill in which it will be implemented. Practical and in-depth studies are recommended to analyze other possible practices for the destination of the concentrate, covering environmental, economic, logistical and technical aspects. Furthermore, in order to assert the operational efficiency of RO systems, concentrate recirculation methods should be further discussed and discussed in the literature, as well as their medium- and long-term effects. Analyzing with a pre-established frequency, in order to be able to observe significantly the changes of the leachate parameters, the quality and variation of biogas flow, the settlement and the periods after the closure of landfills.

It should be noted that the studies would be of greater enrichment and reliability if done comparatively, containing a mutual analysis of landfills with similar morphological characteristics, with one and the other without recirculation of the concentrate. Further study of the technological alternatives for concentrate treatment is also interesting, particularly assessing effectiveness, costs and operational logistics under real scale implementation conditions.

REFERENCES

BARINA, G., BUDKA, A., GISBERT, T., GUYONNET, D., PUGLIERIN, L.; CIRINO, N., 2001. Identification and assessment of leachate recirculation effects at real-scale landfill. In: Christensen, T.H., Cossu, R. and Stegmann, R. (eds), Eighth International Waste Management and Landfill Symposium, Proceedings Sardinia 2001. S. Margherita di Pula, Cagliari, Italy, CISA, vol. II, pp. 95–104.

BIDONE, R. F. Tratamento de Lixiviado de aterro sanitário por um sistema composto por filtros anaeróbios seguidos de banhos construídos: estudo de caso Central de resíduos do Recreito, Minas do Leão – RS [dissertação]. São Carlos: Escola de Engenharia de São Carlos/USP; 2008

CABEÇAS, A. J. L. Inspecção-Geral do Ambiente e do Ordenamento do Território. Lisboa, 2008.

CALABRÒ, P. S.; GENTIL, E.; MEONI, C.; ORSI, S.; KOMILIS, D. Effect of the recirculation of a reverse osmosis concentrate on leachate generation: A case study in an Italian landfill. Waste Management, 2018;76:643–651. DOI: https://doi.org/10.1016/j.wasman.2018.03.007

EPA - U.S. ENVIRONMENTAL PROTECTION AGENCY. Municipal Solid Waste. Disponível em: <https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/index.html>. Acesso em: 13 abr. 2018.

HENIGIN, P. Auswirkungen der Konzentratruckfurungh nach der membranefiltration auf die sickerwassernelbildung von hausmulldeponien. [s.l.] Technische Universitat Dresden, 1999.

HURD, S. Low-Pressure Reverse Osmosis Membrane Treatment of Landfill Leachate. [s.l.] University of Ottawa, 1999.

JAMALY, S.; DARWISH, N. N.; AHMED, I.; HASAN, S. W. A short review on reverse osmosis pretreatment technologies. Desalination, 2014;354:30-38. DOI: https://doi.org/10.1016/j.desal.2014.09.017. 2014;354:30–38.

JOO, S. H.; TANSEL, B. Novel technologies for reverse osmosis concentrate treatment: A review. Journal of Environmental Management, 2015;150(11):322–335.

LABIADH, L.; FERNADES, A.; CIRÍACO, L.; PACHECO, MJ.; GADRI, A.; AMMAR, S.; LOPES, A. Electrochemical treatment of concentrate from reverse osmosis of sanitary landfill leachate. Journal of Environmental Management, 2016;181:515–521. DOI: 10.1016/j.jenvman.2016.06.069.

LOBLICH, S. 5ª Jornadas Técnicas Internacionais de Resíduos Sistemas de Tratamento de lixiviados. Soluções para descarga direta no meio hídrico Lixiviados - Valores de Literatura (Kruse 1994). Situação Actual em Portugal. 2005.

MORELLO, L.; COSSU, R.; RAGA, R.; PIVATO, A.; LAVGNOLO, C. Recirculation of reverse osmosis concentrate in lab-scale anaerobic and aerobic landfill simulation reactors. Waste Management, 2016;56(11):262–270. DOI: https://doi.org/10.1016/j.wasman.2016.07.030

ONSTANTAKOPOULOSX, K. I.; TRIANTAFILLOPOULOS, A.; A. SKORDILIS. Landfill Behaviour With Leachate. In: Christensen, T.H., Cossu, R. and Stegmann, R. (eds), Eighth International Waste Management and Landfill Symposium, Proceedings Sardinia 2001. S. Margherita di Pula, Cagliari, Italy, CISA.

PETERS, T. A. Biodegradation and immobilization in the landfill body based on controlled infiltration of leachate concentrate. Proceedings Sardinia, Eighth International Waste Management and Lanfill Symposium. Anais S.Margherita di Pula, Cagliari, Italy: CISA, Environmental Sanitary Engineering Center, 2001.

STEGMANN, R.; SCHELLERDAMM, P. The impact of re-infiltration of reverse osmosis concentrate in landfills - Experience, evaluation and recommendations. Consultants for Waste Management. Germany. 2007.

RENOU, S.; GIVAUDAN, J. G.; POULAIN, S.; DIRASSOUYAN, F.; MOULIN, P. Landfill leachate treatment: Review and opportunity. Journal of Hazardous Materials, 2008; 150(3): 468–493. DOI: https://doi.org/10.1016/j.jhazmat.2007.09.077.

ROBINSON, A. H. Landfill leachate treatment. Membrane Technology, 2015;6:6–12.

SCANTAMBURLO, E. Reinjection of leachate reverse osmosis concentrate in the landfill body [dissertation]. University Degli Studi Di Padova; 2015.

TALALAJ, I. A. Removal of organic and inorganic compounds from landfill leachate using reverse osmosis. International Journal of Environmental Science and Technology, 2015;12(9):2791–2800.

TALALAJ, I. A.; BIEDKA, P. Impact of concentrated leachate recirculation on effectiveness of leachate treatment by reverse osmosis. Ecological Engineering, 2015;85:185–192.

ZHANG, Q. Q.; TIAN, B. H.; ZHANG, X.; GHULAM, A.; FANG, C.; HE, R. Investigation on characteristics of leachate and concentrated leachate in three landfill leachate treatment plants. Waste Management, 2013;33(11):2277-2286. DOI: https://doi.org/10.1016/j.wasman.2013.07.021.