Landfill leachate membrane concentrate management ─ a mini-review and SWOT analysis

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Abstract

Landfill leachate membrane concentrate (LLMC) such as reverse osmosis concentrate (ROC) and nanofiltration concentrate (NFC) is a by-product of landfill leachate treatment when membrane processes are used. ROC and NFC have high salinity and organic loads, representing a challenging management task for landfill operators. The present work aims to (1) review the common practices for LLMC management and (2) summarise the current challenges and opportunities using the SWOT framework. The concentrate disposal into the landfill body is the most convenient, simplest, and cheapest management option. However, the consequences of this practice are not fully known. Due to the LLMC composition, an approach based on material extraction (e.g., humic substances, nutrients, and salts) seems promising and fits the modern wastewater treatment plants' concept. The design of integrated systems for resource recovery and environmental and cost life cycle studies in pilot and full-scale can play a crucial role in developing sustainable strategies to manage LLMCs with more environmental and economic benefits.

Keywords: Concentrated leachate, Landfill leachate, Resource recovery, SWOT analysis

1. Introduction

Membrane filtration processes, especially reverse osmosis (RO) and nanofiltration (NF), have been the most efficient technology for landfill leachate treatment [1,2]. However, managing the concentrate streams generated during these processes represents a major challenge [3]. Concentrate streams include almost all the contaminants in the landfill leachate treatment plant (LLTP) influent and; therefore, they have high pollution potential, representing a threat for soil, water bodies, and living organisms. In this backdrop, there is an urgent need for sustainable solutions to address not only leachate treatment but also the management of membrane concentrates from LLTPs.

Strengths-Weaknesses-Opportunities-Threats or SWOT analysis is a strategic planning technique. Among its various usage, it can be applied to assess internal and external factors, identifying current and future technological potentials [4,5]. The present article provides a review of common practices of LLMC disposal and the current treatment systems proposed in the recent literature. In addition, challenges and opportunities for LLMC management are summarised using a SWOT framework.

2. Materials and Methods

The databases, including Web of Science and Scopus, were explored. The following keywords were combined to find the scientific literature: 'landfill leachate', 'membrane concentrate', and 'concentrated leachate'. It should be highlighted that our study is exploratory and intends to provide insights and research directions.

The present article is structured as follows: first, the main characteristics of NF and RO concentrate from LLTPs are introduced. Second, a critical analysis of LLMC destination practices and current treatment systems are presented. Last, challenges and opportunities are summarised through a SWOT (i.e., strengths, weaknesses, opportunities, and threats) framework.

3. Results and Discussion

3.1 Composition of membrane concentrates from landfill leachate treatment plants

Table 1 shows the range of typical pollution parameters of NFC and ROC found in the literature.

Table 1. Physico-chemical composition of LLMCs from RO and NF systems [6–12].

Parameter	NFC	ROC
pH	6.6—8.9	6.2—8.3
COD (g/L)	1.28—9.50	1.65—49.52
NH_3-N (mg/L)	14.82—3276	62.90-8300
BOD_5/COD	< 0.09	0.01—0.40
Chloride (g/L)	1.28—10.00	1.82—30.77
Sodium (mg/L)	890—4206	15400
Potassium (mg/L)	210—2806	9600
Copper (mg/L)	0.01—9,26	0.022—1.49
Lead (mg/L)	0.006—56.97	0.05—0.54
Nickel (mg L^{-1})	0.08—3.182	0.20—1.59

COD: Chemical Oxygen Demand; BOD_5: 5-day Biochemical Oxygen Demand; NH3-N: Ammoniacal nitrogen; NFC: Nanofiltration concentrate; ROC: reverse osmosis concentrate

As can be seen, LLMCs are characterized by high levels of organics, nutrients, and salts. The organic matter, reported as COD, ranges from 1.28 to 49.52 g/L. It was also demonstrated that humic substances accounted for a higher fraction of organic matter (60—70%) [12]. Salts, including chlorine, sodium, and potassium are found in concentrations of up to 30, 15, and 9 g/L, respectively. These values are in the same range as those found in brines produced from seawater desalination plants [13].

In addition to the high amount of organics and salts, NFC and ROC can also be high-rich in nutrients like nitrogen and phosphorus. The ranges of concentrations are 14.82—3276 and 62.90—8300 mg NH_3-N/L for NFC and ROC, respectively. These concentrate streams are also metal-polluted. For instance, the maximum level of heavy metals such as Ni, Pb, and Cu are found in concentrations higher than that of established Brazilian legislation for wastewater disposal (Conama n. 430/2011) [14].

3.2 Common LLMC management practices

Conventional LLMC management can be grouped into two main categories: final disposal and treatment. The disposal includes the concentrate accumulation in natural pounds and subsequent recirculation to the landfill body. While treatment options comprise the use of technologies that aimed to degrade/reduce concentrate pollutants before LLMC disposal.

The disposal of LLMC streams into the landfill body is the most convenient, simplest, and cheapest method. The concentrate is injected onto the waste mass through vertical and/or horizontal drains [15]. Robinson [16] presented monitoring data of a German landfill that operated a RO system for one year returning the concentrate to the landfill. He showed that ROC infiltration increased ammonia and salinity of the generated leachate, which immediately affected the treatability performance of the RO system. Similar results were found by [17] and [18]. On the other hand, 15-years monitoring data of an Italian landfill revealed a moderate change in leachate quality (slight increase in NH_4^+, Cl^-, and SO_4^{-2}) and increase in leachate quantity, but RO treatment performance was not impacted [8]. In sum, the literature shows that the consequences of concentrate disposal to landfill is site-specific and if adopted as a concentrate management strategy, proper engineering design must be done follows by monitoring of site conditions.

Concerning the treatment of leachate concentrate streams, several technologies have been proposed and assessed in laboratory investigations; however, data of full-scale projects are scarce and researches are needed to cover this aspect. Some of LLMC treatment procedures and their salient features are summarised in Table 2.

Table 2. Advantages and disadvantagens of proposed treatment technologies for LLMCs. Based on Refs. [7,10,19–26]

	Treatment technology	Pros	Cons
Physico-chemical	Coagulation/Flocculation	Low cost	Insufficient removal efficiencies Requires addition of chemicals Requires sludge management
	Electrocoagulation	Good removal efficiencies High-tech and automated system No chemical needed	Requires energy input
	Adsorption	Low cost	Insufficient removal efficiencies Adsorbent regeneration is needed
	Fenton oxidation	Low cost	Requires addition of chemicals Possible change in ecotoxicity
	Photo-Fenton	Increase concentrate biodegradability	Requires sludge management Possible change in ecotoxicity
	Ozonation	Increase concentrate biodegradability	High cost Possible changes in ecotoxicity
	Solidification/stabilisation	Low cost	Time-consuming process Non-destructive technique The volume of treated concentrate increases
Biological	Co-bioevaporation	Efficient removal of water and organics	Requires energy input Time-consuming process Gaseous emissions
	Algal treatment	High nutrients removal Requires low energy Low cost	Time-consuming process
Thermal	Submerged combustion evaporation	High reduction of concentrate volume	High energy demand Requires management of the residual stream
	Membrane distillation	High water quality High reduction of concentrate volume	High energy demand Membrane fouling susceptibility

Physico-chemical processes are among the most investigated treatment technology. Coagulation/flocculation, electrocoagulation, and adsorption are low-cost techniques with good removal efficiencies. However, due to their low salinity removal, these processes are primarily applied as a pretreatment step rather than a stand-alone technology. Advanced processes such as chemical Fenton and ozonation although can produce a high-quality treated effluent have high installation and operational expenses, which restricts full-scale implementation. Biological techniques stand out in terms of simplicity and low cost. However, due to the high salinity and poor concentrate biodegradability (low BOD_5/COD ratio) (Table 1), they are not recommended for the treatment of LLMCs.

3.3 SWOT analysis

Table 3 shows the SWOT matrix of concentrate management from LLTPs. SWOT analysis was performed to list the strengths and weaknesses of the most ordinary LLMC management option adopted in LLTPs, i.e., concentrate infiltration into the landfill body. While opportunities were indicated in line with the modern concept for wastewater management, considering areas where researches are needed. Accordingly, threats linked to these opportunities are presented.

Table 3. SWOT analysis for LLMC management.

Strengths	**Weaknesses**
✓ Concentrate infiltration – simplest and convenient option ✓ Concentrate infiltration – one of the perceived cost savings of membrane processes in LLTPs	✓ Concentrate infiltration: temporary solution resulting in never-ending recirculation of pollution ✓ LLMC contaminants may eventually accumulate in LLTPs
Opportunities	**Threats**
✓ Green technology and sustainable processes development	✓ Higher costs than that of conventional options ✓ Possible associated environmental impacts

As forementioned, recirculation of concentrate streams into the landfill body is the most convenient and cheapest management option. However, several negative impacts can emerge from this practice, including the accumulation of pollutants in LLTPs and reduction of leachate's treatability efficiency. Concentrate components like humic substances, nutrients, salts, and metals that would be infiltrated on the landfill body can be used as raw materials to produce valuable products (e.g., fertilizers and mixed solid salts). Therefore, the development of sustainable and cost-effective methods for LLMCs treatment combining resource recovery processes is a promising field of research. Membrane-based technologies like forward osmosis (FO) and bioelectrochemical systems (BESs) seem promising for material extraction from concentrated leachates. However, high costs and the process's robustness may hamper future field applications. At present, more studies are needed to optimise resource recovery techniques and assess their techno-economic feasibility in pilot and large-scale. Furthermore, cost and environmental life cycle assessments will play a key role in the development of sustainable solutions for LLMC management.

4. Conclusions

The current article reviewed the management practices for membrane concentrates from LLTPs. According to analyses, the opportunities for sustainable LLMC management were presented, and the areas where future research is needed were suggested. Recirculation of concentrate streams into the landfill body is the most convenient and cheapest management option. However, several negative impacts can emerge from this practice, including the accumulation of pollutants in LLTPs and reduction of leachate's treatability efficiency. In this backdrop, resource recovery from concentrate streams is a promising field of research. FO and BESs have potential applications to cover this topic. However, more studies are needed to optimise these technologies. Future studies should focus on developing resource recovery systems and their evaluation through a life-cycle perspective in pilot and full-scale.

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