Waste Management 56 (2016) 262–270

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Recirculation of reverse osmosis concentrate in lab-scale anaerobic and aerobic landfill simulation reactors

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ARTICLE INFO

Article history:
Received 19 April 2016
Revised 5 July 2016
Accepted 23 July 2016
Available online 27 July 2016

Keywords:
Landfill leachate treatment
Recirculation of reverse osmosis concentrate in landfill
Persistent emissions in landfill
Injection of wastewaters in landfills
Bioreactor landfill

ABSTRACT

Leachate treatment is a major issue in the context of landfill management, particularly in view of the consistent changes manifested over time in the quality and quantity of leachate produced, linked to both waste and landfill characteristics, which renders the procedure technically difficult and expensive. Leachate recirculation may afford a series of potential advantages, including improvement of leachate quality, enhancement of gas production, acceleration of biochemical processes, control of moisture content, as well as nutrients and microbe migration within the landfill. Recirculation of the products of leachate treatment, such as reverse osmosis (RO) concentrate, is a less common practice, with widespread controversy relating to its suitability, potential impacts on landfill management and future gaseous and leachable emissions. Scientific literature provides the results of only a few full-scale applications of concentrate recirculation. In some cases, an increase of COD and ammonium nitrogen in leachate was observed, coupled with an increase of salinity; which, additionally, might negatively affect performance of the RO plant itself. In other cases, not only did leachate production not increase significantly but the characteristics of leachate extracted from the well closest to the re-injection point also remained unchanged. This paper presents the results of lab-scale tests conducted in landfill simulation reactors, in which the effects of injection of municipal solid waste (MSW) landfill leachate RO concentrate were evaluated. Six reactors were managed with different weekly concentrate inputs, under both anaerobic and aerobic conditions, with the aim of investigating the short and long-term effects of this practice on landfill emissions. Lab-scale tests resulted in a more reliable identification of compound accumulation and kinetic changes than full-scale applications, further enhancing the development of a mass balance in which gaseous emissions and waste characteristics were also taken into consideration. Results showed that RO concentrate recirculation did not produce consistent changes in COD emissions and methane production. Simultaneously, ammonium ion showed a consistent increase in leachate (more than 25%) in anaerobic reactors, free ammonia gaseous emissions doubled with concentrate injection, while chloride resulted accumulated inside the reactor.

1. Introduction

Leachate emissions are one of the main sources of environmental risks originated by landfills, especially in case of uncontrolled leakages during aftercare period. This environmental dangerousness comes from the leachate content of inorganic salts, heavy metals, persistent organic matter, xenobiotic compounds, microorganism, etc., which can be monitored in consistent concentrations also during long-term phases (Kjeldsen et al., 2010; Zhang et al., 2013). For this reason, leachate treatment is a major issue in the context of landfill management: treatment design should take into account not only quantity and quality but also variation over time, in line mainly with landfill age (Brennan et al., 2016). Amongst the various forms of leachate treatment, membrane filtration consists in a physical process that separates wastewater into two different fluxes through use of a membrane; this in turn results in the production of a filtrate capable of crossing the membrane, and a concentrate in which compounds not able to cross the membrane accumulate. Membrane processes are generally classified as microfiltration (MF), ultrafiltration (UF) or reverse osmosis (RO), according to the decreasing dimension of membrane pores (Renou et al., 2008; Zhang et al., 2013). Filtration efficiency is related not only to pore dimension but also to the type of membrane material, the nature of the driving force, the separation mechanism and the

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http://dx.doi.org/10.1016/j.wasman.2016.07.030
0956-053X/

nominal size of the separation achieved (Metcalf & Eddy.inc, 2004; Subramani and Jacangelo, 2014). Treating leachate, RO is the membrane treatment with the highest removal efficiency: retention of 80–95% organic substances and 60–70% inorganic compounds in a single membrane process; if stages further down the line are taken into consideration these percentages increase to more than 99% (Hunce et al., 2012; Renou et al., 2008; Henigin, 1993; Eipper and Maurer, 1999). The semipermeable RO membrane has a porosity of several nanometers in which a pressure higher and opposite than osmotic one is applied, thus enhancing separation of permeate and concentrate. The main issues encountered with this technology are the high membrane and management costs and membrane fouling that requires periodic cleaning (Metcalf & Eddy.inc, 2004; Talalaj and Biedka, 2015). Concentrate-permeate ratio ranges from 1:4 to 1:5 in a reverse osmosis treatment, depending on the treatment plant and wastewater characteristics; this ratio is generally respected also with leachates (Henigin, 1993). At the end of the process, the remaining concentrate (20–25% the initial wastewater volume) requires further treatment. The most effective treatments for leachate concentrate include incineration in an appropriate facility, solidification with materials such as fly ashes, mixing with sludge from municipal wastewater treatment, dewatering-disposal in industrial landfills and recirculation into the landfill body (Peters, 1998; Subramani and Jacangelo, 2014). The latter procedure is a cheaper and more easily implementable option; however, results found in literature are still conflicting since success and issues with the effects of concentrate recirculation have been reported (Talalaj and Biedka, 2015).

Rainwater and occasionally recirculated leachate are the sole contributors to moisture management in conventional landfills, whilst in bioreactor landfills injection of storm water, wastewater, and wastewater treatment sludge may be implemented (EPA, 2015). Bioreactor landfills are characterized by the use of technologies such as water and/or air injection, leachate recirculation and other combinations of in-situ treatments that facilitate biochemical kinetic control, nitrification, pH adjustment, control of redox conditions and moisture content to create a more suitable environment for the enhancement of degradation processes (Berge et al., 2009; Townsend et al., 2015). Recirculation of concentrate therefore is in line with the bioreactor concept. This practice affords similar advantages to leachate recirculation, redistributing moisture and nutrients inside the landfill body and promoting biochemical processes. MSW can act either as compounds source and as storage, having relevant water sorption capacity, effectively entrapping metals and consuming easily biodegradable substances. However, waste capacity of attenuating ammonia and chloride coming from recirculated leachate was found to be negligible (Calabrò and Mancini, 2012).

Field experiments have shown contradictory results: in Italy, the recirculation of concentrate is a practice commonly adopted in a series of old landfills where this type of wastewater is viewed as a process liquid. According to Calabrò et al. (2010), the reinjection of RO concentrate does not affect leachate quality, due to an apparent buffer capacity of the waste mass on ammonium (NH_4^+) and chloride (Cl^-). On the contrary, according to other authors, concentrate reinjection is not deemed to be sustainable in the long term due to a persistent accumulation of pollutants (Henigin, 1993; Talalaj and Biedka, 2015) which exerts an immediate effect on leachate characteristics, increasing COD and ammonium concentration (Robinson, 2005; He et al., 2015). In field-scale also hydraulic consideration must be taken into account since dried wastes has a high capacity of retaining waters before reaching field capacity.

The purpose of this paper was to investigate the effects of concentrate reinjection in an MSW landfill using lab-scale simulation reactors, contributing to the debate concerning sustainability of RO concentrate recirculation, engaged by many literature studies (Calabrò et al., 2010; Robinson, 2005; He et al., 2015; Talalaj and Biedka, 2015). Lab-scale tests could provide more precise evidence of compound accumulation than full-scale applications in which the heterogeneity of waste may buffer accumulation effects. The management of reactors foreseen different weekly concentrate inputs and a constant monitoring of leachable and gaseous emissions, useful for a subsequent elaboration of data for clarifying the short and long-term effects of this practice. Monitoring of emissions was focused on three specific components: carbon and nitrogen compounds, plus chloride as salinity index tracer. In particular, salts are not biodegradable, can accumulate inside solid mass (Zhang et al., 2013) and affect negatively RO membrane performances (Talalaj and Biedka, 2015). Aeration was applied to half of reactors, in order to identify whether the proven efficiency of aeration techniques in remediating the persistence of carbon and nitrogen compounds in leachate (Ritzkowski et al., 2016; Raga et al., 2015; Calabrò anc Mancini, 2012) might also mitigate the possible accumulation of these compounds following injection of concentrate. Literature evidenced that recirculation of aerobically treated concentrate inside an anaerobic lab scale reactor could have positive effects on leachate quality (He et al., 2015). Finally, a mass balance was developed for carbon, nitrogen and chloride, based on the results obtained from monitoring of the liquid and gaseous emissions.

2. Materials and methods

2.1. Equipment

Experiments were carried out using six plastic columns (height 106 cm, diameter 24 cm) filled with 14.7 kg of MSW compacted to reach a density of around 0.5 t/m^3. A 15-cm thick gravel layer (20–40 mm) was placed at the bottom and a 5-cm layer at the top of each column as drainage to facilitate the distribution of moisture and concentrate (Fig. 1).

Leachate extraction was carried out through a valve on the bottom of the reactor, connected directly with an accumulation tank to ensure against loss of biogas. A further three valves were used for air injection, gas extraction and liquid input from the top of the lab-scale equipment. Liquid distribution inside the reactor was sufficiently homogeneous thanks to a shower system distribution and the top gravel layer. Injected air was channeled into a vertical pipe with side perforation placed inside the waste body to promote a uniform distribution of air throughout the reactor. A Prodac Air Professional pump 360 was used, and inlet airflow was regulated by means of a Sho-Rate GT1135 flow meter (Fig. 1). Biogas generated from each column was collected using a Tedlar® sampling bag connected to the upper gas port and biogas volume and quality were measured daily by means of a volumetric flow meter (Cossu et al., 2016).

Temperatures were monitored using six probes PT 100 (Endress + Hauser) placed in the core of the waste body. Reactors were thermo-regulated by means of a heating system comprising a spiral circuit of silicon pipes placed around the columns in which circulating hot water ensured a constant temperature of 33–35 °C.

2.2. Waste and concentrate samples

RO concentrate used for the test was sampled from the leachate treatment plant of an old Italian MSW landfill which had been closed in 2004 and is currently in the aftercare phase. The plant comprised an UF prior to a four step RO (Fig. 2): samples were obtained at the end of the whole process. The main biochemical