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Effect of the recirculation of a reverse osmosis concentrate on leachate generation: A case study in an Italian landfill

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ABSTRACT

"Fossetto" landfill has been operating in the municipality of Monsummano Terme (Pistoia Province, Italy) since 1988; the authorized volume for landfilling is about 1,000,000 m^3; at the moment the plant is being mainly used to dispose of mechanically and biologically treated residual municipal solid waste. Since September 2006, an in-situ reverse osmosis leachate treatment plant has been operating to treat leachate. The treated water is being discharged into a small nearby stream while the concentrated leachate is being recirculated back into the landfill body following Italian Regulations and an authorization from the local authority (Pistoia Province). This paper presents monitoring results on leachate generation rates and composition for the past fifteen years. A moderate increase of the concentration of some of the monitored parameters occurred (e.g. ammonium, chlorides) and a decrease for most heavy metals. The increase of concentrations for Cl^- and NH_4^+ was more evident in the leachate coming from the wells closer to reinjection area. However, the change in leachate composition did not affect the quality of the effluent from the leachate treatment plant. The annual volume of the generated leachate increased significantly right after the recirculation started.

1. Introduction

Landfilling is still the most widely used waste management system in the world. Landfilling is still relatively cheap, simple and is not linked to uses of complicated and patented technologies. Unfortunately, the environmental impacts associated to landfills are not negligible. Even after fifty years of research focusing on the complex physical, chemical and biological processes occurring within landfills to design technologies to minimize environmental impacts, much work is still needed.

Modern landfills are equipped with multi-barrier systems (Cossu, 1995) designed to minimize the environmental impact (leachate impact among others) both in the active and in the post-closure periods. One of the barrier systems is the leachate drainage and collection systems that allow the treatment of this potentially hazardous liquid discharge.

One of the most widely used leachate treatment technology in many countries and in Italy in particular Among various options is the co-treatment of landfill leachate with municipal sewage after its transportation by trucks in off-site authorized plants. Other techniques exist, such as the co-treatment with municipal sewage and the treatment in dedicated plants using advanced oxidation or adsorption processes, on or off-site (Renou et al., 2008; Wiszniowski et al., 2006). Another option increasingly considered is the on-site treatment using reverse osmosis facilities. A comparison between co-treatment with sewage and reverse osmosis is outlined in Table 1.

It is therefore clear that the economic sustainability of the adoption of a leachate treatment based on reverse osmosis is directly connected to the management of the resulting concentrated leachate. The most economically convenient option is the recirculation of concentrated leachate into the same landfill (Calabrò et al., 2010; Liu et al., 2008; Qu et al., 2008; Renou et al., 2008; Sluiter et al., 2012; Wiszniowski et al., 2006). The specific studies present in scientific literature on this practice are not numerous and opinions are often conflicting. Some researchers support that the impact of the recirculation of concentrated leachate is negligible or at least limited in time (Heinigin, 1995;

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Table 1
Advantages and disadvantages of landfill leachate treatment options most commonly adopted in Italy.

Co-treatment with sewage off-site		Reverse osmosis treatment on-site	
Advantages	Disadvantages	Advantages	Disadvantages
Simplicity	Cost (about 50–100 €/m^3 in Italy including transportation)	Highly efficient pollutants removal from purified water	Concentrated leachate generation (about 30% of incoming leachate)
	Excess sludge often non-usable for agriculture due to the presence of heavy metals and other pollutants		Non-competitive if concentrated leachate must be treated in an external plant
	Some of the pollutants are simply diluted (Off-site treatment)	Cost (about 15–40 €/m^3 in Italy) (On-site treatment)	

Peters, 1998); others declare that its application is not sustainable in the long term (Heyer and Stegmann, 2002).

This paper aims to advance the knowledge published previously on the same topic (Calabrò et al., 2011, 2010; Calabrò and Mancini, 2012). Specifically, we analysed the long-term effect of concentrated leachate recirculation in an Italian landfill (Fossetto) where the reverse osmosis technology to treat leachate is applied since September 2006. In particular, we aimed to analyse the effect of recirculation on the qualitative and quantitative leachate characteristics.

2. Materials and methods

The landfill under study (including all its ancillary plants such as mechanical–biological treatment (MBT), leachate treatment and biogas extraction and utilisation plants) is considered a complex, partially controlled, reactor where physical, chemical and biological processes occur. The study uses leachate data from a database of 15 years (2002–2016). Between years 2002 and 2006, no leachate recirculation was practised since the reverse osmosis system had not been installed yet. Therefore, data from years 2002–2006 provide a baseline of leachate quantity and composition when no concentrate recirculation existed. Concentrate recirculation was applied beyond year 2006, and its impact on leachate characteristics is investigated here.

2.1. The landfill "Il Fossetto" in Tuscany (Italy)

"Il Fossetto" landfill has been operating since 1988. It is located in the province of Pistoia (Northern Tuscany, Italy) in a flat area and has a total authorized volume of about 1,000,000 m^3; it is used to dispose of municipal waste after mechanical and biological treatment (MBT) and small amounts of street-cleaning residues and some bulky waste. Until 2011, also non-hazardous bottom ash and slag coming from a municipal incinerator were landfilled there, while until June 2003 (when the on-site MBT plant entered in operation) mixed municipal waste were directly landfilled. In addition to the MBT plant, a biogas recovery and energy production and a leachate treatment plant are operating in the landfill. For more information on "Il Fossetto" landfill see available literature (Calabrò et al., 2010).

In "Il Fossetto" landfill, leachate collected by the drainage system is extracted by 13 wells; until 2006, all the leachate produced by the landfill was sent to external plants for treatment. Since September 2006, most of the extracted leachate is treated on site in a reverse osmosis plant. This plant includes mixing and pre-aeration, sieving, pre-filtration by cartridge filters, membrane ultrafiltration, chemical conditioning to reach a pH of about 5 by adding sulphuric acid, membrane reverse osmosis (two modules), chlorination, activated carbon filtration. Purified water obtained by leachate treatment is discharged into a small nearby channel while the generated concentrated leachate is recirculated back into the landfill by a vertical reinjection well located in the 2nd cell of Landfill 4. The generated concentrated leachate that is reinjected into the landfill represents about 30% of the total incoming leachate.

2.2. Monitoring activities

According to the requirements of the Control Authority (Pistoia Province), an extensive monitoring program is being regularly carried out in "Il Fossetto" landfill.

Data available are related to the meteorological parameters (e.g. temperature and rainfall), to the amount of waste landfilled (detailed for each single type), to leachate produced and biogas extracted.

Once a year, the leachate from each recovery well is sampled and analysed according to Standard Methods (Eaton and Franson, 2005) to measure the pH and to determine the concentration of COD, ammonia nitrogen, chloride and of several metals and metalloids (As, total Cr, Cu, Hg, Ni, Zn). Moreover, since 2005, samples are being collected four times per year from the homogenization tank to measure pH, conductivity, suspended solids, COD, BOD_5, ammonia nitrogen, chloride, sulphides, total Cr, Ni, Zn, As, Hg, Cu. Similar analyses are being carried out on the concentrated leachate too.

2.3. Statistical analysis

Statistical analysis was performed to check differences between the mean annual leachate generation (i.e. amounts) prior to and after leachate recirculation (i.e. before and beyond 2006). The normality criterion for the data was checked using the Shapiro-Wilk test. A parametric independent *t*-test was then employed to check the statistical differences between leachate quantities and leachate quality for the two aforementioned periods. Only the statistically significant regression equations are presented. Statistics were done with Minitab® v17.

3. Results and discussion

3.1. Leachate generation

Due to an increasingly efficient separate collection in the area served by "Il Fossetto" landfill, incoming MSW decreased from about 50,000 t/y in 2000 to about 28,000 t/y in 2015 and 2016. From year 2000 to early 2011, an average of about 7200 t/year of non-hazardous bottom ash and slag were also landfilled there.

Fig. 1 depicts the cumulative leachate recovery as a function of the cumulative waste amounts entering the landfill. It is clear that a sharp increase in the leachate recovery exists beyond 2006, as witnessed by the increase of the slope of the line fitting the data right after year 2006, that signifies the initiation of the concentrated leachate recirculation project. It is noted that leachate recovery (i.e. amount withdrawn via pumping) is similar to leachate generation as long as the leachate level remains constant at the landfill bottom. This is true for the leachate recovery wells, since according to the permits leachate level must be kept almost

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