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Impact of different schemes for treating landfill leachate

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ABSTRACT

Different technological schemes for treating the leachate generated by an existing landfill were compared in a life cycle perspective. On-site advanced processes based on reverse osmosis and evaporation were compared to conventional off-site co-treatment with civil sewage in wastewater treatment plant (WWTP). The inventories of the different scenarios were built by both direct observation of existing facilities and by retrieving data from the literature and similar equipment. Particular care was given for evaluating the energetic and chemical needs for operating the on-site advanced treatments. The evaporation system required 40 kW h/m^3 of electricity and 18.5 kW h/m^3 of heat, whereas reverse osmosis needed only 8.5 kW h/m^3 of electricity. On the other hand the amount of liquid concentrate returned by the evaporation system was only about 0.03 m^3/m^3 instead of about 0.30 m^3/m^3 returned by reverse osmosis. The evaporation system also consumed the highest amount of chemicals. Life cycle analysis showed that the impact categories most affected by the different options were human toxicity, both non-cancer and cancer, together with freshwater ecotoxicity. The uncertainty analysis highlighted the major contribution associated with direct emissions from the processes. On the basis of mean values, the qualitative trends were substantially confirmed.

1. Introduction

In the EU28 area, 31% of the whole municipal solid waste collected, corresponding to about 74 Mtonnes/year, is directly landfilled (ISPRA, 2015). It is known that spontaneous degradation processes of the waste generate heavy pollutants represented mainly by a gas rich in methane and carbon dioxide (*i.e.* landfill gas) (Barlaz et al., 2009) and a liquid generated by the leaching of rainwater through the waste mass (*i.e.* leachate). The leachate can be considered a triphasic system with the characteristics of a heavily polluted wastewater with a high concentration of organic and inorganic contaminants, pathogens, humic acids, ammonia nitrogen, heavy metals, xenobiotics and inorganic salts. Furthermore leachate undergoes spatial and temporal modifications (Kjeldsen et al., 2002; Renon et al., 2008). In fact, the content of such pollutants depends on the composition of the landfilled waste, on climatic conditions and on the extent of degradation and decomposition of the waste (Schiopu and Graviliescu, 2010; Slack et al., 2005). The most diffused options for leachate treatment are by off-site and on-site treatments. These can be grouped as conventional and advanced treatments (Renou et al., 2008; Wisizniowski et al., 2006). The main conventional treatments are: leachate transfer for combined treatment with civil sewage in wastewater treatment plants (WWTP); biodegradation (aerobic/anaerobic); chemical and physical methods (chemical oxidation/precipitation, adsorption, coagulation, flocculation, flotation, air stripping...).

These techniques have been used and continue to be used for the treatment of heavily polluted liquids and for landfill leachate. Silva et al. (2017) investigated the efficiency of pollutant removal from old landfill leachate of a multistage treatment system based on biological oxidation, coagulation/sedimentation and photo-Fenton processes. The main results indicated COD and alkalinity removal efficiencies ranging from about 62% to about 99% and from 70% up to 100%, respectively. Brennan et al. (2017) reported on the treatment of leachate in WWTP indicating efficiencies in COD and ammonium removal ranging from about 88% to 93% and from about 87% to 98%, respectively. Treatment of leachate in aerobic granular sludge sequencing batch reactor was investigated by Wei et al. (2012). In this case the average efficiencies in COD and nitrogen removal were about 85% and 80%, respectively. However the continuous aging of landfills and of the leachate generated together with more rigorous water quality standards makes conventional processes not always able to satisfy adequately the pollutant removal efficiencies.

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For this reason new technologies such as reverse osmosis (RO) and evaporation systems have been developed and adapted for leachate treatment. Efficiencies in pollutant removal of these technologies were investigated by Ushikoshi et al. (2002) and Di Palma et al. (2002). The former showed that RO was able to remove pollutants from leachate with an efficiency up to >99%. Similar performances were also reported by the latter concerning the evaporation system.

All this demonstrates that major effort has been exerted for investigating the efficiency in pollutant removal of both conventional and innovative processes/technologies, but there is a lack of information and studies on the evaluation of the global performances of these systems.

For this reason the aim of the present study was to compare different schemes for treating the leachate of an existing landfill in a life cycle assessment (LCA) perspective. Conventional co-treatment of leachate with civil sewage in WWTP was compared with processing it using advanced on-site technologies such as RO and evaporation. For doing this the amount of energy and chemicals required by the different technologies were assessed and specific life cycle inventories (LCI) were developed. The uncertainty associated to the LCA study was also evaluated by the methodology proposed by Di Maria et al. (2016a) and Di Maria et al. (2016b).

2. Materials and methods

2.1. Base scenario - BS

The landfill considered in the present study is located in central Italy and started operating in 1995. The waste management scheme of the area in which the landfill operates is currently characterized by a separate collection intensity of about 50% and the absence of incinerator facilities. Disposed waste is mainly municipal solid waste coming from separated collection after mechanical biological treatment aimed at reducing residual biological reactivity (Di Maria et al., 2013a,b; Di Maria and Micale, 2014a). As reported in Table 1 for the period ranging from 2010 to 2014, it is possible to note a rather good correspondence between the amount of waste disposed and the amount of leachate generated. Landfill gas (LFG) is collected and exploited as fuel in an existing co-generation facility with a maximum electrical output of 2000 kVA. For each m^3 of LFG, the co-generators produce 1.4 kW h of electrical energy. Current leachate treatment is based on mixed on-site and off-site treatment systems. The on-site treatment consisting of an evaporation facility (Fig. 1) processes on average 45 m^3/day, corresponding to 33% of the leachate produced in 2014. The other 67% is co-treated off-site with civil sewage in an existing WWTP located about 170 km from the landfill site. The leachate processed on-site is first stored in tanks from which it is successively pumped to the first evaporation stage TC60000 at a maximum rate of 60 m^3/day. In this device a temperature and pressure of 90 °C and 70 kPa are maintained by the aid of a thermal resistance and volumetric pump, respectively. The evaporated fraction extracted by the volumetric pump is condensed and processed in a RO unit before being discharged to surface water. The fraction of leachate not evaporated is further processed in the second evaporator RW3000, which is able to process up to 3 m^3/day. A temperature and pressure of 70 °C and 10 kPa are maintained in the RW3000 by the heat recovered from the LFG by the existing co-generators and by an ejector, respectively. The evaporated fraction extracted by the ejector is condensed and processed in the same RO unit, whereas the liquid concentrate (about 1.5% of the inlet leachate) is treated off-site in the same WWTP.

For each m^3 treated, the facility consumes 70 kW h of electricity, 65% of which is necessary for heating the TC60000, and 46 kW h of thermal heat from co-generators for the RW3000. At the RO outlet the permeate is further processed in active carbon and ion exchange resin filters, followed by pH adjustment, before being discharged. Table 2 reports the output flows and the amount of chemicals necessary for operating the evaporation system of the BS referred to 1 m^3 of leachate treated.

2.2. Modified scenarios MS1, MS2 and WWTP

The modified scenarios consisted of two different on-site treatments and one exclusively off-site treatment scheme able to process the whole leachate generated referred to the year 2014. On-site solutions were those proposed by the builders on request of the company managing the landfill.

2.2.1. MS1

The leachate treatment scheme for the 1st modified scenario (MS1) was designed considering the following two main aspects:

(1) The residual treatment capacity of the TC60000 presently not exploited (see Section 2.1);
(2) The surplus of thermal heat currently deliverable by the existing co-generator plant.

For this reason a second RW3000 was added to the current evaporation facility (Fig. 2). The amount of leachate entering the TC60000 was increased and maintained constant by the introduction of a RO pre-treatment. The RO proposed is a commercial type made of one-stage polyamide/polysulphone with 36 spiral wound membranes with a specific surface area of 41 m^2/m^3/h and a maximum inlet pressure of 80 bar. The permeate and the concentrate from the RO were 60% and 40% of the inlet volume of the leachate, respectively. The permeate was directly discharged, whereas the concentrate was processed in the improved evaporation plant. In this configuration the amount of concentrated liquid discharged and co-treated off-site with civil sewage in the wastewater treatment plant was 3% of the volume of the inlet leachate. MS1 required 40 kW h/m^3 of electricity and 18.5 kW h/m^3 of heat completely supplied by the existing co-generators. These data, supplied by the plant builder, together with those concerning the amount of chemicals necessary for the process (Table 2) were in accordance with those of the evaporation system currently adopted in the BS. Lower specific values referred to 1 m^3 of leachate are a consequence of the presence of a RO pre-treatment stage and of the increased amount of leachate treatable by the improved evaporation section. The output flows for the improved evaporation process are reported in Table 2.

Table 1
Waste disposed, leachate generated and chemical characterization with relative variance (σ^2) of the leachate for the landfill considered from 2010 to 2014.

Year	Waste (tonne)	Leachate (m^3)	pH/σ^2	EC/σ^2 (mS/cm)	COD/σ^2 (mg/L)	N-NH_4/σ^2 (mg/L)	Chlorides/σ^2 (mg/L)
2010	169,800	42,752	7.97/0.2	15,822/4488	4334/1654	1668/531	2712/1338
2011	86,160	22,608	8.08/0.4	17,195/7200	4680/2098	2036/398	2021/822
2012	79,521	18,565	7.53/0.5	20,250/3670	11,737/8700	2119/500	2583/1536
2013	198,140	35,416	7.84/0.2	22,130/4160	9694/3300	2614/285	3326/580
2014	156,248	45,762	7.88/0.2	23,242/3015	98,31/2431	2847/376	3993/610

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