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Modeling the leachate flow and aggregated emissions from municipal waste landfills under life cycle thinking in the Oceanic region of the Iberian Peninsula

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ABSTRACT

The most extensively used option for the management of municipal solid waste in the Iberian Peninsula is landfilling. Due to the impossibility of distinguishing emissions from the different types of waste with direct measurements, models have to be developed. A mathematical method to determine the leachate composition from different types of landfilled wastes was proposed according to a life cycle assessment approach.

The model was specially designed to foresee the average generation of leachate in Iberian facilities through the application of a water balance. However, according to climatic differences related to rainfall and temperature, the entire territory is not homogenous and it should not be modeled jointly. Among the different regions, this research work was focused on the worst case scenario with landfills located in the highest rainfall area (the Oceanic region), where a large production of leachate is expected.

With the only requirement of waste composition as data entry, the resultant model provides an estimation of pollutant release and the average leachate production in the Oceanic region. The applicability of both parts of the model was successfully verified with three case studies. The validation was carried out not only through the comparison of field data with the sum of the estimated individual emissions, but also through the contrast of aqueous effluent collected in landfills against the medium value calculated for the Oceanic territory taking into consideration regional weather information. It also enabled to identify those waste fractions responsible for greater environmental impacts.

1. Introduction

Landfill disposal remains as the predominant option for the management of municipal solid waste (MSW) not only in the Iberian Peninsula but also worldwide (Frändegård et al., 2013; Jones et al., 2013; Kaartinen et al., 2013; Kollikkathara et al., 2009). Landfills have been used for the disposal of nearly all types of MSW as well as industrial waste for decades (Kaartinen et al., 2013). This alternative has been applied for waste which cannot or should not be recovered or treated in another way. Though waste is kept in a long-term safe way and landfilling is controlled by a strict regulatory framework, this alternative is a potential source of pollution and hazardous substances (Frändegård et al., 2013). Despite the general effort to decrease the percentage of landfilled waste in the European Union (Directive, 2008/98/EC), this management option was applied to 52% and 62% of the MSW generated in 2009 in Spain and Portugal, respectively (APA, 2010; MARM, 2011).

The landfill can be considered as a complex environment where many interacting physical, chemical and biological processes take place (Ozkaya et al., 2006). The degradation process of MSW in landfills is a long-term event (Belevi and Baccini, 1989; Camobreco et al., 1999; Finnveden, 1999). Therefore, emissions will have to be managed for hundreds of years, contradicting the principles of sustainability (Fellner and Brunner, 2010).

The gaseous and liquid streams generated from waste decomposition, landfill gas and leachate, constitute the sources of the main environmental impacts associated to this practice (El-Fadel et al., 1997). In the absence of any collection or treatment, landfill derived methane contributes to climate change on a global level,

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since its global warming potential over a 100-year time period is about 25-fold larger than CO_2 (Forster et al., 2007). In parallel, the leachate filtration through wastes involves the extraction of dissolved and suspended materials, as well as the uptake of products from hydrolytic and fermentative processes (Lema et al., 1988). These materials and products are responsible for the generally high concentrations of soluble organic matter and inorganic macro-components that may be contained in landfill leachates. Therefore, the leachate may also entail an important threat to the surrounding soil, groundwater and even surface water (Ding et al., 2001; Fatta et al., 1999). Quantity and quality of both landfill gas and leachate depend on a wide range of factors: (i) the composition and age of the landfilled waste, (ii) the design and operation of the landfill and (iii) climatic conditions of the location, specifically rainfall and temperature (Al-Yaqout and Hamoda, 2003; Fellner and Brunner, 2010).

In this work, landfill waste-specific emissions via leachate were modeled from a life cycle assessment perspective, enabling the assessment of the relative influence of each MSW fraction on the overall performance. For this purpose, a life-cycle time horizon of 100 years after the disposal of MSW in the landfill was considered, in agreement with other research works (Bez et al., 1998; Manfredi and Christensen, 2009; Nielsen and Hauschild, 1998). So far the determination of emissions from the different kinds of MSW fractions with field data from existing facilities is not viable; therefore, their estimation by modeling of key decomposition processes within the deposit is required. Although there are several reports on the development of models with similar aims (Doka, 2009a; Eriksson et al., 2002; Manfredi and Christensen, 2009; Nielsen and Hauschild, 1998), the method presented in this research study intends to be an improved adaptation for its application of landfills located in high rainfall areas, such as the Oceanic region of the Iberian Peninsula.

2. Methods. Model description

Two main factors from leachate landfills have been characterized (Renou et al., 2008): (i) the volumetric flow rate and (ii) the corresponding composition. Concerning the average generation and the total release of pollutants, they have been independently modeled in the following sections to determine the medium composition of the aqueous stream.

2.1. Generated and accumulated leachate flow rate

The flow rate of leachate generated at landfills differs from site to site and seasonally at each facility, and thus, the composition varies accordingly (Lema et al., 1988). The design and exploitation of the landfill site (in particular, the degree of compaction and isolation and the collection system for the leachate), hydrological and geological conditions (type of soil and topography), waste characteristics (water content) and climate were identified as the main determining factors influencing the effluent production. As a first approach with the objective of providing a quantitative assessment of landfill leachate generation, the flow rate can be established proportional to rainfall (Al-Yaqout and Hamoda, 2003). However, the application of a water balance to the landfill area is generally a more accurate and appropriate option (Al-Yaqout and Hamoda, 2003; Fatta et al., 1999; Tatsi and Zouboulis, 2002).

An adaptation of hydrological balance based on Thornthwaite and Mather (1955) is proposed (Eq. (1)), where the consideration of the deposit as a mixed reactor implies the assumption of homogeneous conditions and, thus, water retention capacity through the waste mass disposed in different cells (Fig. 1). This homogeneity in hydraulic conditions implies neglecting the leachate storage processes due to low water permeability or the quick flow through the waste mass motivated by preferential channeling.

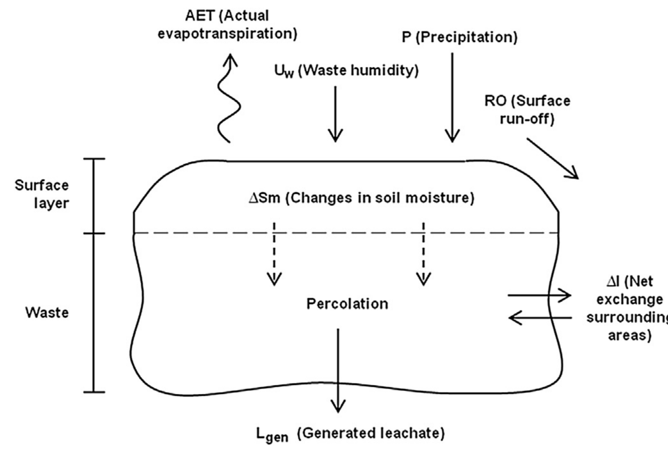

Fig. 1. Schematic representation of the water balance: inputs, outputs and leachate generation.

$$L_{gen} = P + U_W - \text{AET} - \text{RO} \pm \Delta I \quad (1)$$

where, L_{gen} is the cumulative volume of leachate generated per unit area of the refuse tip monthly (expressed in mm or dm^3 per square meter and month), AET is the actual loss of water by evapotranspiration (simultaneous evaporation and transpiration), RO is the surface run off, P is the inlet of water through rainfall, U_W is the incoming of water as waste humidity and ΔI represents the net exchange of water between the landfill and the surrounding area by, for example, lateral flow, infiltrations or deep percolation. It is assumed that the construction of the deposit is performed according to legislation (Directive, 1999/31/EC) and the lifetime expected for barriers embraces the whole time horizon.

Due to their negligible contribution in comparison with other terms as well as the lack of representativeness, several additional sources or sinks of water that may be distinguished in the landfill were finally not included in Eq. (1). This is the case of the outlet as biogas humidity or the recirculation of leachate (Thornthwaite and Mather, 1955). In this model, an average leachate flow is intended for the whole Oceanic region without the necessity of data entry. Therefore, all the parameters involved in the subsequent calculation are substituted by average values representative from the assessed zone. Moreover, the landfill is assumed to be in operation at the moment of the disposal. However, it will be probably closed within the following 100 years. Because of this changing scenario, a hypothetical situation was assumed for the application of the water balance: a closed landfill with vegetative cover but not waterproofed.

2.1.1. Rainfall (P)

As the terms with greater influence are highly dependent on weather and, thus, the geographical situation of the facility, the distinction of three main climatic regions in the Iberian Peninsula: oceanic, mediterranean-continental and mediterranean, was considered (Fig. 2). From the three zones, climatic similarities are observed between the last two ones, which are drier regions with annual precipitations generally below 700 mm. The range from 900 to 1400 mm per year is characteristic of the oceanic climate (AEMET and IM, 2011). Although it may seem a wide interval comprising installations with significant differences depending on climatic conditions, it entails a considerable improvement from previous assumptions taken in LCA papers and databases, where average