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Consecutive anaerobic-aerobic treatment of the organic fraction of municipal solid waste and lignocellulosic materials in laboratory-scale landfill-bioreactors

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ABSTRACT

The scope of this study is to evaluate the use of laboratory-scale landfill-bioreactors, operated consecutively under anaerobic and aerobic conditions, for the combined treatment of the organic fraction of municipal solid waste (OFMSW) with two different co-substrates of lignocellulosic nature, namely green waste (GW) and dried olive pomace (DOP). According to the results such a system would represent a promising option for eventual larger scale applications. Similar variation patterns among bioreactors indicate a relatively defined sequence of processes. Initially operating the systems under anaerobic conditions would allow energetic exploitation of the substrates, while the implementation of a leachate treatment system ultimately aiming at nutrient recovery, especially during the anaerobic phase, could be a profitable option for the whole system, due to the high organic load that characterizes this effluent. In order to improve the overall effectiveness of such a system, measures towards enhancing methane contents of produced biogas, such as substrate pretreatment, should be investigated. Moreover, the subsequent aerobic phase should have the goal of stabilizing the residual materials and finally obtain an end material eventually suitable for other purposes.

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1. Introduction

Global solid waste production has been increasing in the last decades, thus constituting a major issue of concern (Bilgili et al., 2007; Karak et al., 2012). In fact, while a decade ago municipal solid waste (MSW) generation approached 0.68 billion tonnes per year, more recent levels reached approximately 1.3 billion tonnes per year. These levels are expected to increase to almost 2.2 billion tonnes per year by 2025. Apart from the population growth the reasons for this increment include the higher economic development and urbanization rates of several countries (Hoornweg and Bhada-Tata, 2012). Increased MSW quantities and their management practices affect various environmental issues, posing numerous threats and creating major potential problems. This has made the development and application of appropriate and sustainable waste management options essential for the mitigation of this phenomenon (Karak et al., 2012).

Landfilling is still one of the most adopted MSW management practices, mostly due to its short term cost effectiveness (Bilgili et al., 2007; Xie et al., 2015; Xu et al., 2014). As a matter of fact, according to data retrieved from Eurostat (2015), 36% of the municipal waste produced in Europe in 2013 was deposited in landfills. More specifically, data referring to thirty-six European countries for this year, reveal that in seven of these, more than 80% of the waste they produced was deposited in landfills, while another nine countries adopted this practice for 60–80% of their waste. Among the remaining countries, four of them had landfills as the final destinations for 40–60% of their waste, six countries landfilled 20–40% of the totally produced waste and finally, the number of countries depositing less than 20% of their waste in landfills, was ten.

The option of operating landfills as bioreactors has gained a lot of interest in the past years, since it is a way of accelerating biodegradation and enhancing stabilization of deposited waste. Moreover, with the application of this methodology, higher amounts of biogas are produced and recovered, while at the same time the organic strength of the leachate generated from the system is diminished (Valencia et al., 2011; Xu et al., 2014). Such systems are operated under controlled conditions, maintained by leachate recirculation, as well as by the addition of water, air and nutrients (Berge et al., 2006; Reinhart et al., 2002). Bioreactor landfills can be categorized as anaerobic, aerobic, facultative, and hybrid systems (Berge et al., 2006). Among these categories, hybrid bioreactors, which usually combine anaerobic and aerobic

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conditions, are considered promising, since they offer not only energy recovery through methane generation, but also compost production (Kayhanian and Tchobanoglous, 1993; Xu et al., 2014).

Research regarding bioreactor landfills has been focusing on several subjects over the years, with those being particularly emphasized including bioreactor process types and operational implementation (Feng et al., 2014; Nikolaou et al., 2010), nitrogen management in landfills (He and Shen, 2006; He et al., 2011; Lubberding et al., 2012; Valencia et al., 2011; Wang et al., 2014) and landfill gas production and emissions (Liu et al., 2014; Mali Sandip et al., 2012; Nair et al., 2014; Xu et al., 2014). Nevertheless, the majority of these researches used MSW as the sole substrate for their studies. Therefore, there is lack of information concerning the operation of landfill-bioreactor systems using different types of substrates, such as lignocellulosic materials and waste, especially in combination with MSW, and additionally, under both anaerobic and aerobic conditions.

The purpose of this study is to investigate the treatment of the organic fraction of municipal solid waste combined with two waste materials of lignocellulosic nature, namely green waste and dried olive pomace, using laboratory-scale landfill-bioreactor systems. Anaerobic and aerobic conditions were adopted consecutively during the experiment and the bioreactors operation was monitored by periodically determining a series of parameters, which included waste mass temperature and height, leachate quality determination in terms of pH, electrical conductivity, redox potential, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total nitrogen (TN), NH_4-N, NO_2-N, NO_3-N, PO_4-P, Cl^-, SO_4^{2-}, and total phenols (TPH) concentrations, as well as biogas composition (CO_2, CH_4, O_2).

2. Materials and methods

2.1. Substrates

The organic fraction of municipal solid waste (OFMSW), as well as green waste (GW), originated from the Inter-municipal Enterprise of Solid Waste Management (DEDISA) of Chania, while dried olive pomace (DOP) was obtained from an olive mill situated in the Akrotiri area in Chania. In order to help initiate anaerobic processes inside the bioreactors, anaerobic sludge, originating from a mesophilic anaerobic digester situated in the Municipal Wastewater Treatment Facility of Chania, Crete, was initially added to the main substrates. Prior to the experiment, the three substrates were first subjected to a brief preparation procedure. Specifically, GW, which was composed of city tree pruinings, was dried at 60 °C and then comminuted to a particle size less than 500 μm, using a universal cutting mill, while DOP was kept as received (mean particle size 1000–2000 μm). As far as the initial MSW sample is concerned, after opening the plastic bags containing this sample, the whole quantity was homogenized and finally a representative portion of it was set aside, for fractional composition determination. The latter was conducted by separating this portion into the different fractions and subsequently weighing their mass. The remaining quantity of MSW was further manually screened in order to remove plastic, inert, metallic and hazardous materials, thus only leaving the materials corresponding to the organic fraction, i.e. putrescibles and (tissue) paper. The quantity of waste remaining after this procedure constituted the final OFMSW sample which was used in the experiment, after further homogenization, but without size reduction.

2.2. Experimental setup

In total three plexiglass bioreactors were used in this study. The first one (R1) was cubic with each side measuring 0.7 m and the other two (R2 and R3) were cylindrical of height H = 0.5 m and diameter D = 0.25 m. All reactors were equipped with a leachate collection system at their bottom, consisting of collection tanks (30 L and 1 L capacity for the cubic and cylindrical reactors, respectively) and PVC (polyvinyl chloride) tubes connecting the reactors to the tanks. Leachate recirculation was conducted using a peristaltic pump (Minipuls evolution, Gilson) and through PVC tubes connecting the collection tanks to the top of the bioreactors.

Each bioreactor was equipped with an aeration system, consisting of vertically placed PVC tubes (four for the cubic reactor and one for each cylindrical reactor), which had small holes lengthwise that allowed air supply during the aerobic phase of the experiment. The aeration system also included tubing allowing excess gas release to a tank filled with water. During the anaerobic phase of the experiment the aeration system was kept closed using valves.

During filling operations a plastic grid was initially placed at the bottom of each bioreactor and on top of that a layer of fine gravel (approximately 10 and 5 cm for the cubic and cylindrical reactors, respectively) was added, in order to retain any particulate and prevent clogging of the leachate recirculation system. Subsequently, each bioreactor was filled with its respective feedstock. More specifically, R1 received only OFMSW, in R2 a mixture of OFMSW (70%) and GW (30%) was introduced and finally R3 was filled with a mixture of OFMSW (70%) and DOP (30%). Prior to their introduction into the bioreactors, each feedstock was mixed with an appropriate amount of anaerobic sludge, in order to obtain a ratio of 0.025 L of sludge/kg of wet substrate mass. Finally, another layer of fine gravel was placed on top of the substrates to facilitate further compaction. Before sealing the bioreactors, deionized water (20 and 2 L for the cubic and cylindrical reactors, respectively) was added in order to initiate leachate production. A schematic diagram of the experimental setup can be seen in Fig. 1.

2.3. Bioreactor operation

The first phase of the experiment was conducted under anaerobic conditions and lasted until stabilization of the measured parameters was achieved, i.e. until no significant variations (with a maximum around 10–15%) were observed for the majority of parameters. Therefore, this phase had a duration of 186 days. After that moment the second phase of the experiment was initiated, by switching to aerobic conditions and starting aeration of the substrates at a rate of 0.3 L/(kg_{dry} min). Leachate recirculation was carried out during both phases of the experiment, three times a week and at a rate of 30 mL/(kg_{dry} day). It is noted that the aeration and leachate recirculation rates refer to the initial dry mass of each feedstock. Throughout the experiment, the bioreactors were kept in an environment where the temperature was maintained constantly at 25 ± 3 °C through the operation of air-conditioning systems. Moreover, in order to avoid having unwanted external influences, the bioreactors were kept away from sunlight and covered with insulating mantles. A summary of the operational parameters adopted during the experiment is presented in Table 1.

The three substrates were characterized regarding their elemental composition and their total solids (TS) and volatile solids (VS) contents. Throughout the whole duration of the experiment leachate samples from all three bioreactors were periodically taken and analyzed regarding pH, electrical conductivity (EC) and redox potential (redox), as well as chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total nitrogen (TN), NH_4-N, NO_2-N, NO_3-N, PO_4-P, Cl^-, SO_4^{2-} and total phenols (TPH) concentrations. Temperature and height of the waste mass, as well as the composition of the biogas (CO_2, CH_4, O_2) produced inside the bioreactors were also determined.

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