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Alternating pure oxygen and air cycles for the biostabilization of unsorted fraction of municipal solid waste

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ABSTRACT

Biostabilisation is a process of treating the unsorted fraction of municipal solid waste (UFMSW) mechanically pre-treated. Although concepts such as circular economy would seem to limit biostabilization, several authors have recently described the advantages of biostabilization in regions where recycling systems are inadequate. In this perspective, the development of new MBT technologies is of considerable importance.

The objective of the study was to evaluate the effects of the use of alternating air and oxygen cycles on the treated waste stability as well as on the quality of leachate and process gaseous emissions. Two Herhof biocells were prepared for this purpose. One implemented the conventional process and the other the "Air + O_2" process. The biostabilization of the inlet UFMSW (3965 ± 1965 mgO_2/kgVS/h) resulted in a final product with a dynamic respirometric index almost equal in both processes. The mass balance indicated that of the 400 tons representing the input waste, 37.57% were biostabilized waste, 0.29% leachate and 62.14% CO_2 and odours. However, the biostabilized waste was lower than that of the conventional process (equal to 40.18%). The Air + O_2 system resulted in a shorter duration, increased production of leachate (although characterized by higher quality) and process gaseous emissions quality. The energy balance (20.3 kJ/kg per input waste) and cost analysis (80.0 €/ton per input waste) showed values equal or better to those of the conventional system. By contrast, weakness was in the O_2 diffusion system. Although a life cycle analysis is necessary, the results highlighted the feasibility of the proposal especially for emergency situations.

1. Introduction

Biostabilization (biological stabilization) is a variation of aerobic decomposition, used within mechanical–biological treatment (MBT) plants to dry and stabilise residual municipal solid waste (MSW). Within the biostabilization bioreactor the thermal energy released during aerobic decomposition of degradable organic matter is combined with excess aeration to dry and stabilize the waste (Tom et al., 2016).

MBT plants integrate mechanical processing with bioconversion reactors, such as composting or anaerobic digestion (Velis et al., 2009). Typically, the biostabilization reactor within MBT plants receives shredded unsorted residual MSW and produces a biostabilized output which, after a selection/screening step (generally, at max 80 mm), is in part sent to the SRF (solid recovered fuel) production and in another part for landfilling (undersized component) (Spinosa and Carella, 2011).

Literature shows several studies on the biodrying-biostabilization of waste. Adani et al. (2002) investigated the influence of biomass temperature; they showed how appropriate management of the processing parameters (air-flow rate and biomass temperatures) could achieve biomass drying in very short times (8–9 days). Furthermore, they highlighted the important role of other conditions such as pile turning and the direction of the air-flow within the biomass; if the air-flow is always from one direction, temperature gradients arise within the biomass, resulting in a lack of homogeneity in the moisture and energy content of the final product. In addition, Sugni et al. (2005) investigated a new procedure for biodrying MSW by varying the air-flow direction through the biomass. They demonstrated how the daily inversion of air-flow eliminates marked temperature differences and leads to a homogeneous final product. In 2004, Adani et al. monitored for one year a mechanical–biological process for the treatment of a waste composed by undersized (<50 mm) and organic (Adani

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et al., 2004). They showed how a retention time of three weeks was sufficient to obtain stabilized products. By means of a 5-month full-scale monitoring, Tambone et al. (2011) studied the possibility to produce energy from the biostabilized material via biogas production after waste re-moistening; they showed how the partial degradation of the organic matter reduced the potential producible biogas of about 28%. Furthermore, Zhang et al. (2008) improved the water content reduction of high water content MWS by supplementing a hydrolytic stage prior to aerobic degradation and inoculating the bio-drying products. Shao et al. (2009) characterized the evolution of water-extractable organic matter (WEOM) during the biostabilization of MSW, investigating the correlation between biostability and WEOM characteristics. Pantini et al. (2015) and Zhang et al. (2011) investigated the leaching behaviour of wastes coming out from MBT plants showing how, despite MBT wastes are characterized by relatively high heavy metals content, only a limited amount was actually soluble and thus bioavailable. According to Pantini et al. (2015), the release percentage was generally lower than 5% of the total content with the only exception of dissolved organic carbon (DOC), Zn, Ni and Co with release percentages up to 20%. Yuan et al. (2017) and Tom et al. (2016) utilized the bulking agents like paper and plastic, cornstalks or wood peat on the MSW bio-stabilization and drying, demonstrating interesting opportunities to reduce the amounts of produced leachate. Instead, in terms of odours mitigation techniques, Shao et al. (2014) studied the effects of rice straw addition on odorous compounds emissions in a pilot-scale composting plant for organic fraction treatment; He et al. (2012) investigated the emission patterns of volatile organic compounds (VOCs) during aerobic MSW biotreatment using continuous and intermittent aeration obtaining interesting results useful for both MTB plants operators and those concerned with odour management practices.

Although concepts such as circular economy (Winans et al., 2017) and zero waste philosophy (Pietzsch et al., 2017) would seem to limit the use of biostabilization, recently Trulli et al. (2018) described the advantages of the use of an MBT within regions where recycling systems are inadequate. MBT plants in these regions are subject to frequent overloading, generally during the summer tourist season, generating management (longer storage time for incoming waste before treatment) and social problems (odours) as reported in De Gisi et al. (2016) and De Feo et al. (2013), respectively.

Velis et al. (2009) analysed the most commercial biodrying-biostabilization-MBT applications, also identifying the main technology providers such as Eco-deco, Entsorga, Future Fuels, Herhof, Nehlsen and Wehrle Werk. In the Eco-deco system, waste input is firstly shredded to about 200–300 mm, with the aim of homogenisation and size reduction; subsequently, biostabilization occurs in an enclosed hall, with comminuted input automatically stockpiled by crane in adjoining windrows. Air suction is applied through the waste matrix, through the vents of a pre-cast perforated floor. The airflow rate is automatically adjusted depending on the exhaust air temperature; typically, residence time within the biostabilization unit is 12–15 d and temperature ranges are 55–70 °C (Velis et al., 2009). Entsorga offers the "Le Coccinelle®" technology; it is a system with mobile reactors of modular type, where the basic module consists of 8 reactors (25 m^3 each) and 1 biofilter, and with a 14-day treatment cycle (De Feo et al., 2012). In the Future Fuels system, an inclined rotating drum ("Rotary bio-dryer") to process a mechanically separated organic fraction of MSW is proposed. According to the process developers, the system operates in the range 40–55 °C and the treatment cycle is 3 days long. In the Herhof system, rotary shredders are used for mechanical pre-treatment while downstream a magnetic conveyor belt removes the ferrous material. The comminuted Fe-free output is biostabilized within air- and liquid-tight boxes ("Herhof-Rotteboxes®"); the reactor residence time ranges from 5 to 10 d, with 7 d the most common (De Gisi et al., 2016; Velis et al., 2009). The Nehlsen system is similar to Herhof, using containers with underflow of partially circulated process air; the treatment cycle is 7 days long. Finally, the Wehrle Werk system uses mechanical pre-treatment followed by percolation ("Bio-percolat") and anaerobic digestion; solid residuals from the percolator are firstly dewatered by a screw press and then fed into closed tunnel reactors with matrix circulation known as "Percotry®". In these systems, ventilation plays an important role (Shao et al., 2012).

Following this overview, the technology described in this study was developed on the basis of the Herhof biocell, specifically modified. As explained subsequently, it involves the alternating use of cycles of air and pure oxygen; the intent was to benefit from the numerous advantages deriving from the enrichment of air with pure oxygen, stated in the literature (Outwater and Tansel, 1994), but never quantified. Such a solution, however based on a commercially available technology, could be applied especially in emergency scenarios where MBT plants operate inefficiently due to over-supply. As it is well known, surplus load in terms of inlet waste, if not properly managed, can exacerbate impacts on the environment (i.e., by producing odours) and therefore be a problem in terms of social acceptance (De Feo et al., 2013).

Thus, the objective of the study was to evaluate the effects of the use of alternating air and oxygen cycles on the mechanically–biologically treated waste stability as well as on the quality of leachate and process gaseous emissions by performing a full-scale experiment. Having the conventional system as a benchmark, based on air only, the following sub-objectives were investigated: (i) reduction of the duration of the conventional treatment cycle; (ii) improvement the quality of leachate in terms of percentage removal of organic matter; (iii) improving the quality of the process gaseous emissions to be destined for biofilter in terms of the concentration of odorous compounds and; (iv) verification of the energy and economic feasibility as well as raw material consumption of the proposed solution.

2. Materials and methods

2.1. Experimental plan

The experimentation was carried out on a full-scale plant consisting of two Herhof biocells, each of a 5.4 m × 25.9 m × 6.5 m size (∼909.1 m^3).

The typical treatment cycle of such systems involved an initial heating phase of the pile (phase I), a hygienization step (phase II), a maintenance phase (phase III) and a final cooling step (phase IV) (Favoino and Confalonieri, 2009). The first phase had the objective of heating the waste pile until it reaches the temperature of 55 °C. It typically lasts 1 day. The second phase aimed to remove the pathogenic content of the waste pile maintaining a temperature at about 65 °C for 3 days. The third phase had the goal of finishing the removal processes of the previous phase. According to the Regional Law (Apulia Regional Waste Management Plan, 2013) the hygienization and maintenance phases had to have duration of at least 6 days. Finally, the cooling phase consisted of injecting cold air into the pile of waste in such a way as to lower the temperature to at least 30–35 °C. This last phase usually lasts 1 day. Consequently, the total cycle time was 8 days long.

The conventional biostabilization process with air was implemented in the biocell of Fig. 1a. The Air + O_2 process, on the other hand, was implemented in the biocell of Fig. 1b which was suitably modified to allow the diffusion of oxygen, as described in Section 2.3.

For each run, the experimental plan provided for the following phases: (i) Characterization of the inlet waste; (ii) Testing and monitoring of process parameters; (iii) Sampling and characterisa-