THE EFFECT OF STORAGE AND MECHANICAL PRETREATMENT ON THE BIOLOGICAL STABILITY OF MUNICIPAL SOLID WASTES

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Abstract

Modern mechanical-biological waste treatment plants for the stabilization of both the source-separated organic fraction of municipal solid wastes (OFMSW) and the mixed stream of municipal solid wastes (MSW) include a mechanical pretreatment step to separate recyclable materials such as plastics, glass or metals, before biological treatment of the resulting organic material. In this work, the role of storage and mechanical pretreatment steps in the stabilization of organic matter has been studied by means of respiration techniques. Results have shown that a progressive stabilization of organic matter occurs during the pretreatment of the source-separated OFMSW, which is approximately 30% measured by the dynamic respiration index. In the case of mixed MSW, the stabilization occurring during the reception and storage of MSW is compensated by the effect of concentration of organic matter that the pretreatment step provokes on this material. Both results are crucial for the operation of the succeeding biological process. Finally, respiration indices have been shown to be suitable for the monitoring of the pretreatment steps in mechanical-biological waste treatment plants, with a strong positive correlation between the dynamic respiration index and the cumulative respiration index across all samples tested..

Keywords: Mechanical-biological treatment plant, Mechanical pretreatment, Municipal Solid Wastes, Organic Fraction of Municipal Solid Wastes, Respiration index, Stabilization.

1. Introduction

MSW and OFMSW are treated in industrial facilities of different configurations such as mechanical-biological treatment (MBT), anaerobic digestion and composting plants. An objective of these plants is to reduce the biodegradable organic matter in order to minimize the environmental burdens related to the landfill of wastes (odor problems, methane emissions or leachate generation). It has been reported that biological stability of organic matter is positively correlated with low environmental impacts associated to waste management (Muller et al., 1998).

MBT plants are of different configurations. They can include aerobic (composting), anaerobic processes or the combination of both (Ponsá et al., 2008a; Wagland et al., 2009). Nevertheless, they all include a first mechanical pretreatment step with a double objective: to recover recyclable materials (glass, plastics and metals) and to prepare the organic matter for biological treatment. Although scientific literature is full of references on the performance, monitoring and optimization of the biological steps involved in the treatment of MSW, to the authors' knowledge, no studies have been published on the possible effect of the mechanical pretreatment on the stabilization of organic matter. This is an interesting point since any stabilization occurring in this first step could have a critical influence on the biological process behavior afterwards. For instance less biogas production would be expected in anaerobic digestion or less aeration requirements would be necessary in a composting-like treatment. These both aspects are crucial in the configuration of a MBT plant.

The analysis of a waste treatment plant requires a reliable measure of the biological activity of the organic matter or, similarly, its stability defined as the extent to which readily biodegradable organic matter has decomposed (Lasaridi and Stentiford, 1998). In this field, the application of respiration indices has proven to be very useful in the monitoring of waste treatment plants and for the prediction of the stability of final products such as stabilized material for landfill or compost (Adani et al., 2006; Barrena et al., 2009). For instance, Ruggieri et al. (2008) reported the stabilization reached during the composting of OFMSW using several aeration modes and Ponsá et al. (2009) have recently presented the use of respirometry for the optimization of the amount of bulking agent used for porosity adjustment in wastewater sludge composting at full-scale. In relation to the techniques used for the determination of respiration index, several studies have reported the suitability of dynamic methods to overcome possible problems of mass transfer limitations in solid-state respirometry (Adani et al., 2003; Barrena et al., 2006; Tremier et al., 2005), which is crucial when very active materials are studied (for instance, raw OFMSW and MSW).

In a previous work (Ponsá et al., 2008a), we carried out the complete respirometric monitoring of a complex MBT plant that included in this order, mechanical pretreatment, anaerobic digestion and composting and we observed that the main step for organic matter stabilization was anaerobic digestion. However, a significant decrease of stability was observed in the pretreatment operations. The main objective of this study is to investigate the possible effect of mechanical pretreatment on both the OFMSW and MSW stabilization.

2. Materials and Methods

2.1. Mechanical-biological treatment plant

The MBT plant studied is located in Barcelona province. Mixed MSW and OFMSW consisting of kitchen and garden wastes from the Metropolitan Area of Barcelona are treated in this plant. MSW and OFMSW are treated separately in two independent lines. The capacity of the plant is 240,000 t/year (70,000 t/year of OFMSW and 170,000 t/year of MSW). The treatment of organic wastes includes three main processes:

Process 1: Mechanical pretreatment: Both OFMSW and MSW are treated to remove inorganic materials such as plastics, metal, glass and stones, which are recycled. The mechanical pretreatment includes in this order: two trommel screens (to remove large impurities, first cut off 60 mm, second cut off 150 mm, Masias Recycling SL Girona, Spain), a magnetic separator (to remove ferric materials), a Foucault separator (to remove aluminum), a ballistic separator (to remove large density materials) and a shredder. After this pretreatment sequence the organic materials are essentially free of inorganic contaminants.

Process 2: Anaerobic digestion: organic matter is anaerobically digested in three digesters of 4,500 m^3 of capacity. The plant uses the Valorga process, in which the material is processed in solid state and under mesophilic conditions (38ºC) during 21 days.

Process 3: Composting: Material coming from anaerobic digesters is mixed with bulking agent (pruning wastes in a ratio 2:1) and composted in a tunnel composting system (17 tunnels) during three weeks to stabilize and sanitize the material. Final compost (from OFMSW) or stabilized waste (from MSW) is stockpiled before commercialization.

2.2. Sampling

Three campaigns were carried out in this study, C1 on October 2008, C2 on December 2008 and C3 on January 2009. In each of these campaigns waste samples were collected from the three significant points of the pretreatment process for both MSW and OFMSW lines: Step 1-- waste collected as received in the plant from the transport truck; Step 2-- waste from the collection pit, where the maximum retention time is two days, and Step 3-- waste after the entire mechanical pretreatment, which takes approximately four hours to completion. The total number of samples analyzed was: 2 lines (MSW and OFMSW) x 3 sampling points (Steps 1, 2 and 3) x 3 Campaigns (C1, C2 and C3) = 18 samples.

Analytical methods were carried out on a representative sample (approximately 100 kg) obtained by mixing subsamples of about 25 kg each, taken from at least four different points of the bulk of material. All samples were entirely ground to 10 mm particle size to increase the available surface and maintain enough porosity and matrix structure. The separation of large objects was not carried out because the grinder used was able to grind all kinds of objects, such as plastic film, metals and glass bottles.

Next, the ground samples were vigorously mixed in the laboratory and approximately 10 kg of each sample were immediately frozen and conserved at -20ºC. Before analysis, samples were thawed at room temperature for 24 hours.

2.3. Analytical methods

Water content or dry matter (DM) and organic matter content were determined according to the standard procedures (The US Department of Agriculture and The US Composting Council, 2001, TMECC 0309 and TMECC 0507, respectively). All the results are presented as an average of three replicates with standard deviation.

2.4. Respirometric tests

A dynamic respirometer has been built as described by Adani et al. (2006). A sample of 100 g of organic material was obtained by randomly taking different small sub-samples from the 10 kg of thawed material after vigorous remixing. This sample was placed in a 250 mL Erlenmeyer flask and incubated in a water bath at 37ºC. The starting organic material moisture was adjusted to a range of 50-60%, if necessary. Air was continuously supplied to the samples using a mass flowmeter (Bronkhorst Hitec, The Netherlands) to ensure aerobic conditions during the experiment (oxygen concentration higher than 10%). Oxygen content in the exhaust gas from the flask was measured using a specific probe (Xgard Crowcon, UK) and recorded in a personal computer equipped with commercial software (Indusoft Web Studio, version 2008, USA). No lag-phase was detected in any of the respirometric analysis carried out. From the curve of oxygen concentration vs. time, two respiration indices can be calculated:

a) Dynamic Respiration Index (DRI): calculated as explained in Adani et al. (2004). It represents the average oxygen uptake rate during the twenty-four hours of maximum activity observed during the respiration assay. It is expressed in mg of oxygen consumed per g of dry matter and per hour.

b) Cumulative Respiration Index (CRI): explained in Cossu and Raga (2008) and calculated as in German Federal Ministry for the Environment (2001). It represents the cumulative oxygen consumption during the four days of maximum respiration activity without considering the lag initial phase and under the same conditions of DRI. It is expressed in mg of oxygen consumed per g of dry matter.

2.5. Statistical methods

An ANOVA test was performed to compare different sampling points. If the ANOVA test resulted in statistically significant differences, a Tukey test was performed in pairwise comparisons. 95% confidence level was selected for all statistical comparisons. Statistical tests were conducted with SPSS 15.0.1 (SPSS Inc., USA).

3. Results and discussion

3.1. Respirometric study

The general properties of the samples studied are reported in Tables 1 and 2. Although OFMSW presented higher values of moisture and total organic matter content than those of MSW, no trend was observed when analyzing the different points of the pretreatment process. Other authors have previously demonstrated that the use of compositional methods such as dry matter or organic matter content for the evaluation of biodegradability of municipal solid wastes is not recommended (Sánchez, 2009; Wagland et al., 2009).

Figure 1 shows the evolution of DRI in the samples collected from the selected points of the mechanical pretreatment and for both lines of OFMSW and MSW. All sampling points following the pretreatment process were statistically different in terms of respiration activity at 95% confidence level except in one case (Table 4). However, different trends were observed when considering OFMSW and MSW.

In the case of OFMSW, the trend is a gradual decrease of DRI, from 4.3 to 3.01 mg O_2 g^{-1} DM h^{-1}, which corresponds to a 30% decrease (Table 3). It is evident that both operations involved in pretreatment (pit storage and mechanical removal of inorganic impurities) provoke the biodegradation of the most rapidly biodegradable fraction contained in this material. In the case of the OFMSW pit the maximum residence time is two days, which is adequate for plant operation and to adapt the plant to the logistics of the source-separated collection systems that are being implemented (Tanskanen and Kaila, 2001). However, this study reveals that this time is long enough to affect the waste respiration activity. The last step in pretreatment, although shorter than pit storage, involves separation processes and transport between them. This clearly acts as aerobic treatment for OFMSW. In fact, several composting systems are based on the use of drum aerated composters, which resemble trommels and some of the mechanical pretreatment operation units used in modern MBT (Kalamdhad and Kazmi, 2009).

In the case of MSW, the observed trend is similar in the pit, with an important decrease of the respiration activity (from 2.1 to 1.2 mg O_2 g^{-1} DM h^{-1}, Table 4). Although the reason for this behavior is not clear, it can be hypothesized that the higher level of porosity of mixed MSW because of the presence of inert large materials when compared to OFMSW contributes to enhance the biodegradation of organic matter during pit storage, as porosity has an important effect on oxygen uptake rate (Ruggieri et al., 2009). However, the respiration activity is completely recovered after mechanical pretreatment (Figure 1).

This “recovery” of respiration activity needs to be carefully interpreted. Theoretically, respiration activity in MBT cannot increase and, in consequence, the only way to explain this increase is the concentration effect associated to mixed MSW mechanical selection, that is, inorganic materials (glass, metals) and inert non-biodegradable organic materials (plastics) are removed and biodegradable organic materials (that are responsible for respiration) are then concentrated. According to the values obtained from mechanical pretreatment, this concentration effect is around 1.9 (from 1.2 to 2.3 mg O_2 g^{-1} DM h^{-1}, Table 4). However, another possible hypothesis could be that the pretreatment step can act as a hydrolytic step for biodegradable organic matter and consequently increase the respiration activity as it has been observed in anaerobic sludge pretreatment (Ponsá et al., 2008b).

According to plant manager information the MSW line has 50% rejected materials to landfill while OFMSW line has only 20%. The reason for this difference is that MSW presents an average weight composition of food and green waste (38%), paper (21%), plastics (16%), glass (8%), metals (5%) and others (12%) when directly obtained from collection trucks, while the OFMSW presents an average level of impurities of 15% (Catalan Environment Agency, 2009). Finally, it must be noted that in the case of OFMSW, although this concentration effect is also possible, the lower content of inorganic or inert organic materials does not permit its quantification and, in fact, the respiration activity slightly decreases (Figure 1). Unfortunately, no results on mechanical pretreatment operations related to uptake of oxygen have been found in literature for comparison with DRI values of this study.

3.2. Correlation between cumulative and non-cumulative respiration indices

As there is no consensus in the scientific community on the way to express and report respiration indices (Barrena et al, 2006), both dynamic (DRI) and cumulative respiration indices (CRI) have been used in this study. In fact, previous results have shown good correlations between both indices (Barrena et al., 2009) and significant correlation between aerobic and anaerobic indices such as GB_{21} (Cossu and Raga, 2008; Ponsá et al., 2008a; Wagland et al., 2009). In this study, the correlation between both indices presented in Tables 3-4, with all samples considered, is presented in Figure 2. It is evident that the correlation is good with the correlation coefficient (R^2) of 0.93. These values indicate that DRI and CRI can be positively correlated with highly active raw MSW samples, although more evidence to generalize this would be necessary for other organic wastes or MSW in different stages of the stabilization process in MBT plants. Moreover, it is also clear that the level of activity for mixed MSW and source-separated OFMSW are significantly different. These results have been also reported in other studies (Ponsá et al., 2008a) and they again highlight the need to consider different plant designs for both wastes, especially when biological operations are to be selected.

3.3. Implications for plant operation

The demonstration that the pretreatment process provokes a significant stabilization of organic matter has important implications in the design of MBT plants. For instance, in the case of OFMSW the pretreatment process implies a loss of around 30% of respiration activity (Table 3), which can have different implications depending on the further biological process to be applied. In the case of anaerobic digestion (the case of the studied plant) this loss is expected to provoke a decrease in the biogas yield when compared to the untreated input material, which is the value typically considered when designing anaerobic reactors. If an aerobic composting-like process is selected for OFMSW stabilization, a lower aeration requirement is expected, since respiration activity is directly related to oxygen uptake rate (Tremier et al., 2005).

In the case of MSW, the first decrease of respiration activity after reception is compensated by the concentration effect of organic matter after the pretreatment step. It is evident that the removal of large amounts of inorganic matter during this pretreatment step causes a concentration effect in organic matter; therefore the respiration level after pretreatment is due to a similar amount of organic matter that is now in a higher percentage than that of the input material. However, if no stabilization had occurred during the entire pretreatment process, the respiration activity after this process would have been higher than that of the input waste, due to a considerable amount of inorganic materials that would have been removed. This is not really the case since both activities are very similar (Table 4). Therefore, it can be concluded that the losses of easily biodegradable organic matter are higher than those reported for the case of OFMSW (about 40% when comparing respiration activity for Steps 1 and 2).

4. Conclusions

The results obtained in this study can be summarized in the following conclusions:

1) Complex mechanical pretreatment results in a progressive stabilization of organic matter in mechanical-biological treatment plants. In the case of source-separated OFMSW this stabilization is approximately 30%, whereas in the case of mixed MSW a first stabilization is observed during the reception and storage of MSW, which is compensated by the effect of concentration of organic matter by pretreatment processes.

2) This unexpected degree of stabilization has to be considered in the design of mechanical treatment plants because it implies a lower biogas yield if anaerobic digestion is selected as

biological treatment or a shorter operation time/lower aeration requirements if composting is proposed.

3) Dynamic respiration indices are a suitable technique to measure the effect of mechanical pretreatment on the stabilization of municipal solid wastes that are intended to be biologically treated.

4) The great variability observed in the samples of MSW suggests a need to extend this work to other plants and other municipalities.

5) Other biological phenomena involved in the pretreatment stages should be the focus of further studies. The role of the collection system should be also analyzed.

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Tables

Table 1: General properties determined during pretreatment process for OFMSW. Step 1: waste collected as received in the plant from the transport truck; Step 2: waste from the collection pit and Step 3: waste after the entire mechanical pretreatment. Results from triplicates are presented as Mean ± Standard Deviation.

Step	Campaign	Moisture content (ww) (%)	Organic matter content (DM) (%)
1	1	58 ± 2	74 ± 2
	2	58 ± 3	59 ± 2
	3	67 ± 2	79 ± 6
	Mean	**61 ± 5**	**71 ± 10**
2	1	61 ± 4	74 ± 3
	2	62 ± 5	80 ± 2
	3	60 ± 3	75 ± 4
	Mean	**61 ± 1**	**76 ± 3**
3	1	56 ± 2	68 ± 2
	2	67 ± 4	65 ± 2
	3	57 ± 4	68 ± 4
	Mean	**60 ± 6**	**67 ± 2**

ww: wet weight

DM: dry matter

Table 2: General properties obtained during pretreatment process for MSW. Step 1: waste collected as received in the plant from the transport truck; Step 2: waste from the collection pit and Step 3: waste after the entire mechanical pretreatment. Results from triplicates are presented as Mean ± Standard Deviation.

Step	Campaign	Moisture content (ww) (%)	Organic matter content (DM) (%)
1	1	46 ± 1	56 ± 4
	2	49 ± 7	70 ± 2
	3	43 ± 2	71 ± 6
	Mean	**46 ± 3**	**65 ± 8**
2	1	39 ± 4	65 ± 4
	2	49 ± 3	76 ± 4
	3	44 ± 9	46 ± 8
	Mean	**44 ± 5**	**62 ± 15**
3	1	51 ± 3	58 ± 6
	2	45 ± 3	48 ± 5
	3	49 ± 2	73 ± 6
	Mean	**48 ± 3**	**60 ± 13**

ww: wet weight

DM: dry matter

Table 3: Respiration indices obtained during pretreatment process for OFMSW. Step 1: waste collected as received in the plant from the transport truck; Step 2: waste from the collection pit and Step 3: waste after the entire mechanical pretreatment. Different letters in the row of "Mean" imply statistically different results. Results from triplicates are presented as Mean ± Standard Deviation.

Step	Campaign	Dynamic respiration index (mg O_2 g^{-1} DM h^{-1})	Cumulative respiration index (mg O_2 g^{-1} DM)
1	1	4.0 ± 0.7	268 ± 80
	2	4.1 ± 0.2	219 ± 27
	3	4.7 ± 0.9	359 ± 79
	Mean[a]	**4.3 ± 0.4**	**282 ± 70**
2	1	3.4 ± 0.3	184 ± 15
	2	3.6 ± 0.3	254 ± 37
	3	3.7 ± 0.1	284 ± 16
	Mean[b]	**3.5 ± 0.2**	**241 ± 51**
3	1	3.1 ± 0.5	202 ± 20
	2	2.7 ± 0.1	183 ± 5
	3	3.2 ± 0.4	187 ± 19
	Mean[c]	**3.0 ± 0.3**	**190 ± 10**

DM: dry matter

Table 4: Respiration indices obtained during pretreatment process for MSW. Step 1: waste collected as received in the plant from the transport truck; Step 2: waste from the collection pit and Step 3: waste after the entire mechanical pretreatment. Different letters in the row of "Mean" imply statistically different results. Results of triplicates are presented as Mean ± Standard Deviation.

Step	Campaign	Dynamic respiration index (mg O_2 g^{-1} DM h^{-1})	Cumulative respiration index (mg O_2 g^{-1} DM)
1	1	1.8 ± 0.1	127 ± 6
	2	1.9 ± 0.4	129 ± 33
	3	2.5 ± 0.3	201 ± 28
	Mean^{a}	**2.1 ± 0.4**	**152 ± 40**
2	1	1.2 ± 0.4	82 ± 30
	2	0.8 ± 0.1	64 ± 4
	3	1.5 ± 0.4	123 ± 34
	Mean^{b}	**1.2 ± 0.3**	**90 ± 30**
3	1	2.4 ± 0.4	150 ± 22
	2	2.2 ± 0.1	163 ± 2
	3	2.2 ± 0.4	179 ± 36
	Mean^{a}	**2.3 ± 0.1**	**164 ± 14**

DM: dry matter

Legends to Figures

Figure 1: Evolution of Dynamic Respiration Index (DRI) during the pretreatment process of MSW (mixed municipal solid wastes) and OFMSW (source-separated organic fraction of municipal solid wastes).

Figure 2: Correlation between Dynamic Respiration Index (DRI) and Cumulative Respiration Index (CRI) for all the analyzed samples. Black-filled symbols correspond to OFMSW samples and white-filled symbols correspond to MSW samples.

Figure 1: Ponsá et al.

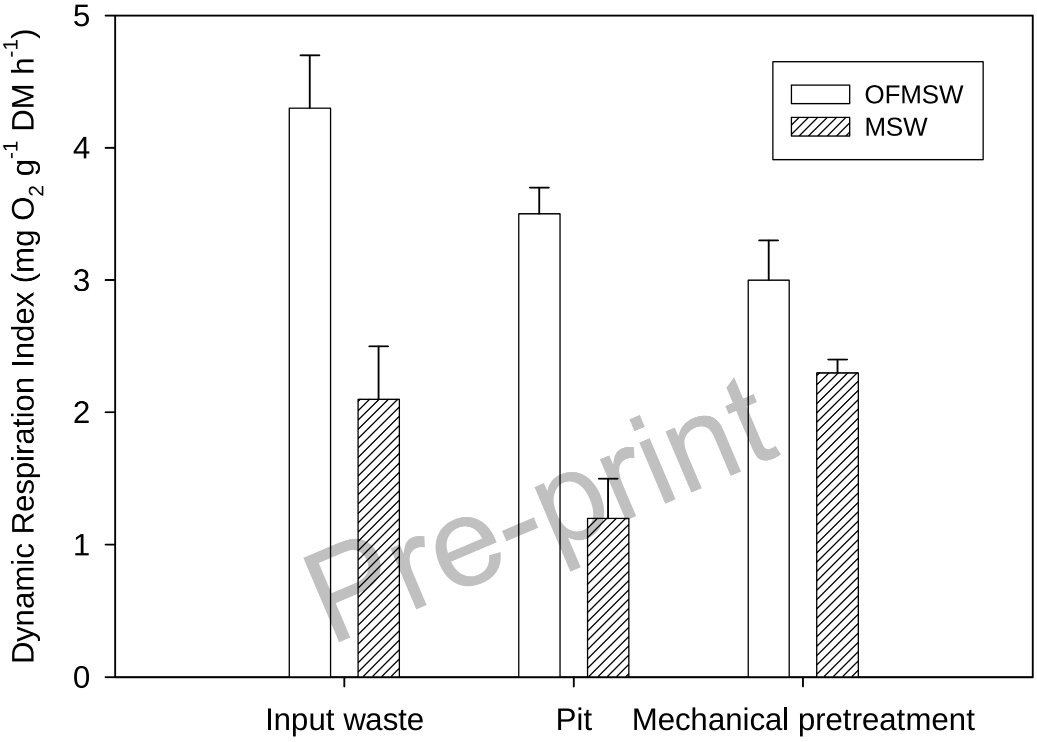

Figure 2: Ponsá et al.