Total organic carbon as a proxy for metal release from biostabilized MBT wastes

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Abstract

In this study, we introduce a simple method to anticipate the metal release from biostabilized waste that can be expected from percolation column tests. The method is based on the combination of total organic carbon (TOC) with a model that allows to simulate the release of DOC as a function of the L/S ratio applied. Next, considering that in organic-rich wastes the leaching pattern of many metals is very similar to the one observed for dissolved organic carbon, it is possible to derive specific correlation coefficients between DOC and metals. In this work, we derived these correlation coefficients based on literature data of leaching tests carried out on different biowastes and biostabilized wastes. These correlation coefficients were then integrated in the model for the cumulative release of DOC, allowing to describe the release of metals. After a brief description of the method, to elucidate how it can be used to evaluate the metal release as a function of the L/S ratios, it was tested on percolation column tests carried out on a biostabilized waste. The comparison of the results obtained with this new method with the experimental data highlighted that this approach replicates quite well the leaching trend observed for most of the selected metals. The results support our proposal to use TOC as a proxy for metal release, by allowing to anticipate the results of percolation column test with a relatively good accuracy and hence for evaluating the effective need for more rigorous laboratory tests.

Keywords: Biostabilized wastes, Leaching Behavior, Metal Release, Screening Method.

1 INTRODUCTION

Municipal solid wastes (MSW) contain large quantities of organic materials that, depending on the country economy and the waste management policies, may reach up to 70% of the produced MSW [1]. To meet the European Landfill Directive 99/31/CE that imposed limits on the amount of biodegradable fraction disposable in landfills, in recent years Mechanical Biological Treatment (MBT) plants of raw MSW were developed in different European countries as a waste management option of residual wastes to produce biostabilized waste and waste-derived fuels aimed at energy recovery [2–4]. MBT facilities can consist of different combinations of mechanical sorting, bio-drying, and biological processes depending on the specific target, that may be a pre-treatment before incineration or in view of a biostabilized product with a lower impact when disposed of in landfills [1, 5–8]. To date, the main fate of the biostabilized fraction of MBT wastes is landfilling because of the relatively high content of non-compostable materials (e.g. plastic and glass pieces) and heavy metals compared to biowaste [9]. However, over recent years, different studies have investigated the feasibility of recovering MBT wastes for land reclamation purpose as cover layer material in landfills or applied to degraded soils for organic matter supply [10, 11].

In this view, it is crucial to properly assess the long-term environmental behavior of these wastes in terms of biogas emissions and leachate quality and quantity [3, 12–14]. In the last decades, a large number of studies were focused on the evaluation of biogas potential capacity in terms of volume and composition of the gas generated from MBT samples [15–18]. Conversely, the leaching behavior of these materials in terms of heavy metals mobility is still poorly investigated [15, 19]. However, together with biogas emission, the release of heavy metals from organic rich wastes is one of the main concern about the long-term environmental behavior of biostabilized wastes. To address this issue, standard batch and percolation column leaching tests can be carried out to evaluate the release of heavy metals as a function of the liquid to solid ratio (L/S) applied [1]. In batch tests, a sub-sample of the studied material is placed in contact with a liquid phase for a fixed time (generally 24-48 h) during which chemical equilibrium conditions between the aqueous and solid phase are assumed to be established [20]. However, batch tests do not provide any information on the release kinetics under dynamic conditions [21]. Conversely, from column percolation tests, in which water is flowed through the material and collected at set cumulative L/S ratios, the effects of the elution rate of constituents into the pore solution at different L/S ratios can be estimated [20]. For this reason, percolation column tests are often considered a better basis for assessing the release of contaminants from granular materials, as they should approximate more accurately field percolation conditions compared to batch tests [20]. However, column percolation tests are more complicated and time-consuming compared to batch tests. For this reason, an easy-to-use screening tool that can be used to evaluate in which specific cases the adoption of these type of tests is needed can be of help. In this study, we introduce a simple method that can be used to anticipate the metal release from biostabilized wastes expected from percolation column tests. The method is based on the combination of total organic carbon (TOC) with a simple model that allows to simulate the release of DOC as a function of the L/S ratio applied. Next, considering that in organic-rich wastes the leaching pattern of many metals is very similar to the one observed for dissolved organic carbon, it is possible to derive specific correlation coefficients between the DOC and metals. After a brief description of the method, we will show the correlation coefficients between metals and DOC that we derived based on literature data of leaching tests carried out on different biowastes and biostabilized wastes. Next, to elucidate how it can be used to evaluate the metal release as a function of the L/S ratios, we tested it on percolation column tests carried out on a biostabilized waste.

2 MATERIALS AND METHODS

2.1 Description of the method

Considering that in organic-rich wastes the leaching pattern of many metals is very similar to the one observed for dissolved organic carbon, it is possible to derive specific correlation coefficients between the DOC and metals. In this view, the method proposed in this work is based on the combination of total organic carbon (TOC) with a simple model that allows to simulate the cumulative release of metal [Me] as a function of the L/S ratio applied:

$$\begin{cases} [Me] = \left(L/S \cdot \dfrac{TOC}{K_d} \right) \cdot K_{DOC,Me} & \text{for L/S} \le \text{L/S}^* \\ [Me] = \left(L/S \cdot \dfrac{TOC}{K_d} + 2\dfrac{TOC}{h_c} \left(\dfrac{D\left(t-t^*\right)}{\pi} \right)^{1/2} \right) \cdot K_{DOC,Me} & \text{for L/S>L/S}^* \end{cases}$$

where TOC is the total organic carbon content in the solid matrix, K_d the partitioning coefficient between TOC and DOC (e.g.1-10 L/kg), $K_{DOC,Me}$ the empirical partitioning coefficient between metal (Me) and DOC (see Table 1), h_c the column height, D the diffusivity coefficient of DOC in the porous medium (e.g. 10^{-5} cm^2/s), t* and L/S* the critical time and liquid to solid ratio that allow to switch from flux-controlled to mass transfer-controlled scenario (which can be assumed equal to L/S* = 1 L/kg).

2.2 Literature database

Data collected from different studies about percolation of biostabilized waste have been considered in this work for validating the proposed methods. In particular, they refer to samples from composting of source segregated organic waste [22] and to the Mechanical Biological Treatment (MBT) of the residual mixed municipal wastes [1, 14, 23–25]. Furthermore, in this work we considered the results of percolation column tests that were carried out on wastes collected at the end of their biological stabilization treatment at MBT plant (lasting 28 days) and subjected to a further 6 months-prolonged curing step, in order to extend our dataset by analyzing a treated organic-rich waste at different biological stabilization degree. A brief description of the treatments occurred for the biological stabilization is reported below.

2.2.1 Biowastes

Two different composts were investigated in Lombardi et al. (2018) [22]. Compost A was collected in a plant located in Rome fed by the source-segregated Organic Fractions of Municipal Solid Wastes (OFMSW) of the near areas. It was sampled at the end of its aerobic composting process (28 days of active phase followed by a maturation stage of up to 180 days, both under covered conditions), after a preliminary mechanical sieving at 10 mm occurred before the maturation stage. Compost B derives from a combined treatment of anaerobic digestion and composting of mainly food and green waste, carried out in a plant located in the central Italy. Wastes feed a horizontal reactor where an anaerobic digestion stage is carried out for 15 days; the digested output is mixed with not digested OFMSW and sent to the aerobic composting stage in bio-cells. The latter last about 20 days and is followed by a maturation stage of 90 days, at the end of which compost is mechanically sieved at 10 mm.

2.2.2 Biostabilized wastes

Cossu and Lai (2012) [23] analyzed the effect of a washing treatment on the leaching behavior of different types of waste, considering also a sample of biostabilized waste. The latter was produced from the treatment of undifferentiated fraction of waste from separate collection, sampled after mechanical sorting and biological treatment (4 weeks at forced aeration conditions and 6 weeks-maturation phase). Percolation column tests were performed in glass columns (diameter 5 cm, height 30 cm) with low flow rates and the eluates were collected to obtain a liquid–solid ratio of 1, 2, 5, 10 and 15 L/kgTS.

Emissions from landfilled biostabilized waste produced in a plant located in Cantabria (Spain) was evaluated in López et al. (2018) [24]. Here the residual mixed waste that passes through a 9 mm trommel screen underwent 8 weeks-aerobic process, during which the waste was weekly turned and there was no addition of water. In this study real-scale data about BSW percolation were obtained realizing a pilot-scale cell and collecting data at the end of the monitoring period, when a liquid–solid ratio (L/S) of 0.11 L/kg was obtained.

Pantini et al. (2015a) [1] analyzed the leaching behavior of raw municipal solid waste treated in a MBT plant of the central Italy. The average composition of the untreated waste reported in their study shows that it is mainly composed of organic scraps, paper and plastics. In the MBT plant, the waste was mechanically sieved at 80 mm, in order to separate the light dry materials from the organic fraction before its biological stabilization. The latter was daily turned and moisturized for 28 days, in order to promote the aerobic biodegradation of the organic matter. Samples were collected after the secondary refining unit (a 20 mm sieve at the end of the close-reactor tank) during three different campaigns.

Also Salati et al. (2013) [25] evaluated the leaching behavior of a biostabilized waste collected in a MBT plant after a biological treatment lasting 28 days. In this study, the biostabilization, conducted on the undersize fraction of the residual mixed waste (sieve-hole diameter of 90 mm), was performed under forced aeration conditions, periodically turning the material. Samples from the outflow of the MBT plant were incubated in laboratory-scale landfill reactors for 12 months and the leachates collected each day were used for composing two-months period samples.

Siddiqui et al. (2013) [14] present the results of laboratory experiments carried out on two different biostabilized wastes to investigate the flushing of contaminants from these materials once landfilled. The first sample came from mechanically shredding and screening before its aerobic biostabilization; the biodegradation was in forced aerated windrows with regular wetting and turning in an enclosed hall for a period of 6 weeks. The second one differs in the biological stage: here the wastes were anaerobically digested for 3 weeks before being aerobically composted in enclosed windrows for 6 weeks. The disposal of these materials was simulated using a consolidating anaerobic reactor from which leachate samples were collected every three days during the first three months of operation and weekly thereafter.

2.3 Percolation tests on biostabilized wastes subjected to prolonged curing

In this work, we also considered the results of percolation column tests carried out on a biostabilized waste subjected to a prolonged curing [26]. These samples were collected at the outflow of a MBT plant, located in Rome, fed with residual mixed waste collected in the near areas. Here again, after a primary removal of the materials larger than 90 mm, the wastes underwent metal removal step and were subjected to 28 days of aerobic biodegradation at forced aeration conditions in closed reactor-tanks. The output was than mechanically sieved at 30 mm, with the aim of removing plastics and inert materials. Then, to simulate a pilot-scale prolonged curing, about 300 kg of biostabilized waste were collected downstream from the treatment line of the MBT plant, and a natural aerated windrow was stored indoor for 180 days. Every 10 days the windrow was manually overturned and water was added, to ensure the suitable conditions (i.e. sufficient aeration and moisture content) for the further 6 months-prolonged curing phase. As result, three different samples were considered for the percolation column test:

the outflow of the MBT plant (BSW-28) and two samples collected after further 90 and 180 days of prolonged curing (BSW-118 and BSW-208 respectively).

The up-flow column percolation tests were performed following the procedure described in the ISO/TS 21268–3. In particular, a water solution (0.001 mol/l $CaCl_2$) was up-flowed at specified flow rate through a column of 5 cm diameter and 30 ± 5 cm height, where the sample was softly compacted. The eluate was collected in several separate fractions at fixed L/S ratio (0.1, 0.2, 0.5, 1, 2, 5 and 10 L/kg) analyzing the metal content by ICP-OES and the DOC by Shimadzu TOC-V CPH/CPN.

3 RESULTS AND DISCUSSIONS

3.1 Empirical correlation coefficient between metal and DOC

Figure 1 shows the correlation between the concentration (as mg/L) of DOC and some selected metals. With the different colors are reported the data of the leaching tests carried out on different biowaste and biostabilized wastes examined in the different studies available in the literature. Furthermore the data obtained in the up-flow column percolation tests performed in the present study are also shown. In each figure, the diagonal lines representing the metal to DOC correlation coefficients are also reported as reference. From this figure it can be noticed, that in nearly all cases, the data fall within two consecutive diagonal lines, indicating that generic metal to DOC correlation coefficient can be derived independently from the origin of the organic-rich material. Based on this evidence, the median (50th percentile) and the lower (25th percentile) and upper bound value (75th percentile) of the distribution of each metals to DOC correlation coefficient was calculated. These values are reported in Table 1. It can be observed that the variability of this range is relatively narrow (usually within one order of magnitude).

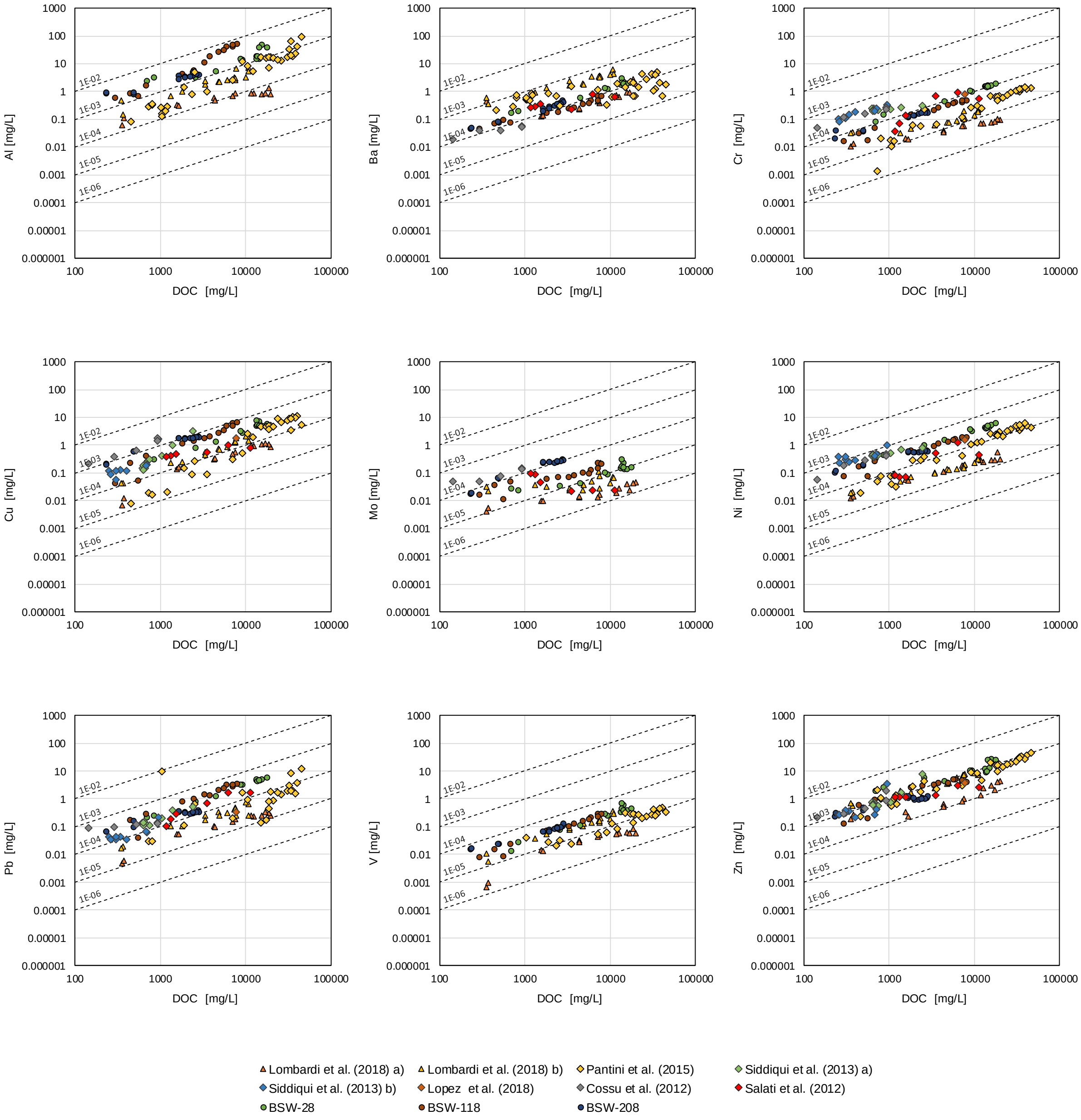

Figure 1. Metal to DOC correlation coefficients.

Table 1. Statistics of empirical correlation coefficient between metal (Me) and DOC ($K_{DOC,Me}$)

$K_{DOC,Me}$	Al	Ba	Cr	Cu	Mo	Ni	Pb	V	Zn
N° of samples	106	117	131	130	83	133	126	97	135
Lower range (25th Percentile)	4.0E-04	8.2E-05	2.6E-05	1.5E-04	7.7E-06	5.5E-05	5.5E-05	9.2E-06	5.6E-04
Median (50th Percentile)	9.1E-04	1.5E-04	6.9E-05	2.9E-04	2.1E-05	1.7E-04	1.4E-04	2.4E-05	8.8E-04
Upper range (75th Percentile)	1.8E-03	3.7E-04	1.2E-04	5.7E-04	8.1E-05	3.7E-04	2.8E-04	3.6E-05	1.1E-03

3.2 *Partial validation of the method*

In this section, to elucidate the capability of the proposed method, we show some comparison of the results obtained in the up-flow column percolation tests performed in this study and the values expected using the screening tool. In particular, Figure 2 shows a comparison of the cumulative mass release observed in the percolation column tests carried out on a the biostabilized waste produced in the MBT plant (BSW-28) and the results obtained using the screening method introduced in this work. Specifically, the results are shown in terms of lower, median and upper value expected based on the range of the correlation coefficients between the DOC and metals release derived from the literature (see Table 1). The obtained results highlight that the approach proposed in this work anticipates quite well the leaching trend observed in the percolation column test for most of the selected metals.

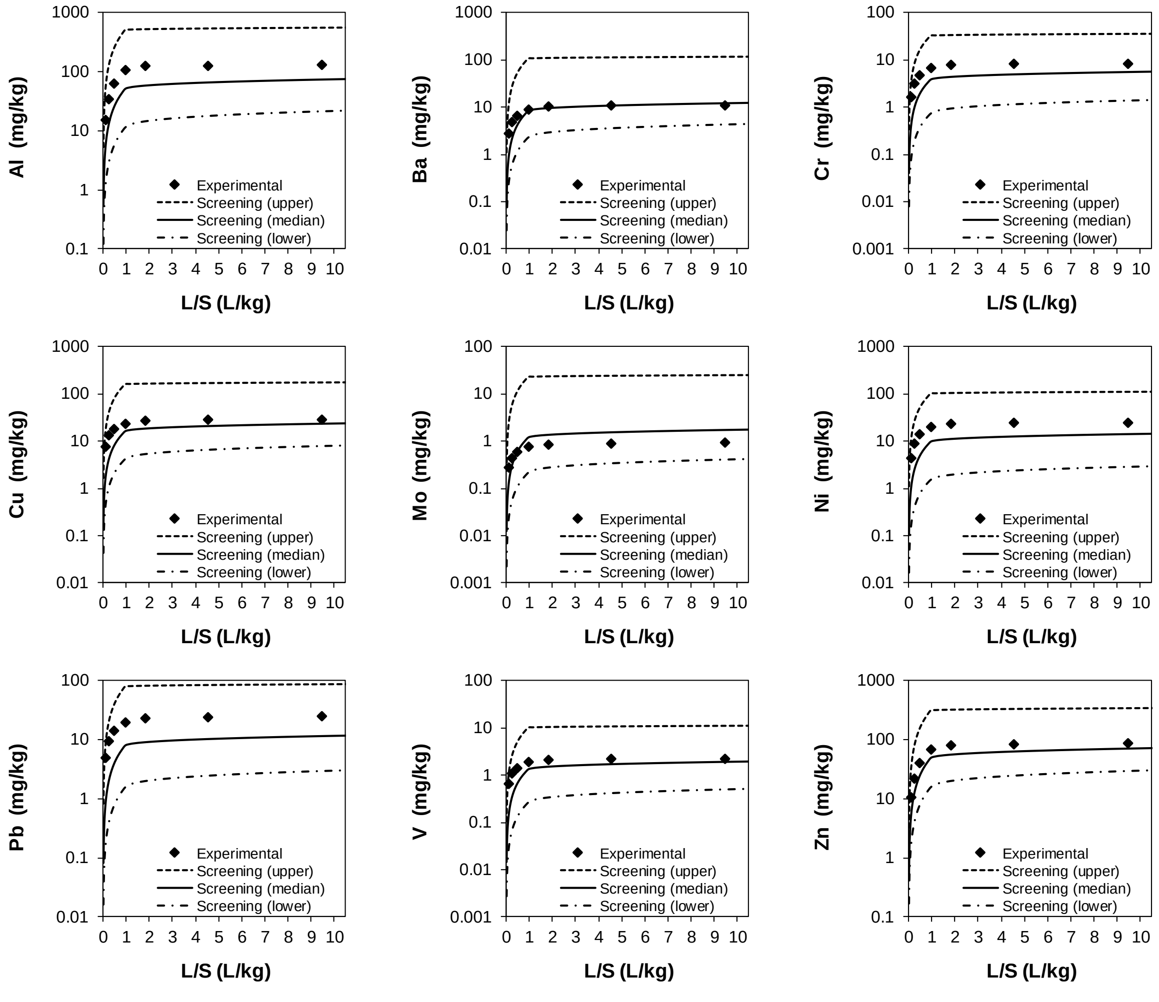

Figure 2. Metal cumulative mass release as a function of the L/S ratio: comparison between measured data (symbols) and predicted values (lines).

4 CONCLUSIONS

The results shown in this work, support our proposal to use TOC as a proxy for metal release, by allowing to anticipate with a relatively good accuracy (within one order of magnitude) the results of percolation column test and hence for evaluating the effective need for more rigorous but more expensive laboratory tests. Future research will be oriented to refine the metal to DOC correlation coefficients in order to possibly reduce the uncertainty associated to the application of the proposed screening tool.

5 REFERENCES

[1] Pantini, S., Verginelli, I., Lombardi, F.: Analysis and modeling of metals release from MBT wastes through batch and up-flow column tests. Waste Manag. 38, 22–32 (2015). doi:10.1016/j.wasman.2014.12.002

[2] Lornage, R., Redon, E., Lagier, T., Hébé, I., Carré, J.: Performance of a low cost MBT prior to landfilling: Study of the biological treatment of size reduced MSW without mechanical sorting. Waste Manag. 27, 1755–1764 (2007). doi:10.1016/j.wasman.2006.10.018

[3] Pan, J., Voulvoulis, N.: The role of mechanical and biological treatment in reducing methane emissions from landfill disposal of municipal solid waste in the United Kingdom. J. Air Waste Manag. Assoc. 57, 155–163 (2007). doi:10.1080/10473289.2007.10465317

[4] Abdullahi, Y.A., Akunna, J.C., White, N.A., Hallett, P.D., Wheatley, R.: Investigating the effects of anaerobic and aerobic post-treatment on quality and stability of organic fraction of municipal solid waste as soil amendment. Bioresour. Technol. 99, 8631–8636 (2008). doi:10.1016/j.biortech.2008.04.027

[5] Adani, F., Tambone, F., Gotti, A.: Biostabilization of municipal solid waste. Waste Manag. 24, 775–783 (2004). doi:10.1016/j.wasman.2004.03.007

[6] Di Maria, F., Sordi, A., Micale, C.: Experimental and life cycle assessment analysis of gas emission from mechanically-biologically pretreated waste in a landfill with energy recovery. Waste Manag. 33, 2557–2567 (2013). doi:10.1016/j.wasman.2013.07.011

[7] Farrell, M., Jones, D.L.: Critical evaluation of municipal solid waste composting and potential compost markets. Bioresour. Technol. 100, 4301–4310 (2009). doi:10.1016/j.biortech.2009.04.029

[8] Montejo, C., Ramos, P., Costa, C., Márquez, M.C.: Analysis of the presence of improper materials in the composting process performed in ten MBT plants. Bioresour. Technol. 101, 8267–8272 (2010). doi:10.1016/j.biortech.2010.06.024

[9] Di Lonardo, M.C., Lombardi, F., Gavasci, R.: Quality evaluation and improvement of mechanically–biologically treated municipal solid waste in view of a possible recovery. Int. J. Environ. Sci. Technol. 12, 3243–3254 (2015). doi:10.1007/s13762-014-0735-4

[10] Farrell, M., Jones, D.L.: Use of composts in the remediation of heavy metal contaminated soil. J. Hazard. Mater. 175, 575–582 (2010). doi:10.1016/j.jhazmat.2009.10.044

[11] Angermeier, R., Tintner, J., Smidt, E., Ottner, R., Matiasch, L., Binner, E., Boehm, K.: Development of Mechanically Biologically Treated Municipal Solid Waste under Different Vegetation Types. J. Environ. Eng. 137, 340–346 (2011). doi:10.1061/(ASCE)EE.1943-7870.0000336

[12] Lou, X.F., Nair, J.: The impact of landfilling and composting on greenhouse gas emissions - A review. Bioresour. Technol. 100, 3792–3798 (2009). doi:10.1016/j.biortech.2008.12.006

[13] van Praagh, M., Heerenklage, J., Smidt, E., Modin, H., Stegmann, R., Persson, K.M.: Potential emissions from two mechanically-biologically pretreated (MBT) wastes. Waste Manag. 29, 859–868 (2009). doi:10.1016/j.wasman.2008.06.028

[14] Siddiqui, A.A., Richards, D.J., Powrie, W.: Biodegradation and flushing of MBT wastes. Waste Manag. 33, 2257–2266 (2013). doi:10.1016/j.wasman.2013.07.024

[15] Pantini, S., Verginelli, I., Lombardi, F., Scheutz, C., Kjeldsen, P.: Assessment of biogas production from MBT waste under different operating conditions. Waste Manag. 43, 37–49 (2015). doi:10.1016/j.wasman.2015.06.019

[16] Ponsá, S., Gea, T., Alerm, L., Cerezo, J., Sánchez, A.: Comparison of aerobic and anaerobic stability indices through a MSW biological treatment process. Waste Manag. 28, 2735–2742 (2008). doi:10.1016/j.wasman.2007.12.002

[17] De Gioannis, G., Muntoni, A., Cappai, G., Milia, S.: Landfill gas generation after mechanical biological treatment of municipal solid waste. Estimation of gas generation rate constants. Waste Manag. 29, 1026–1034 (2009). doi:10.1016/j.wasman.2008.08.016

[18] Bayard, R., de Araújo Morais, J., Ducom, G., Achour, F., Rouez, M., Gourdon, R., Bayard, R., Gourdon, R., de Araújo Morais, J., Achour, F.: Assessment of the effectiveness of an industrial unit of mechanical–biological treatment of municipal solid waste. J. Hazard. Mater. 175, 23–32 (2010). doi:10.1016/j.jhazmat.2009.10.049

[19] Siddiqui, A.A., Richards, D.J., Powrie, W.: Investigations into the landfill behaviour of pretreated wastes. Waste Manag. 32, 1420–1426 (2012). doi:10.1016/j.wasman.2012.03.016

[20] Van Der Sloot, H., Comans, R.N.J., Meeussen, J.C.L.: Leaching Methods for Soil , Sludge and Treated Biowaste. ECN Environ. Risk Assessmen. 73 (2003)

[21] Grathwohl, P., Susset, B.: Comparison of percolation to batch and sequential leaching tests: Theory and data. Waste Manag. 30, 1746–1747 (2010). doi:10.1016/j.wasman.2009.12.022

[22] Lombardi, F., Chiara, D.L.M., Lieto, A., Sirini, P.: Investigating the leaching properties of MBT wastes and composts from aerobic/anaerobic processes. Ambient. e Agua - An Interdiscip. J. Appl. Sci. 13, 1 (2018). doi:10.4136/ambi-agua.2160

[23] Cossu, R., Lai, T.: Washing of waste prior to landfilling. Waste Manag. 32, 869–878 (2012). doi:10.1016/j.wasman.2011.12.005

[24] López, A., García, M., Esteban-García, A.L., Cuartas, M., Molleda, A., Lobo, A.: Emissions from mechanically biologically treated waste landfills at field scale. Int. J. Environ. Sci. Technol. 15, 1285–1300 (2018). doi:10.1007/s13762-017-1497-6

[25] Salati, S., Scaglia, B., Di Gregorio, A., Carrera, A., Adani, F.: The use of the dynamic respiration index to predict the potential MSW-leachate impacts after short term mechanical biological treatment. Bioresour. Technol. 128, 351–358 (2013). doi:10.1016/j.biortech.2012.10.101

[26] Lieto, A., Zingaretti, D., Lombardi, F., Gavasci, R.: Effect of a Further Maturation Phase on the Chemical and Environmental Properties of a Bio-stabilised Waste from a Mechanical–Biological Treatment Plant. Waste and Biomass Valorization. (2019). doi:10.1007/s12649-019-00672-3