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Research article

Characterization of selected municipal solid waste components to estimate their biodegradability

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A B S T R A C T

Biological treatments of Residual Municipal Solid Waste (RMSW) allow to divert biodegradable materials from landfilling and recover valuable alternative resources. The biodegradability of the waste components needs however to be assessed in order to design the bioprocesses properly. The present study investigated complementary approaches to aerobic and anaerobic biotests for a more rapid evaluation. A representative sample of residual MSW was collected from a Mechanical Biological Treatment (MBT) plant and sorted out into 13 fractions according to the French standard procedure MODECOM™. The different fractions were analyzed for organic matter content, leaching behavior, contents in biochemical constituents (determined by Van Soest's acid detergent fiber method), Biochemical Oxygen Demand (BOD) and Bio-Methane Potential (BMP). Experimental data were statistically treated by Principal Components Analysis (PCA). Cumulative oxygen consumption from BOD tests and cumulative methane production from BMP tests were found to be positively correlated in all waste fractions. No correlation was observed between the results from BOD or BMP bioassays and the contents in cellulose-like, hemicelluloses-like or labile organic compounds. No correlation was observed either with the results from leaching tests (Soluble COD). The contents in lignin-like compounds, evaluated as the non-extracted RES fraction in Van Soest's method, was found however to impact negatively the biodegradability assessed by BOD or BMP tests. Since cellulose, hemicelluloses and lignin are the polymers responsible for the structuration of lignocellulosic complexes, it was concluded that the structural organization of the organic matter in the different waste fractions was more determinant on biodegradability than the respective contents in individual biopolymers.

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1. Introduction

Various management strategies have been developed in Europe to reduce Municipal Solid Waste (MSW) landfilling and promote selective material recycling and/or energy recovery, under the incentives of EU Council Directive 99/31/EC (Slack et al., 2005). Mechanical and Biological Treatments (MBT) of Residual MSW (RMSW) have been implemented as one of the options to achieve these targets. MBTs consist in mechanical pre-processing stages followed by biological stages meant to reduce and stabilize biodegradable matter under controlled anaerobic and/or aerobic conditions (Heerenklage and Stegmann, 1995; Scheelhaase and Bidlingmaier, 1997).

Characterization of RMSW is needed for the development and proper design of efficient waste management processes such as MBTs (Wagland et al., 2009). Bioassays are useful tools to assess experimentally the biodegradability of waste materials, which is a key parameter to design, operate and monitor MBTs or other types of bioprocesses (Cossu and Raga, 2008; Böhm et al., 2010). Several procedures have been proposed, both relative to the experimental conditions of the tests and the modes of expression of the results (Lesteur et al., 2010). They differ from each other on a certain number of key parameters such as aeration (aerobic tests) or absence of di-oxygen (anaerobic tests), nature of the parameters monitored over incubation time, temperature of incubation, reactional volume, nature and proportion of microbial seed (inoculum), mode of preparation of waste samples, water content and mode of agitation, time of incubation. Aerobic test methods are usually based on respirometric techniques involving the measurement of di-oxygen consumption and, if needed, carbon dioxide production under static or dynamic conditions of air supply (Gomez et al., 2006). Anaerobic bioassays are based on the monitoring of biogas

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List of abbreviations

BD_{Aero}	Bioconversion yield in aerobic condition ($\%_{COD}$)
BD_{Anae}	Bioconversion yield in anaerobic condition ($\%_{COD}$)
BOD_{28}	Biological Oxygen Demand on suspended solid in liquid phase. 28 days of incubation ($mg_{O2}.g^{-1}{}_{TS}$)
BMP_{60}	BioMethane Potential on suspended solid in liquid phase. 60 days of incubation ($NmL.g^{-1}{}_{TS}$)
CELL	Cellulose ($\%_{VS}$)
DRI	Dynamic Respiration Index
GB	German and Austrian incubation test using ground sample to < 10 mm with 300 mL with water (Austrian test performed with sieved sample and sludge for inoculation)
GS	Austrian incubation test using moist fresh sample saturated to water-holding capacity and incubated at 40 °C under anaerobic conditions
HEM	Hemicelluloses ($\%_{VS}$)
MBT	Mechanical biological treatment
MSW	municipal solid wastes
PCA	Principal Component Analysis
RES	lignin-like, non-soluble residual fraction not extracted in the Van Soest's procedure
RMSW	residual municipal solid waste
SCOD	Chemical Oxygen Demand on leachate collected from leaching test (L/S ratio = 10, contact time 3 h) on solid material after filtration at 0.45 μm ($mg_{O2}.g^{-1}{}_{TS}$)
SL	Soluble fraction ($\%_{VS}$)
SRI	Static Respiration Index
TCOD	Total Chemical Oxygen Demand on Solid material ($mg_{O2}.g^{-1}{}_{TS}$)
TS	Total solid ($\%_{wS}$)
VS	volatile solid ($\%_{TS}$)
wS	wet solid

or methane production over incubation time under controlled conditions of incubation Good correlations have been reported between biodegradability results obtained from aerobic and anaerobic bioassays (Godley et al., 2004; Cossu and Raga, 2008; Ponsá et al., 2008; Barrena et al., 2009; Wagland et al., 2009; Scaglia et al., 2010). However, strong variations are usually observed from one lab to another on a given type of biowaste (Binner et al., 2007; Holliger et al., 2016) because of the difficulty to control precisely and continuously many parameters of influence such as moisture, pH, compaction, physiological state of inoculum, etc.

Several anaerobic bioassays have been standardized, such as the Austrian and German tests GS_{21} and GB_{21} and the generic BioMethane Potential test BMP (Wagland et al., 2009). Under aerobic conditions, standard protocols include Static Respiration Index (SRI), Dynamic Respiration Index (DRI), and the Specific Oxygen Uptake Rate (SOUR) (Komilis and Ham, 2000; Ponsá et al., 2008; Barrena et al., 2009; Bayard et al., 2010; Scaglia et al., 2010). No standard method is available however for solid waste at the European level.

Whether standardized or not, bioassays remain relatively difficult to conduct under reproducible and reliable conditions, and may be quite time-consuming. As an alternative to experimental bioassays, quantitative and qualitative analyses of organic matter from waste materials may be conducted to provide information regarding their potential biodegradability. Although more rapid than bioassays, chemical or biochemical analyses demand however careful sampling operations and well adapted protocols and equipment. Furthermore, a number of analytical parameters are usually needed to allow reliable assessment of solid waste biodegradability (Wagland et al., 2009). Several studies have reported the development of complementary analyses to assess the potential biodegradability of heterogeneous waste and/or their "biostability" (Komilis and Ham, 2003; Ponsá et al., 2008; Barrena et al., 2009; Bayard et al., 2010). Most of them include the quantitative determination of organic matter contents using a variety of analytical parameters such as Volatile Solid (VS) content, Total Organic Carbon (TOC) content, Chemical Oxygen Demand (COD), or water-extractable dissolved organic carbon (DOC) (Godley et al., 2004). Biodegradability of waste materials however not only depends on their contents in organic matter, but also on the nature and composition of their organic constituents. Further (bio)chemical methods are therefore needed to assess the organic constituents qualitatively. Sequential extractions procedures such as Van Soest's method (Van Soest and Wine, 1967) or NREL Laboratory Analytical Procedure (Sluiter et al., 2008) are often cited as good methods to quantity soluble fraction, hemicelluloses-like, cellulose-like and lignin-like compounds in biomass resources and biowaste materials.

Many studies have also investigated the relationships between the quantitative and qualitative characteristics of waste and biomass materials and the results obtained from aerobic and anaerobic bioassays (Chandler et al., 1980; Eleazer et al., 1997; Komilis and Ham, 2003; Gunaseelan, 2004; Buffiere et al., 2006; Liu et al., 2015). However, to our knowledge no published work on complex materials such as RMSW and its constitutive fractions has yet been publish to identify a limited number of variables which could provide a reliable evaluation of biodegradability. In a previous article, Bayard et al. (2016) suggested that the chemical composition of complex heterogeneous organic waste materials was not the determinant factor of their biodegradability.

The objective of the present study was to investigate whether correlations could be observed in selected fractions constitutive of Residual Municipal Solid Waste between the results obtained from different procedures of characterization aiming at the determination of their biodegradability. Biochemical Oxygen Demand (BOD) and anaerobic BMP bioassays were conducted on aqueous suspensions of crushed solid waste materials obtained from each fraction. Different complementary protocols were used for quantitative and qualitative analysis of organic matter, including leaching tests, soluble fraction, hemicelluloses-like, cellulose-like and lignin-like components. The whole set of experimental data was statistically analyzed by Principal Components Analysis (PCA) to identify the possible correlation between the variables and parameters.

2. Materials and methods

2.1. RMSW collection and sample preparation

A representative sample of 500 kg of RMSW was collected from a MBT plant located in the south east of France according to the French standard procedure MODECOM™ (ADEME, 1993; AFNOR NF X30-408, 2013). The wet sample was immediately taken to the laboratory where it was sorted out into 13 different categories of materials (or waste fractions) following the same standard

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