ARTICLE IN PRESS

Bioresource Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Application of advanced techniques for the assessment of bio-stability of biowaste-derived residues: A minireview

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HIGHLIGHTS

- Conventional and advanced methods for bio-stability assessment are reviewed.
- Conventional methods are re-classification based on the essence of organic matter.
- Advanced methods are discussed for their principles, advantages and disadvantages.
- Effectiveness of advanced methods depends on the explanation by conventional ones.
- Conventional methods are indispensable even advanced ones are extensively studied.

ARTICLE INFO

Article history:
Received 28 April 2017
Received in revised form 7 June 2017
Accepted 8 June 2017
Available online xxxx

Keywords:
Maturity
End-of-waste
Biostabilization
Pyrolysis
Landfill

ABSTRACT

Bio-stability is a key feature for the utilization and final disposal of biowaste-derived residues, such as aerobic compost or vermicompost of food waste, bio-dried waste, anaerobic digestate or landfilled waste. The present paper reviews conventional methods and advanced techniques used for the assessment of bio-stability. The conventional methods are reclassified into two categories. Advanced techniques, including spectroscopic (fluorescent, ultraviolet–visible, infrared, Raman, nuclear magnetic resonance), thermogravimetric and thermochemolysis analysis, are emphasized for their application in bio-stability assessment in recent years. Their principles, pros and cons are critically discussed. These advanced techniques are found to be convenient in sample preparation and to supply diversified information. However, the viability of these techniques as potential indicators for bio-stability assessment ultimately lies in the establishment of the relationship of advanced ones with the conventional methods, especially with the methods based on biotic response. Furthermore, some misuses in data explanation should be noted.

Contents

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http://dx.doi.org/10.1016/j.biortech.2017.06.045
0960-8524/

Please cite this article in press as: Lü, F., et al. Application of advanced techniques for the assessment of bio-stability of biowaste-derived residues: A minireview. Bioresour. Technol. (2017), http://dx.doi.org/10.1016/j.biortech.2017.06.045

1. Introduction

The term "bio-stability" refers to the resistance of organic matter to further decomposition by organisms (mainly by microorganisms), and therefore, differs from physical or chemical "stability" resistant to mechanical abrasion or chemical reaction. On one hand, bio-stability, is related to mineralization or biodegradability, i.e., the decomposition of biodegradable organic matter (e.g., easily biodegradable starch, proteins and lipids; recalcitrantly biodegradable cellulose, hemicellulose, lignin, pectin, keratin and collagen). On the other hand, it is related to humification, i.e., the generation of recalcitrantly biodegradable humus or humus-like substances (e.g. humic acid, fulvic acid, humin) accompanied with the enhanced humification degree (e.g. the increased aromaticity and molecular weight).

Bio-stability is a key feature for the utilization and final disposal of biowaste-derived residues, such as compost and vermicompost of food waste, source-selected organic fraction of municipal solid waste (OFMSW), livestock manure, lignocellulosic straw, sugarcane vinasse, olive mill waste, as well as fiber digestate from anaerobic digestion of biowaste, or residues from mechanical biological treatment (MBT) or biodrying of mixed municipal solid waste (MSW) prior to landfilling, or landfilled waste for the purpose of post-closure care, remediation or landfill mining. The reason lies in that bio-stability is usually associated with the pollution potential of these biowaste-derived residues. Unstable residues are inclined to present higher level of leachate generation or odor emission. As indicated in Shao et al. (2009), aerobic respiration activity for four days (AT_4) had a positive linear relationship with the concentration of dissolved organic carbon (DOC) in the water exactable organic matter (WEOM) of biodried MSW, where DOC implied the pollution potential from leachate generation. Similarly, AT_4 had a positive relationship with the concentration of gaseous pollutants (including ammonia, hydrogen sulfide, ketones, terpenes, carbonyls, alcohols, aromatics, reduced sulfur compounds, and volatile fatty acids) of MSW compost (He et al., 2012; Shao et al., 2012). Meanwhile, since bio-stability is related to the generation of humic substance, it is somewhat interchangeably used with the term "maturity", which refers to the influence of a material when applied as plant-growing media (Wichuk and McCartney, 2013). Furthermore, bio-stability of waste is also associated with the mechanical property of waste which is important for the geotechnical stability of waste treatment facility (Chen et al., 2014; Zhan et al., 2017). Therefore, several countries set bio-stability requirements in the regulations of compost quality or landfill acceptance criteria (Saveyn and Eder, 2014).

Several methods are proposed to assess the bio-stability of biowaste-derived residues. Some of them are widely acknowledged and applied. Readers can find detailed information on these classic approaches in the reviews by Bernal et al. (2009), Wichuk and McCartney (2013). Whereas, in recent years, the application of advanced techniques appear to evaluate the stability or maturity, mainly including spectroscopic (ultraviolet–visible, fluorescent, infrared, nuclear magnetic resonance and Raman), thermogravimetric and thermochemolysis analysis. The present review would focus on these advancement and discuss their relationship with the conventional assessment methods.

2. Conventional methods for bio-stability assessment

A re-classification and summary of the methods conventionally used for bio-stability assessment is listed in Table 1. Compared with the traditional classification according to physical, chemical and biological properties, these methods are now re-classified oriented to two aspects: one is based on the biotic response to the tested materials, the other is based on the physio-chemical characteristics of the organic matters contained in the tested materials.

2.1. Methods oriented to the biotic responses

Microbial activity is directly associated with the content and the bioavailability of organic matter, and therefore is extensively applied. Microbial activity can be evaluated according to the rate or amount of oxygen uptake/consumption or carbon dioxide production, or the temperature increment level owing to aerobic respiration of biodegradable organic matter, or the methane production under anaerobic environment. Different testing conditions and data reporting formats lead to a series of indices. For aerobic respiration, there are static respiration indices without aeration, including Respiration Activity (RA) or Atmungsaktivität (AT), Oxygen Uptake Rate (OUR) or Specific Oxygen Uptake Rate (SOUR), Respiration Index (RI), Dewar self-heating index, Solvita@ CO_2 index (Hill et al., 2013; Khan et al., 2014), as well as Dynamic Respiration Index (DRI) with continuous aeration involving ORG0020, DR_4 and Respiration Quotient (RQ). For anaerobic methanization, Biochemical Methane Potential (BMP) test is conducted, and the results are reported as Gas Generation Sum (GS) or Gas Evolution ("Gasbildung", GB). Determination of these indices usually needs to carefully consider the effects of temperature (Komilis and Kletsas, 2012), sample amount (Komilis and Kletsas, 2012), sample size (Komilis and Kanellos, 2012), static or dynamic (Aspray et al., 2015; Binner et al., 2012; Scaglia et al., 2000), aeration mode of being constant or adjustable (Almeira et al., 2015), air flow rate (Almeira et al., 2015; Komilis and Kanellos, 2012), water content, inoculum (Aspray et al., 2015), nutrients (Aspray et al., 2015), nitrification inhibitor (Aspray et al., 2015), lag phase of bio-reaction, data calculation methods by rate or cumulative amount (Barrena et al., 2009; Sánchez et al., 2012), etc. Aspray et al. (2015) compared the bio-stability tests through ORG0020, DR_4, RQ, OUR, RA and Dewar self-heating. They found strong correlation coefficients for ORG0020, DR_4 and OUR, and dynamic respiration tests were superior to static ones owing to be suited to deal with wide range of tested samples; Comparatively, static respiration tests were unsuitable for highly active or low pH samples. Binner et al. (2012) measured AT_4 parallels by Sapromat@ instrument without oxygen limitation and OxiTop@ instrument; They manifested strong correlation between two methods, nevertheless, OxiTop@ gave only around 88% of values of those obtained from Sapromat@. Sánchez et al. (2012) also observed a good linear correlation between RI_{24} and AT_4, but their values might indicate