Journal of Cleaner Production 121 (2016) 169–175

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A sewage sludge co-composting process using respirometric monitoring method in hermetic rotary reactor

Edvaldo José Scoton [a,*], Rosane Aparecida Gomes Battistelle [a], Barbara Stolte Bezerra [a], Jorge Akutsu [b]

[a] UNESP – Univ. Estadual Paulista, Faculty of Engineering, Bauru Campus, Brazil
[b] Universidade Federal de São Carlos UFSCar, Brazil

ARTICLE INFO

Article history:
Received 29 August 2014
Received in revised form
3 April 2015
Accepted 20 April 2015
Available online 30 April 2015

Keywords:
Sewage sludge
Solid organic residues
Composting
Respirometric method
Rotary reactor

ABSTRACT

This paper has the objective of monitoring the biological activity of composting process of sewage sludge, sugarcane bagasse and ground coffee in a hermetic rotary reactor using the respirometric method in laboratory scale, in order to obtain parameters and system design for large scale projects. Another particularity of this study is the use of a hermetic reactor with gas purging cycles. Purging was performed when the percentage of oxygen reached less than 5%, thus eliminating the gaseous mixture (with elevated CO_2 ratio) and the introduction of environmental air with around 21% of O_2, successively until the compost was stabilized. The average purge intervals obtained were 29 h and 2 min with reactor rotation frequency of 15 min. The time of the compost stabilization was optimized in 60% if compared to the 90 days in the traditional method. The results obtained can be used to design the process in industrial scale using a simple O_2 gas analyzer.

1. Introduction

Nowadays society is urging for better environmental conditions, thus increasing the demand for wastewater treatment services. As a consequence, there is a greater quantity of sewage sludge that needs to be managed and disposed (Agrawal and Singhand, 2007). Managing such volume of sewage sludge in compliance with environmental regulations is not an easy task (Khiari et al., 2008; Rodríguez et al., 2012), especially because the adequate disposal and treatment of sewage sludge can be costly. The conventional final disposition of sewage sludge which consists of simply throwing it away on the ground or in the sea has been forbidden or become restricted due to recrudescence of legislations worldwide (Rodriguez et al., 2013). Nonetheless, incineration and landfills continue to be the main forms of final disposal. One way of properly disposing of sewage sludge is by composting; in European Union countries it has been estimated that approximately 36% of the sewage sludge is recycled through composting (Righi et al., 2013; Hamoda et al., 1998).

The definition of composting is associated to the process of aerobic decomposition of organic matter such as leaves, food remains, paper and manure that is performed by microorganisms. Under controlled conditions, these microorganisms convert organic matter into a stable product similar to humus (Adani et al., 2004). Thus, it is possible to compost organic residues with sewage sludge. As reported by Barrena et al. (2011), composting is considered a more sustainable alternative when compared to sanitary landfills and the incineration of food remains, but only 4% of the 20.8 million tons of urban solid waste were recovered in the USA for composting (SAER et al., 2013). In Brazil, in accordance with the National Plan of Solid Waste (2012), from the estimated total of organic residues that are collected (94,335.10 t/d), only 1.6% (1509 t/d) is used for composting.

One important point of interest is the conversion of treatment facilities into resource recovery facilities (Nakakubo et al., 2012). In fact, the processes of composting sewage sludge and organic residues into a viable compost, can generate economical benefits that can reduce the cost of treatment and the pressure on natural resources. This final sub-product may be destined to agricultural use, consequently improving the soil's physical characteristics by increasing its permeability, retaining water and nutrients in sandy soils, and enabling a larger concentration of essential nutrients (Chiba et al., 2008; Galka, 2004; Ponsa et al., 2009).

* Corresponding author. Av. Eng. Luiz Edmundo Carrijo Coube, n° 14-01, Vargem Limpa, CEP 17.033-360, Bauru, São Paulo, Brazil. Tel.: +55 14 997 936 886.
E-mail address: scoton@hotmail.com (E.J. Scoton).

http://dx.doi.org/10.1016/j.jclepro.2015.04.081

Despite the researches already carried out on composting, there are limited papers addressing sewage sludge. Consequently, it is necessary to understand the composting process for this residue (Kalamdhad et al., 2008; Rodríguez et al., 2012). As stated in Petiot (2004), additional researches are necessary to extend our knowledge on this process, especially when it comes to compost stabilization time, the technology and the types of residues to be used. The majority of the studies that have been carried out used traditional technologies, such as windrows and static piles. Rotary reactors have been pointed out as a promising technology for composting process, inasmuch as they offer many advantages, namely: aeration, compost homogeneity, no production of odors and no percolation of leachate into the soil during the process (Kalamdhad et al., 2008; Klemes et al., 2012).

As reported by Ponsa et al., 2009, the desired stability level in a composting process is what determines the several parameters for controlling and designing the system, such as the aeration rate and the time of treatment required for each type of organic residue. In composting processes in which there is a predominance of aerobic bacteria activities, both the quantification of the oxygen (O_2) consumption rate and the temporal carbon dioxide (CO_2) generation rate, may be performed in a controlled environment using a reactor, which is known as the respirometric method (Getahun et al., 2012; Rodriguez et al., 2012; Fang et al., 1999; Gea et al., 2004; Scaglia et al., 2005). In such method, the biological degradation parameters of organic residues are measured at the gaseous stage, thus ensuring the homogeneity of the results in real time, which demonstrates to be a superior assessment tool than the traditional composting process (Gea et al., 2004; Rodriguez et al., 2012), that is basically restricted to analyzing the temperature that is randomly gauged in a heterogeneous environment at weekly intervals.

Among the various tested indices, the oxygen consumption rate (also called the dynamic respirometric index) has provided the most reliable values for the evaluation of microbial activity in a composting environment. Experiments performed by Tremier et al. (2005) using the respirometric method studied the kinetics of biological reactions involved in the treatment of organic waste and sludge mixed with pine bark. The rates of oxygen consumption of such mixture were monitored for 10–20 days maintained at constant temperature and humidity. The influence of temperature on the kinetics was tested. The results showed that the respirometric method is a useful tool for the characterization of biodegradability of the solid matter and for modeling the biological kinetics of the composting process.

As mentioned by Kalamdhad et al. (2008) most of the literature about respiration indices on composting stability refers to traditional composting techniques and more researches are needed to evaluate the stability of compost using respirometric method in a rotary reactor. Kalamdhad et al. (2008) also evaluated the composting of cattle manure, grass cuttings, food waste cooked, vegetable waste, saw dust, manure with four different C/N ratios, where the reactor was rotated manually four times per day. In addition, to date it is scarce literature about sewage sludge stabilization monitored by the respirometric method (Ponsa et al., 2009).

In this way, this research is a pilot study that has the purpose of follow-up an operational control methodology for composting process using sewage sludge, and organic residues of sugarcane bagasse and ground coffee using a rotary hermetic reactor and the respirometric method in a laboratory scale. The results obtained in this research can be used to establish parameters and system designs for this type of composting residues and that could then be implemented in industrial scale (with less sophisticated equipments for control the composting process).

2. Materials and methods

The method employed was the respirometric, which is a procedure that measures speed, oxygen consumption rate and the rate of gaseous sub-product generation deriving from the active biomass respiratory activity (biological degradation) of an organic substrate performed on liquid or gaseous means (Lasaridi and Stentiford, 1998; Scaglia et al., , 2005; Guardia et al., 2008; Rodriguez et al., 2012).

The experiments were conducted at the facilities of the Solid Residue Laboratory of the School of Engineering of UNESP – Bauru Campus. The following equipments were developed for the experimental analysis of composting: a 90-liter rotary reactor mounted inside a closed box with double-glass walls (to minimize variation in temperature); a gas analyzer; a microcomputer; and the rotation control for the reactor, set for four rotations per hour (Fig. 1).

The reactor was connected to two air pumps, one intended to feed the reactor with O_2 and the other intended to purge the air when the oxygen level reaches less than 5% inside the reactor. Connected to the recirculation line (air pumps) is a gas analyzer manufactured by Sick Maihak model S710, which has a display and registers the concentration values of the gases in terms of percentages (%O_2 and %CO_2). This equipment has a serial communication interface that sends data online to a computer in the format of string in an alphanumeric character sequence, and data is recorded at 1 s–600 s intervals. This software was developed at the Computer Department of UNESP Bauru Campus. Fig. 2 shows the diagram of the composting experiment.

This software also controls a hardware mechanism that allows to inject the desired and previously established concentration of air inside the reactor to be consumed by the bacteria involved in the degradation of the residues. Oxygen levels between 5% and 21% were used in this research (Akutsu et al., 2009). The composting process was analyzed according to the time required for O_2 to reach 5% inside the reactor, considering that at the beginning of the process this concentration was approximately 21% of the total gaseous mixture, i.e. O_2 is consumed. Reaching a percentage lower than 5%, the system automatically performs the purging, that is the elimination of a gaseous mixture inside the reactor (with elevated CO_2 concentration) and introduces environmental air at the ratio of approximately 21% of O_2, in successive ways until the compost is stabilized.

Fig. 1. Structure of the composting experiments that, basically, comprise a rotary reactor, a gas analyzer and a microcomputer to retrieve data.