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Effect of initial physical characteristics on sludge compost performance

Anne Trémier [a,b,*], Cécile Teglia [a,b], Suzelle Barrington [c]

[a] Cemagref, UR GERE, 17 Avenue de Cucillé, CS 64427, F-35044 Rennes Cedex, France
[b] Université Européenne de Bretagne, F-35000 Rennes, France
[c] Macdonald Campus of McGill University, 21 111 Lakeshore, Ste Anne de Bellevue, Canada H9X 3V9

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ABSTRACT

To develop an active microbial activity quickly developing stabilizing thermophilic temperatures during the composting of wastewater sludge, the bulking agent (BA) plays a major role in establishing the recipe structure, exposed particle surface area and porosity. To optimize the biodegradation of a sludge compost recipe, the objective of this paper was to study the effect and interaction of initial moisture content (MC) and BA particle size distribution. Three 300 L insulated laboratory composters were used to treat two series of ten (10) recipes with different combinations of MC and BA particle size distribution. Using a wastewater sludge to BA dry mass ratio of 1/6, the ten (10) recipes were repeated using two BA, residues recycled from a commercial sludge composting plant and crushed wood pallets. Each four week trial monitored O_2 uptake, temperature, compost consolidation and airflow distribution. The Central Composite Factor Design method produced a model from the results estimating the impact of a wider range of MC and BA particles size distribution. The MC directly affected the total O_2 uptake and therefore, organic matter biodegradation. The BA particle size distribution influenced compost consolidation with a MC crossed effect. Both BA particle size distribution and MC influenced compost airflow dispersion. Composting was optimized using the BA consisting of recycled green waste residues with particle size of 20–30 mm and a 55% MC. The predictive models suggested the need for further optimization of sludge and wood residue composting recipe.

1. Introduction

The European Community is advocating principles of prevention, recycling and reuse to reduce the environmental and social issues associated with the landfilling of organic wastes (Parlement Européen Conseil, 2006). In this context, biological treatments such as composting are promoted to transform organic wastes into soil amendments. Nevertheless and for wastewater sludge, environmental advantages must be demonstrated to justify expensive composting infrastructures. The quality of the finished product requires stabilization and sanitization, components highly dependent on microbial activity especially at the onset of the process (Miller, 1991).

Optimal aerobic microbial activity is developed as a result of three main conditions: (1) accessible biodegradable organic matter; (2) aerobic conditions maintained throughout the mass, and; (3) chemical and physical conditions conducive to microbial development, such as optimal pH, C:N ratio, moisture content (MC) and temperature. The compost recipe must be formulated based on the properties of the waste to be treated such as: its biodegradability, particle size exposing a specific surface area and porosity; the nature of the aeration system, namely static, passive or dynamic, and; the turning frequency of the compost (Barrington et al., 2002). A specific composting process is influenced by the nature of the treated waste, and specifically its physical characteristics (Agnew and Leonard, 2003).

Numerous studies have measured the biodegradable potential of organic wastes through chemical or biochemical measurements, but few have investigated the effect of physical parameters on the biodegradability of the compost material. Physical characteristics play a major role in determining O_2 distribution and microbial access to biodegradable organic matter. Based on their impact, the physical characteristics of compost can be classified into five (5) categories: moisture content (MC); density; particle size distribution; air porosity, and; air distribution throughout the compost (Agnew and Leonard, 2003). According to Kraft (2002), two more parameters affect gas flux, namely specific surface area of the compost particles and air permeability. Indeed, microbial growth depends on MC because water for example, is a reactant during hydrolysis. Nevertheless, MC must not limit the transfer of gases such as O_2 and CO_2 (Miller, 1991; Aguilar-Juarez, 2000). Compost consolidation influences density and as a consequence, aeration and gas exchanges. Particle size distribution defines the particle

* Corresponding author. Address: Cemagref, UR GERE, 17 Avenue de Cucillé, CS 64427, F-35044 Rennes Cedex, France. Tel.: +33 2 23 48 21 21; fax: +33 2 23 48 21 15.

E-mail address: anne.tremier@cemagref.fr (A. Trémier).

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surface exposed to microbial biodegradation (Mohee and Mudhoo, 2005) and the compost consolidation potential. By acting on permeability, air porosity influences airflow pathways (Veeken et al., 2003) and therefore, biodegradation kinetics through heat and gas transfers (Agnew and Leonard, 2003). Lastly, particle size distribution and air porosity define the tortuosity factor, namely the ratio between real and linear airflow pathways, which impacts the effective dispersion of air (Coulson and Richardson, 1994). For a successful composting process, these physical characteristics must be managed to quickly produce thermophilic temperatures. The MC can be optimized by adding water or a dry bulking agent (BA). Specific surface area and air porosity can be modified by selecting the proper BA particle size distribution and waste to BA ratio.

When composted, wastewater sludge offers no structure and a high MC, thus, requiring a very specific BA particle size distribution and mass ratio. Eftoda and McCartney (2004) studied BA requirements to optimize the free air space (FAS) value of sludge composted with wood chips. Gea et al. (2007) are among the few who studied the individual effect of BA particle size distribution and mass ratio on sludge compost behaviour (O_2 uptake, consolidation and airflow patterns), but the interaction between MC and BA particle size distribution was not investigated.

Therefore, the objective of this project was to study the impact and interaction of initial MC and BA particle size distribution on compost material biodegradability. Two different BA were tested: BA1 consisting of green wastes recycled from a commercial sludge composting plant, and; BA2 consisting of crushed wood pallets. The study was conducted using three laboratory composters, each with a 300 L working volume. The final objective was to optimize the composting of sludge with wood residues, and ensure its complete and fast stabilization.

2. Methods

2.1. Composting reactor and monitoring instruments

The composting of sludge and BA was studied using three pilot reactors (Fig. 1) simulating the active phase of the composting process (De Guardia et al., 2008). Each reactor consisted of an airtight 300 L stainless steel cylindrical chamber with an inside diameter of 0.7 m and a length of 0.8 m. A 50 mm layer of polyurethane insulated the reacting chamber and limited heat losses. Aeration was provided by an air blower introducing air through the bottom plenum of the reactor, at a continuous rate of 550 L h^{-1}. Gas samples were collected for analysis from the top plenum.

Parameters monitored during the experiments were: air flow rate as measured by a volumetric air flow meter (Actaris, France, Gallus G 1.6, Q_{max} of 2.5 $m^3\,h^{-1}$), mass loss using a continuous mass monitoring device (Precia Molern, France) on each reactor, temperature of the compost using Pt 100 temperature probes (TC SA France, thermocouple K), inlet and outlet air temperature and relative humidity (Vaisala, France, HMP 243, 0–100%/0–100%), depth of the compost inside the reactor (manually), and inlet and outlet air stream O_2 concentration using a paramagnetic analyser (Servomex, France, Analyser 4200, 0–25% O_2).

Moreover, the airflow pathway was characterized using a gas tracing method determining the Retention Time Distribution (RTD) and the airflow dispersion coefficient (D') within the reactors (Tremier et al., 2005). Methane was chosen as tracer because of its detection in limited concentrations of less than 50 ppm at the outlet of the reactors and it lack of impact on the microorganisms involved in the composting process. Also, methane offers gas properties similar to those of air and it is easily quantified using an infrared detector. For each RTD measurements, 150 ml of tracer gas (methane) were injected as a pulse into the entering airstream using a 150 ml syringe. The concentration of tracer gas at the reactor airstream exit was monitored every minute using an infrared detector (Servomex, France, Analyser 4200, CH_4 of 0–10%) until its volume was almost completely recovered. The RTD curve ($E(t)$), the mean residence time ($\bar{t}$) and the variance (σ^2) were computed from the measured tracer gas concentration and air stream flow rate (Levenspiel, 1999).

All three compost pilot reactors were used during the study to test each composting recipe for four (4) weeks and the compost material was turned once, early in the third weeks of composting.

2.2. Experimental materials

The experimental dewatered sludge was obtained from an activated sludge reactor treating the wastewaters of a slaughterhouse. The two experimental bulking agents were: BA1 composed of green wastes recycled from a commercial plant composting slaughter house sludge, and; BA2 consisting of crushed wood pallets. As opposed to BA1, BA2 consisted of relatively inert organic matter carrying a limited microbial population adapted to composting. All mixtures composed of BA1 and BA2 were called M1 and M2, respectively. Both M1 and M2 had the same sludge to BA dry mass ratio of 1/6, to compare recipes with the same potential organic matter biodegradability. Thus, composting behaviour for each trial, such as O_2 uptake and loss of mass, was mostly affected by its physical characteristics.

2.3. Experimental design

For composting and to study the influence of the initial MC and BA particle size distribution, the statistical procedure consisted of setting up a Central Composite Factor Design. This design produces a second order polynomial equation or model (Goupy, 1999). Using the two independent variables, namely MC and BA particle size distribution, two series of ten (10) experiments were conducted where, for each series, four (4) experimental points corresponded to a two factors complete factorial design, two (2) points offered central values and four points offered extreme values ($\alpha = 1.414$). Thus, five values were tested for each independent variable: MC in the range of 20–70%, and; BA particle size distribution in the range of 8–>40 mm. For each type of BA, five (5) particle size distributions were obtained using a rotary sieve and then dried. The experimental MC was obtained by either adding water or partially drying the sludge for a few days at 30 °C. Table 1 summarizes the experimental conditions tested using a set of ten (10) trials for each type of BA. To conduct the statistical analysis, the values for both independent variables were normalized (Table 1).

2.4. Statistical analysis

The Central Composite Factor Design uses the following second-order polynomial model to predict the composting behaviour of a large number of combinations for various MC and BA particle size distribution, based on the results obtained from each set of ten (10) experimental trials:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_{12} + \beta_4 x_{11} + \beta_5 x_{22} \quad (1)$$

where y is the predictive response (O_2 uptake; compost consolidation and airflow dispersion), x_1 and x_2 are the normalized independent variables, x_{12} is the interaction between the independent variables, x_{11} and x_{22} are the quadratic interactions of the independent variables and β_i are the model coefficients. Separate models were produced for M1 and M2.

Analysis of variance (ANOVA) determined the significance of the models using the F-test, at a confidence level of 90% ($P < 0.1$).