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An enhanced compost temperature sampling framework: Case study of a covered aerated static pile

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ABSTRACT

Spatial and temporal temperature variations exist in a compost pile. This study demonstrates that systematic temperature sampling of a compost pile, as is widely done, tends to underestimate these variations, which in turn may lead to false conclusions about the sanitary condition of the final product. To address these variations, a proper scheme of temperature sampling needs to be used. A comparison of the results from 21 temperature data loggers randomly introduced into a compost pile with those from 20 systematically introduced data loggers showed that the mean, maximum and minimum temperatures in both methods were very similar in their magnitudes. Overall, greater temperature variation was captured using the random method. In addition, 95% of the probes introduced systematically had attained thermophilic sanitation conditions (⩾55 °C for three consecutive days), as compared to 76% from the group that were randomly introduced. Furthermore, it was found that, from a statistical standpoint, readings from at least 47 randomly introduced temperature loggers are necessary to capture the observed temperature variation. Lastly, the turning of the compost pile was found to increase the chance that any random particle would be exposed to the temperature ⩾55 °C for three consecutive days. One turning was done during the study, and it increased the probability from 76% to nearly 85%. Using the Markov chain model it was calculated that if five turnings had been implemented on the evaluated technology, the likelihood that every particle would experience the required time–temperature condition would be 98%.

1. Introduction

1.1. Background

Composting is an exothermic process (Haug, 1993). To ensure proper inactivation of pathogens during composting, the guidelines and regulations in North America (e.g. CCME, 2005; USEPA, 2003) require every particle of compost to be exposed to ⩾55 °C for at least 3 consecutive days. For in-vessel systems and static piles, it is assumed that the preceding requirement can be achieved by ensuring that (55 °C is maintained for three days throughout the pile, while for windrows this ⩾55 °C temperature should be maintained for at least 15 consecutive days with five pile turnings during that period (Ge et al., 2006; BNQ, 2005; CCME, 2005; USEPA, 2003). However, the guidelines/regulations do not provide explicit tools or guidance on how to ensure that the specified time–temperature criteria (TTC, ⩾55 °C for 3 consecutive days) have been met in any particular technology. More specifically, the regulations do not mention which type of temperature monitoring devices should be used, nor do they say where these devices should be placed within the compost, how many of them should be placed, how often the temperature readings should be taken, and finally how the results from the readings should be reported (Wichuk and McCartney, 2008). As a result, facility operators are free to choose how to ensure temperature compliance. A review of scientific articles that report on compost temperature monitoring lead to the following conclusions about how TTC compliance is evaluated in composting facilities:

- The temperature in composting heaps is mostly monitored with temperature probes (e.g. Fernandes et al., 1994; Jäckel et al., 2005). These are stationary devices equipped with a thermocouple. Probes can vary in size and reading precision. A temperature probe can either come with built in memory or be wired to a recording device (e.g. computer).

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- To obtain a pool of dataset representative of spatial temperature distribution in the pile the temperature probes are introduced at various spots, which are oftentimes selected as the bottom, middle and upper strata of the compost heap (Marešová and Kollárová, 2010; Bhamidimarri and Pandey, 1996; Fischer et al., 1998; Fernandes et al., 1994).
- Since there is no specific protocol in place that recommends how many temperature probes should monitor the spatial temperature distribution, their number varies dramatically. Some researchers have used only a few probes for temperature monitoring (e.g. Bhamidimarri and Pandey, 1996), while others have used up to several dozen (e.g. Fernandes et al., 1994). It is not clear whether the decision on the number of probes is based on cost factors, previous experience, internal quality control standards, or any other decision-making tools.
- Since there is no consensus on how often the temperature readings should be taken to capture temporal temperature variability, the reported frequency of temperature reading typically varies between minutes and hours. While infrequent readings may reduce the data analysis burden to some degree, more frequent readings enable one to more precisely discern temporal variations on any given timescale.
- There is no general consensus on how to interpret a highly time-correlated, auto-correlated nonlinear temperature profile (Yu et al., 2008), and as a result temperature data is reported in different formats. Oftentimes it is presented as a trend over time (e.g. Marešová and Kollárová, 2010; Bhamidimarri and Pandey, 1996). The descriptive statistics which complement the trend line include the maximum and minimum temperatures, overall mean temperature, the day a particular temperature milestone was reached (e.g. 55 °C), time needed to reach this temperature, and the duration of the elevated temperature ($\geqslant$55 °C). As a test of compliance with the TTC, the time (total and consecutive) that the temperature exceeded 55 °C should be reported (e.g. Christensen et al., 2002). The temperature variability due to the temporal and spatial effects is usually given as the range between highest and lowest temperatures recorded (e.g. Deportes et al., 1998; Hess et al., 2004).

Temperature monitoring methods and procedures need to be addressed more thoroughly in order to meet the sanitation requirements and ensure that public safety is not compromised. Ideally, decisions about the number of temperature probes placed in a pile, their location, and the frequency of data collection should be based on science such as:

- The locations of the temperature probes should ensure that, over the course of composting, the full spatial and temporal temperature variation in the pile is likely to be detected. The method should further ensure that the operator's bias is minimized as much as possible. There are numerous statistical techniques available that can help decide how this can be achieved (Cochran, 1977). These techniques enable the development of a cost-, time-, and labor-efficient method to retrieve information and draw conclusions about the studied population without studying every member within that population.
- The number of temperature probes used for any particular composting technology should be based on the observed temperature variability in the system. In all types of large-scale compost systems, the temperature of the pile varies both temporally and spatially. The variability-inducing factors include wind, solar heating, ambient temperature, forced aeration, and/or substrate availability (Turner et al., 2005; McCartney and Eftoda, 2005; Vinneras et al., 2003; Christensen et al., 2002; Fischer et al., 1998; Hay, 1996).
- The frequency of temperature measurements should be such that any temporal variation is well represented in the data. Due to temporal variations, two or three temperature measurements of $\geqslant$55 °C taken a day or two apart, for example, may not necessarily mean that the TTC has been satisfied. The temperature may have fluctuated in between measurements, especially in open systems such as windrows (Strader and Bromhal, 1997).
- The method used to interpret temperature data must be able to demonstrate whether the TTC was satisfied. Mean temperature values from several temperature logging devices that are commonly reported, such as sanitation indicators, are very sensitive to extreme values. The mean also does not reflect the contact time information, as it collapses the time series into a single thermodynamic index (Yu et al., 2008) and hence can be overly misleading. Therefore, the method to estimate sanitary efficacy should take into the account the time effects. Finally, if pile turning is involved, the interpretation method should also be capable of incorporating this into the sanitary efficacy estimations.

1.2. Objectives of the study

The objectives of this study were threefold. The first objective was to compare the results from the traditional systematic temperature sampling approach with the results from random sampling. Of particular interest were: (1) the discrepancy between the two different approaches in statistical information such as central tendency and variance and (2) a comparison of the likelihood of achieving the required TTC using each of the sampling methods. The second objective was to use the gathered information to estimate the number of temperature probes required to capture the observed temperature variability. The final objective was to infer from objectives 1 and 2 the probability of every particle's exposure to temperatures $\geqslant$55 °C for at least 3 consecutive days, while incorporating the effects of pile turning.

2. Materials and methods

2.1. Materials

2.1.1. Compost pile

The study was conducted during the period from August to October 2010 at the Edmonton Waste Management Centre's composting facility (ECF), which uses Covered Aerated Static Pile (CASP[1]) technology to compost biosolids. The feedstock was formed by mixing the biosolids (28% solids concentration) with bulking agents (mixture of aged pallet chips and freshly chipped pallet/wood waste) at a ratio of 2.5 parts bulking agent to 1 part biosolids (by volume) inside a mixing truck fitted with vertical auger. The mixer content was discharged on the composting pad that is sized for sixteen 50 m long active composting piles with the following approximate dimensions: a length of 50 m; a height of 3 m; and a base width of 6 m. About 264 wet tonnes of feedstock material per pile were composted in two back-to-back stages of approximately 30 days each. Once the pile was built, it was covered with a selective membrane tarp At the end of each stage the cover was removed, the material remixed with the front-end-loader and placed on another pad and covered for an additional 30 days. The final placing on a cure site in the form of mass beds (4–5 piles per mass bed) for 6 months with 5 mixings of the curing mass which then takes place and does not require covering was excluded from the study.

Although on average one CASP in the cure site is formed from 22 loads of vertical mixer trucks, the given study was limited to a

[1] CASP stands for the Covered Aerated Static Pile.