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Energy recovery from commercial-scale composting as a novel waste management strategy

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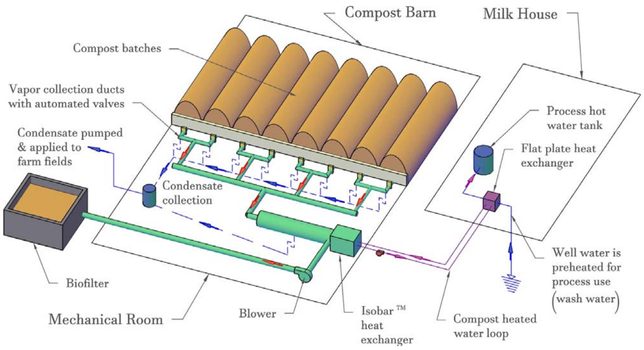
HIGHLIGHTS

- Energy recovery rates from a commercial-scale composting facility are presented.
- Compost vapor between 51 and 66 °C resulted in recovery rates of 17,700–32,940 kJ/h.
- Energy recovery was directly related to compost vapor and heat sink temperatures.
- Temperature lag times between initiation of aeration and system equilibrium existed.
- Temperature lag times warrant unique aeration schedules to maximize energy recovery.

GRAPHICAL ABSTRACT



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ABSTRACT

This study reports operational information from a commercial-scale Aerated Static Pile (ASP) composting system with energy recovery, one of the few currently in operation globally. A description of this innovative system is followed by operational data on energy capture efficiency for 17 experimental trials with variable compost vapor and heat sink temperatures. Energy capture was directly and predictably related to the differential between compost vapor and heat sink temperatures, with energy capture ranging from 17,700 to 32,940 kJ/h with a compost vapor temperature range of 51–66 °C. A 5-day temperature lag time existed between compost pile formation, and when compost vapor temperatures were sufficiently high for energy recovery (≥ 50 °C). The energy recovery system also exhibited a time lag between the initiation of aeration and when the vapor reaching the heat exchanger reached pile vapor temperature. Consequently, future ASP composting sites employing an energy recovery system may have to alter aeration system design and schedules to compensate for any type of heating-up phase that reduces energy recovery.

1. Introduction

Industrial-scale composting is growing rapidly in the United States, due to increased restrictions on the disposal of organic waste in landfills [1]. This, combined with concerns regarding global climate change, have reinvigorated the discussion of innovative methods of composing, and whether the heat released from the composting process is a viable alternative energy source for localized heating needs. With compost

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Abbreviations: ASP, Aerated Static Pile; HST, heat sink tank; CHRS, compost heat recovery system; PVC, polyvinyl chloride; NHAES, New Hampshire Agricultural Experiment Station; USDA, United States Department of Agriculture; SARE, Sustainable Agriculture Research and Education

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pile and vapor temperatures often exceeding 70 °C for several weeks at a time [2], there is a potentially valuable and recoverable resource being released to the environment at many composting sites.

The recovery of energy from the composting process has a long history, dating back to hotbed systems used in China 2000 years ago [3]. However, research on how to capture the microbially-produced heat for beneficial use has been primarily focused on lab-scale [4–7] or pilot-scale [8–11] systems that were never applied in a commercial setting. Of the few peer-review studies describing compost heat recovery systems (CHRS) suitable for a commercial operation [12–16], all involved modeling of a theoretical CHRS. Of the literature describing actual commercial-scale CHRSs, all were published in practitioner-based sources [17–21], where the focus was on describing the CHRS and composting operation in general. Excluding Allain [17], few details have been reported about how changing compost parameters or management effect rates of energy recovery.

While the current combination of peer-reviewed and practitioner-based literature sources offer valuable insight into the ability to recover energy from the composting process for beneficial use, there is a considerable knowledge gap on how changing compost parameters or management strategies effect rates of energy recovery from an actual commercial-scale composting operation. Smith et al. [2] noted this lack of accurate quantitative data in their detailed literature review of CHRSs, and how a majority of studies reported only maximum energy recovery rates using compost vapor and pile temperatures that are not often sustained in the long run. For practitioners trying to decide between various waste-to-energy strategies, the lack of data from actual commercial systems poses a problem.

The lack of available data on commercialization of compost energy recovery systems is also evident in current review articles describing various methods used to recover energy from waste feedstocks [22–28]). In these articles, composting systems with energy recovery were not mentioned as a waste-to-energy strategy. Instead, the focus was on combustion/incineration, gasification, pyrolysis, anaerobic digestion and bio landfills. This is despite commercial composting operations with energy recovery having over a decade of proven success [2]. However, apart from the composting facility in the present study, these commercial operations are not research-based and do not publish results or disclose information regarding their energy recovery technology. They are simply focused on producing compost for sale and using the recovered heat for on-site purposes.

In this study, we report energy recovery rates from an active commercial-scale research composting facility, the only one of its kind globally. The primary parameters studied were compost vapor temperature and the hot water utilization from the recovery unit. This study is unique in that it is the first to present a true range of energy recovery values from a commercial-scale composting operation, based on changing operational parameters, rather than yields from the short-term, highest heat phase of the composting process. This type of information will be of value to practitioners planning composting systems with energy recovery, as it presents a more comprehensive view of the energy recovery potential during a complete composting cycle. This research will also be useful to policy analysts seeking innovative waste management strategies capable of energy recovery and offsetting greenhouse gas emissions through fossil fuel avoidance. Finally, it is our hope that this study will prove that recovering energy from composting is a viable strategy to recover energy from waste.

2. Materials & methods

2.1. Experimental facility

This research was conducted at the Joshua Nelson Energy Recovery Composting Research Facility at the Burley-Demeritt Farm in Lee, New Hampshire. The farm is part of the University of New Hampshire and is managed and operated by the New Hampshire Agricultural Experiment Station (NHAES).

The ASP composting facility processes dairy and equine manure, spent animal bedding (pine wood shavings), and waste feed hay. Monthly batches containing 115 m^3 (68 Mg wet weight or 27 Mg dry weight) of feedstock are loaded into the facility with a rear-discharge manure spreader. Standard compost residence time is 60 days, resulting in an annual composting volume of 2800 m^3 or 1655 Mg wet weight. This is a longer than traditional residence time and is designed to allow testing of a wider range of operational parameters than can be sustained in a commercial operation. If using a more standard 3–4 week turnaround, the facility would have a 5960–7950 m^3 composting throughput.

The facility was designed in conjunction with Agrilab Technologies, using concepts developed from their first CHRS at a dairy operation in Vermont, USA [21]. Feedstocks are aerated by pulling ambient air down through the piles with a 1 HP blower (NY Blower 126 CGI), which is connected to a network of perforated PVC pipes located below each composting bay. Vapor from each bay is routed through a manifold of PVC pipe to a specialized heat exchange system designed by Agrilab Technologies. The blower is located after the CHRS, so that vapor passes through the piles, into the aeration channels, through the manifold and into the heat exchange unit, which contains a 1117-liter heat sink tank (HST). Water from the HST is sent to the farm's milk house through an underground insulated PEX pipe, where it is used for hot water heating needs. Exhaust vapor post-heat exchanger is sent through a woodchip biofilter and released to the atmosphere [29] (Fig. 1).

The blower is controlled by a programmable logic controller (Do-More H2 Series) which also drives an air compressor and a series of pneumatic gate valves (Valterra 6401P) located at the header of every composting bay. The valves open and close according to a programmed aeration schedule for each bay, determined by incoming compost vapor temperature and oxygen concentration.

2.2. Experiments and data acquisition

Energy recovery from this system was determined by changes in temperature in the HST over time. Prior to each energy recovery trial, the aeration system was turned off and the HST drained and refilled with 13 °C well water. Upon refilling the HST, the aeration system was turned back on. Vapor from a single set of bays was used for each trial, and aeration was continuous for the duration of each 3–4 h trial. Because heat exchange is also dependent on the relative humidity and the flow rate of the compost vapor stream, both were held constant at 100% relative humidity and 7 m^3/min, respectively.

Data were collected for a total of 17 trials in May and June 2016. The compost recipe for all trials was a mixture of 40% cow manure, 40% horse manure/bedding mix and 20% waste hay. Vapor temperatures varied due to pile age and minor compositional differences in the compost mixtures. For each trial, vapor was drawn continuously through a single compost batch to assure a constant vapor temperature input to the heat exchanger. Vapor temperatures were recorded on one-minute intervals at every bay header, before and after the heat exchange unit and before the biofilter, using a Web Energy Logger (WEL). Two additional WEL sensors recorded the temperature within the HST (top and bottom) and another recorded ambient air temperature in the mechanical room of the facility. Compost pile temperatures were also recorded using a 2-meter ReoTemp temperature probe at a depth of 1 meter during the first 3 days following pile formation and weekly thereafter. All temperature data were input and analyzed in JMP Pro 13 SAS statistical software.

Energy capture was estimated as the change in water temperature, combined with the specific heat of water and the amount of water in the HST. If 1 kilojoule (kJ) is equivalent to the amount of energy required to raise 1 kg of water 0.24 °C, and the HST contains 1117 kg of water, the following equation was used: