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The influence of substrate C: N ratios on heat generation during the composting process of sewage sludge

Piotr Sołowiej[a], Maciej Neugebauer[a], Jacek Dach[b], Wojciech Czekała[b], Damian Janczak[b]

[a] Uniwersity of Warmia and Mazury in Olsztyn, Oczapowskiego 2, 10-719 Olsztyn, Poland
[b] Poznan University of Life Sciences, Wojska Polskiego 50, 60-637, Poland

Abstract

The volume of sewage sludge generated in Poland has increased significantly in the last two decades due to the construction of new wastewater treatment plants and the upgrading of the existing facilities. Composting is a highly effective method of managing sewage sludge. Sewage sludge has specific physicochemical properties, and it has to be combined with bulking agents to improve the porosity and the C: N ratio of the composted substrate. The aim of this study was to examine the relationships between heat generation during composting and the C: N ratio of substrates composted under identical aeration conditions. The experiment was performed on four batches of sewage sludge combined in different proportions with wheat straw and sawdust with different C: N ratios. Gas emissions (CH_4, CO_2, NH_3, H_2S) were registered during the composting process, and the amount of heat generated by the composted substrates was calculated. The experiment was conducted in a laboratory system which supported the determination of the amount of generated heat. Heat generation was correlated with the C: N ratio of the composted substrate.

Keywords: Energetic efficiency; composting; sewage sludge

1. Introduction

The volume of sewage sludge generated in Poland has increased significantly in the last two decades due to the construction of wastewater treatment plants and the upgrading of the existing facilities. More than 500,000 Mg of sewage sludge dry solids were produced in 2015. As of January 2016, municipal sewage sludge can no longer be deposited in landfills and has to be managed in an environmentally-friendly manner. There are various methods of managing sewage sludge. Thermal treatment is highly effective, but it consumes significant amounts of energy [1], [2]. Composting is one of the least energy-intensive methods of managing sewage sludge [3]-[6]. Due to its specific physicochemical properties (high moisture content, low carbon content), sewage sludge has to be composted with the addition of bulking agents that increase the porosity and the C: N ratio of the substrate. Porous structure of the substrate, effective aeration and a C: N ratio of 20-30 creates optimal conditions for microbial activity [7]-[9]. The most popular bulking agents are cereal straw (wheat, rye), sawdust of deciduous trees, hay and maize straw. Difficult to compost wastes such as chicken manure are also combined with biochar [10], [11] and pine bark. To optimize the composting process, fuzzy logic is used to control aeration and heat generation [12], [13].

Analyses of oxygen absorption rates, carbon dioxide emissions and the decrease in biomass volume during composting [14] revealed the highest metabolic rates of microbial communities at a temperature of 55-65 ℃. This temperature range is optimal for most thermophilic bacteria, and it speeds up the decomposition of composted material. The composting rate decreases and substrate decomposition slows

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Corresponding author. Tel.: +48 502163913; *E-mail address*: pit@uwm.edu.pl.
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down at temperatures higher than 65 ℃.

The aim of this study was to determine the amount of heat generated during the composting of sewage sludge combined with wheat straw and sawdust as bulking agents to increase the porosity and improve the C: N ratio of the analyzed substrate.

2. Materials and Methods

Samples of sewage sludge were obtained from a small wastewater treatment plant in Szamotuły, Poland, with annual processing output of around 7,000 tons. Wheat straw and sawdust of deciduous trees in various proportions were used as bulking agents to increase the porosity and improve the C: N ratio of the composted substrates (Table 1).

Table 1. The composition and properties of the examined mixtures

	Component	Dry matter [%]	Moisture content [%]	C:N ratio	Fresh weight [kg]
M1	Sewage sludge	75	87.2	9.2	49.8
	Straw	5			
	Sawdust	20			
M2	Sewage sludge	60	80.9	12.3	46.5
	Straw	5			
	Sawdust	35			
M3	Sewage sludge	45	78	17	52.2
	Straw	5			
	Sawdust	50			
M4	Sewage sludge	30	80.2	26.4	70.2
	Straw	5			
	Sawdust	65			

3. Laboratory System for Analyzing the Composting Process

The laboratory system for analyzing the composting process (Fig. 1) was composed of four insulated bioreactors equipped with a controlled aeration system, an automated temperature monitoring system, a portable gas analyzer (CH_4, NH_3, H_2S, O_2, CO_2), leachate and condensate collectors. The applied innovative system of condensate and leachate collectors supports comprehensive monitoring of water flow during composting. The resulting data are used to calculate the thermal balance of the composting process.

4. Composting Process

The composting process lasted 25 days. The temperature inside compost piles, the temperature of exhaust air and ambient temperature were measured automatically every 30 minutes and recorded by the data logger. The amount of condensate in exhaust air and leachate volume was also registered. The concentrations of CH_4, NH_3, H_2S, O_2 and CO_2 in exhaust air were measured with a portable gas analyzer (GA5000, Geotech). The average air flow in all bioreactors was estimated at 3 L min^{-1} (Fig. 2).

On composting day 12, the contents of all bioreactors were manually stirred up to increase the porosity of the composted material.

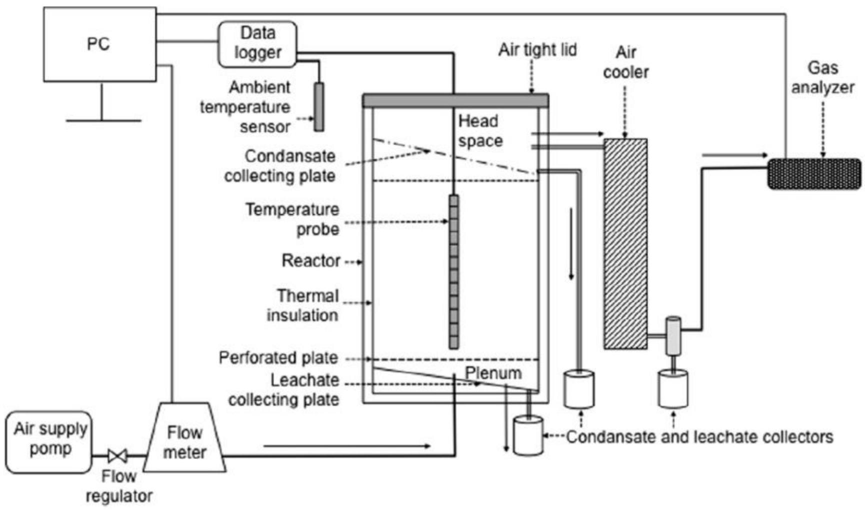

Fig. 1. Schematic diagram of the laboratory composting system.

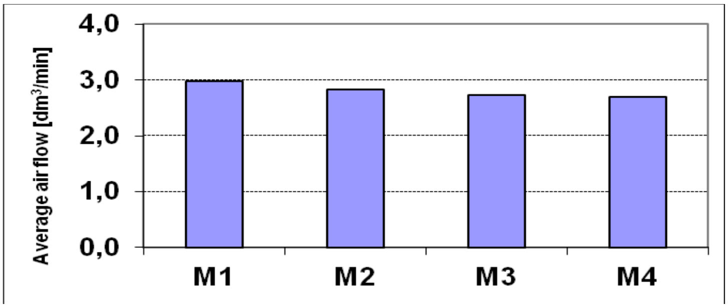

Fig. 2. Average air flow in the analyzed substrates.

5. Temperature Distribution

At the beginning of the experiment, the porosity of the prepared substrates was optimized to speed up temperature increase in all bioreactors. The contents of all bioreactors were stirred up on composting day 12. The data in Fig. 3 indicate that the improvement in substrate porosity increased oxygen availability and, consequently, raised the temperature in all bioreactors. The highest increase in temperature was noted in substrate M1.

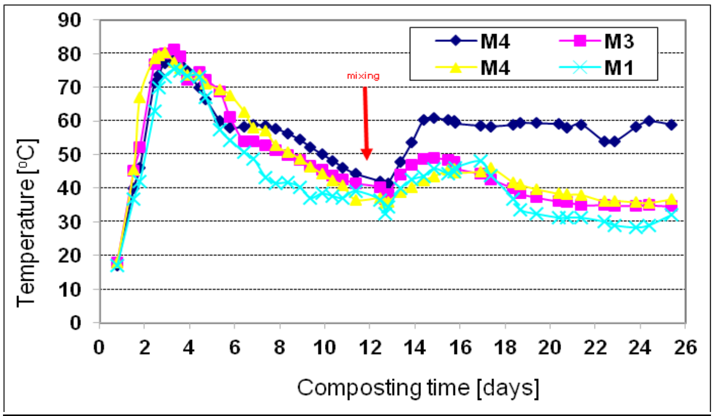

Fig. 3. Temperature distribution in the analyzed substrates.

6. Gas Emissions

Methane was not released from any bioreactor during the entire composting process.

As expected, ammonia emissions were correlated with composting temperature. Ammonia emissions peak at temperatures higher than 60 ℃. They are also influenced by the C:N ratio of the substrate: the lower the C:N ratio, the higher the NH_3 emission (Fig. 4). Ammonia emissions were lowest in substrate M4 which was characterized by the most desirable C: N ratio.

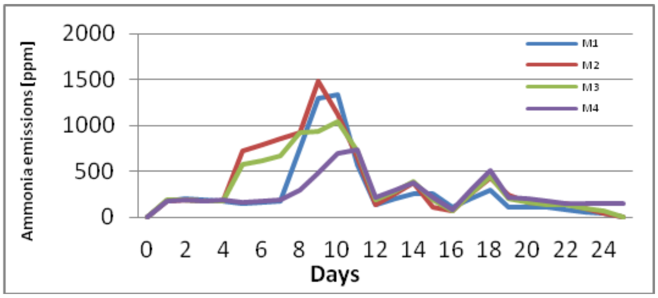

Fig. 4. Ammonia emissions from the analyzed substrates.

Instantaneous emissions of H_2S significantly exceeded 100 ppm only in substrate M1 with the least desirable C: N ratio. Hydrogen sulfide emissions were below 100 ppm in the remaining substrates (Fig. 5). The highest hydrogen sulfide emissions were noted at the highest temperature inside the compost pile.

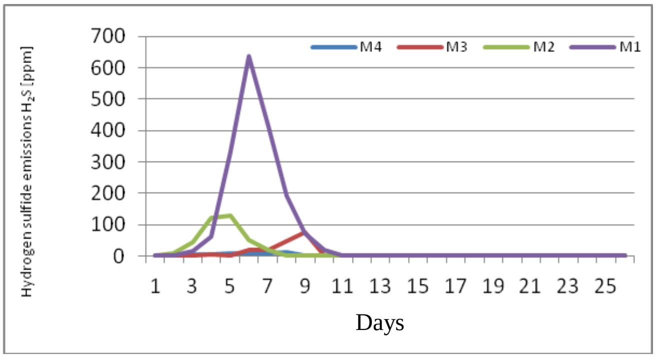

Fig. 5. Hydrogen sulfide emissions from the analyzed substrates.

Carbon dioxide emissions are the most reliable indicator of the metabolic rate of thermophilic bacteria. The amount of CO_2 released from the compost pile increased with a rise in substrate temperature, reflecting the rate of the composting process (Fig. 6).

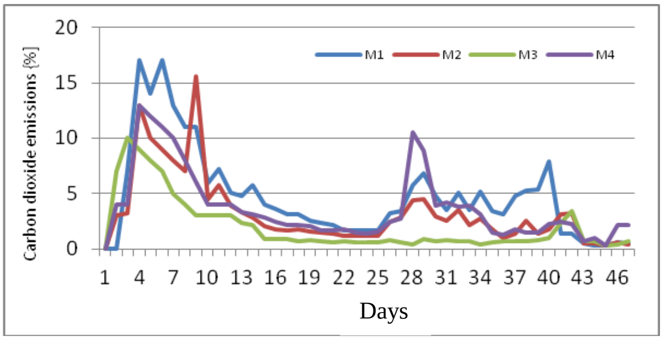

Fig. 6. Carbon dioxide emissions from the analyzed substrates.

7. Heat Generation

The amount of heat generated by the composted sewage sludge was calculated with the use of the method proposed by Sołowiej [15].

The thermal balance of the composting processes was calculated with the use of the below equation (1):

$$Q_M = Q_E + Q_L - Q_I \tag{1}$$

where:
Q_M – heat produced in the composted substrate M [kJ];
Q_E – heat in exhaust air [kJ];
Q_L – heat lost across the surface of the bioreactor [kJ];
The amount of heat generated by every analyzed substrate was expressed per 1 kg of dry weight (Fig. 7).

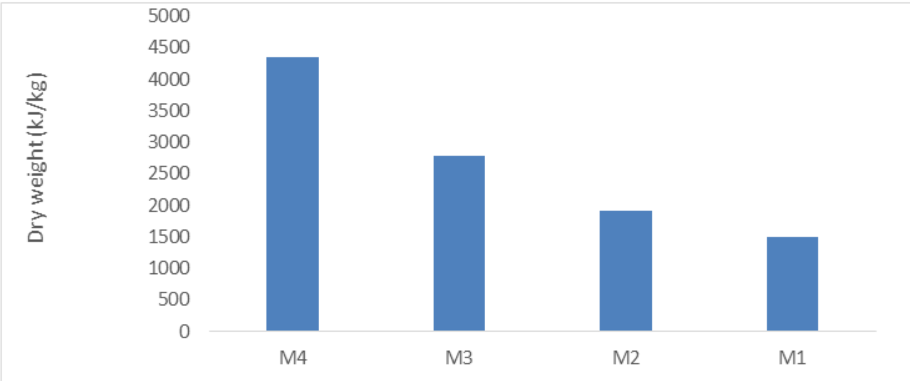

Fig. 7. Heat generated by the analyzed substrates on a dry weight basis.

The data in Fig. 7 indicate that substrate M1 generated nearly three times less heat than substrate M4.

8. Conclusions

The lowest ammonia (NH_3) and hydrogen sulfide (H_2S) emissions were noted in substrate M4 with the most desirable C: N ratio. Ammonia and hydrogen sulfide emissions were also highly correlated with composting temperature. The observed changes in CO_2 emissions indicate that substrate M1 was characterized by the highest microbial activity and, consequently, the highest composting rate.

Heat generation was correlated with the C: N ratio of substrates composted under identical aeration conditions. Substrate M1 was characterized by a three-fold lower C: N ratio, and it generated three times less heat than substrate M4. The composting rate was highest in M4 and lowest in M1. The above results indicate that the amount of heat released during the composting process testifies to the effectiveness of substrate decomposition.

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