

Composting of sewage sludge with solid fraction of digested pulp from agricultural biogas plant

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Abstract. Sewage sludge management is an important element of environmental protection. Composting and anaerobic digestion are the biological conversion methods for sewage sludge management. Mass and volume reduction is a result of a properly composted process. Solid fraction of digested pulp can be use as co-substrate, because it is good structural material. The aim of the study was to determine the possibility of composting sewage sludge with a solid fraction of digestate. The compost mix consisted of 25 kilograms of sewage sludge and 20 kilograms solid fraction of digestate in fresh mass. The experiment was carried out in laboratory conditions. Bioreactors of 165 dm³ volume were used. The experiment included two stages. Stage I took place in bioreactors and lasted until the cooling phase of the compost was complete. Stage II included compost maturation for a period of eight months (to 287 day of composting). The reduction of mass obtained at the end of Stage I amounted 30.2%. At the end of Stage II, it was 86.7% relative to the initial weight of the compost. The maximum value of temperature was 75.1°C. Studies have shown that sludge with a solid fraction of digestate can be a suitable substrate for composting with sewage sludge.

Abbreviations

AD – anaerobic digestion
DM – dry matter
FM – fresh matter
MM – mineral matter
OM – organic matter in Total Solids
SF – solid fraction of digested pulp
SL – sewage sludge

1 Introduction

One of the most important environmental issues is the management of waste, including by-products of wastewater treatment processes such as sewage sludge (SL) [1,2]. Management of waste can take place using technologies compatible with sustainable development [3]. SL can be a problematic product for environment and requires management [4]. The primary reason is the amount of their formation and the content of odorous and harmful substances [5]. Therefore, it is necessary to look for technologies that will help them to be used for the benefit of the environment [6]. The most commonly management method of SL in last years was storage. Legal regulations that entered into force on January 1, 2016 prohibit the storage of SL. There is an order for sewage treatment plants to take measures to manage them in a way that is safe for the environment [7].

Composting and anaerobic digestion (AD) can be mentioned as part of the biological conversion process [8,9]. Composting is a controlled process of aerobic decomposition of organic matter with microorganisms, carried out in prisms or reactors [10]. Among the advantages of this method are the significant reduction in the weight and volume of composted mixtures and the final product, compost, which is an organic fertilizer [11]. SL is a substrate often used for the compost production [12,13]. This is largely due to the high degree of hydration and high nitrogen content. By adjusting the composition e.g. by adding straw it is possible to create the right proportion of substrate.

Methane fermentation takes place at sewage treatment plants, landfills and in the agriculture biogas plants [14]. In each of these cases, biodegradation of the substrates rich in organic matter occurs. The main product of the anaerobic digestion is biogas [15,16]. It is a mixture of gases, dominated by methane and carbon dioxide. Ammonia, hydrogen sulphide, hydrogen and other gases are present in smaller amounts. The second product is digested pulp (digestate), which is a residue from the decomposition process [17]. Digestate is mainly composed of mass of non-fermented compounds and bacterial biomass. Its quantity is closely related to the mass of the feedstock to the biogas plant. However, chemical composition, is largely conditioned by the type of substrates used in the biogas production process. The digested pulp is in the liquid form. Dry matter is usually 2 to 10%. An important element in the digestate management is the separation process [18]. The result of the process are at least two fractions - solid and liquid [19]. Due to its abundance in organic matter, nitrogen and high humidity, it is possible to select the appropriate proportion of the composted mixture. The produced compost is an environmentally safely product and is desirable due to its fertilizer properties [20].

Considering the high volume of nitrogen in SL in on the one hand, and the SF in carbon on the other, it is possible to use them in the composting process. As a result of oxygen decomposition processes compost hygienisation occurs. This is an important aspect of this process, since sludge is often a source of microbiological contaminants and helminths' eggs.

The purpose of the study was to determine the possibility of composting SL in a mix with a SF. The paper shows the origin and properties of the substrates used for composting, presents composting methodology and discusses the changes related to the particular parameters during composting. Moreover, the authors have done the discussion to compare the results of their own research with those obtained by other scientists.

2 Methodology

2.1 Substrates and composting mixtures

SL used in the experiment came from one of the wastewater treatment plants near Poznan. The substrate was dehydrated using presses. Dehydrated municipal substrate was composted with a SF of the digested pulp from an agricultural biogas plant, located in Poland. Primarily corn silage, fruit pulp and distillery were used for the production of biogas in this installation. The compost mix consisted of 25 kilograms SL and 20 kilograms of SF in fresh mass. The dry weight of the SL was 14.56% and the SF was 32.52%. The organic matter content in dry matter was 75.58% for sludge and 92.94% for digested pulp, respectively. During composting the temperature changes, carbon dioxide emissions, dry matter and organic matter, pH, conductivity and bulk density were monitored (tab. 1).

Table 1. Participation and selected properties of the components used in the composting process.

Substrates	Properties				Participation of substrates
	DM [%]	OM [%]	pH [-]	cond. [mS·cm ⁻¹]	FM [%]
SF	32.52	92.94	9.07	1.27	20
SL	14.56	75.58	7.09	0.24	25

The nitrogen content in the compost mixture was 24.82 g·kg⁻¹ DM and phosphorus 16.66 g·kg⁻¹ DM. The experiment included two stages. Stage I took place in bioreactors and lasted until the cooling phase of the compost was complete. Stage II included compost maturation for a period of eight months (to 287 day of composting).

2.2 System for laboratory composting

The experiment was carried out in laboratory conditions in the Laboratory of Ecotechnologies (Poznan University of Life Sciences). Bioreactors of 165 dm³ volume were used for the experiment equipped with equipment for monitoring the decomposition of organic materials in aerobic and anaerobic conditions (fig. 1). Due to unique construction it is possible to continuously control the process going on inside the reactor.

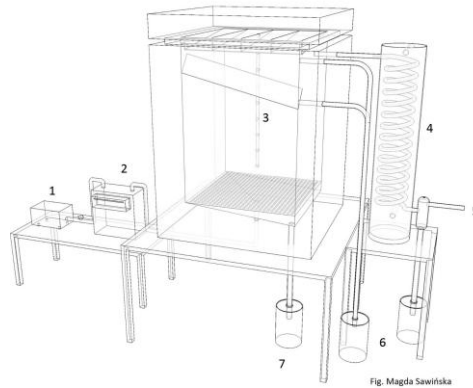


Figure 1. Schematic diagram of the system for laboratory composting 1 – air supply pump, 2 – flow meter and flow regulator, 3 – chamber of reactor, 4 – air cooler, 5 – cold water, 6,7 – condensate and leachate collectors.

2.3 Composting process

During the experiment the air flow was regulated in the range of 0.8 to $2.7 \text{ dm}^3 \cdot \text{min}^{-1}$. The initial value of the air injected into the chamber was $2.5 \text{ dm}^3 \cdot \text{min}^{-1}$. Twice a day correctness was checked by rotameter. When approaching 5% oxygen in the air, the airflow was increased in order to prevent the occurrence of anaerobic conditions.

2.4 Physical and chemical analysis

In order to investigate physico-chemical parameters changes of the compost, samples were taken at the beginning, during the opening of the chambers (turning) and at the end of the experiment. Turning consisted of an opening of the bioreactor and mixing of the total contents of the chamber to aerate the compost and improve the structure of the composting material. The material for analysis was taken from the five different places in chamber and averaged sample was created. At the beginning and at the end of the experiment as well as during the turning, the mass and volume changes measurements were made using a laboratory scale. This allowed to determine the weight loss and volume during the experiment. Based on the changes in the tested parameters the bulk density of fresh compost was calculated.

The construction of the reactors allowed to collect gravity leaks from the compost. Special cooling system allows to condensate the vapor escaping from the chamber and from the radiator. DM of samples was determined by drying method at 105°C for 24 h. Dried samples (each in three replicates) were incinerated to define OM and MM. Organic matter was determined in the furnace (temp. 550°C , 3h). Measurement was done in triplicates. Measurement of pH and conductivity was done using Elmetron CX-401 multifunction device.

2.5 Gaseous measurements

During the composting process, air from the compost chambers was tested using a GeoTech GA5000 gas analyzer. The device allowed analysis of five gases in the concentration range: CH₄ from 0 to 100%, CO₂ from 0 to 100%, O₂ from 0 to 25%, NH₃ from 0 to 1000 ppm, H₂S from 0 to 10000 ppm. Once a week, calibration of gas analyzer was done.

2.6 Temperature measurement

Temperature measurement was done using stick that tests a temperature of 20 centimetres from the bottom of the chamber. These measurements were recorded on the hard disk of the computer every 8 hours.

3 Results

3.1 Characteristics of physical and chemical parameters changes

The mass reduction obtained at the end of Stage I amounted 30.2%. At the end of Stage II, it was 86.7% relative to the initial weight of the compost. This was due to the evaporation of water and the reduction of organic matter. After maturation, the dry matter content was 85.63%.

The highest content of OM occurred on the first day of the experiment - 93.45%. After turning, its content decreased to 81.38%, and at the end of Stage I was 73.32% (tab. 2). During maturation of compost (over five months), the OM level was slightly changed eventually reaching 74.72% on two hundred nineteenth day.

Bulk density increased from 444 kg·m⁻³ at the beginning of the experiment to 557 kg·m⁻³ (34 day) and 620 kg·m⁻³ on the sixty-nine day. Along with the duration of the process, the pH has changed from 7.65 to 8.5 (34 days) to 8.7 (51 days). At the end of Stage I (69 days), the level was 7.53. The maturation phase contributed to a decrease in the reaction, reaching a value of 6.55. Conductivity increased from 0.79 mS·cm⁻¹ at the beginning of the experiment to 3.88 mS·cm⁻¹, an increase of 391%.

Table 2. Selected compost properties during the process

	Phase of composting	Day	FM [kg]	DM [%]	OM [%]
Compost	Start	0	45	32.67	93.45
	Turning	34	36.1	19.71	81.38
	Finish of Stage I	69	31.4	17.25	73.32
	Finish of Stage II	287	6.0	85.63	74.72

3.2 Temperature changes

The temperature of the composted mixture during the experiment ranged between 18 and 75.1°C. The maximum value defining the thermophilic phase was demonstrated on the third day of the experiment. On the thirty-fourth day of the experiment, when the compost temperature reached a similar level of ambient temperature (22.6°C), turning was made. After this step, which was associated with oxygenation of the mixture, the temperature

increased to a maximum of 54.7°C. In the following days there was a gradual decline in temperature to the sixty-ninth day, which was the end of the composting process in chamber (fig. 2).

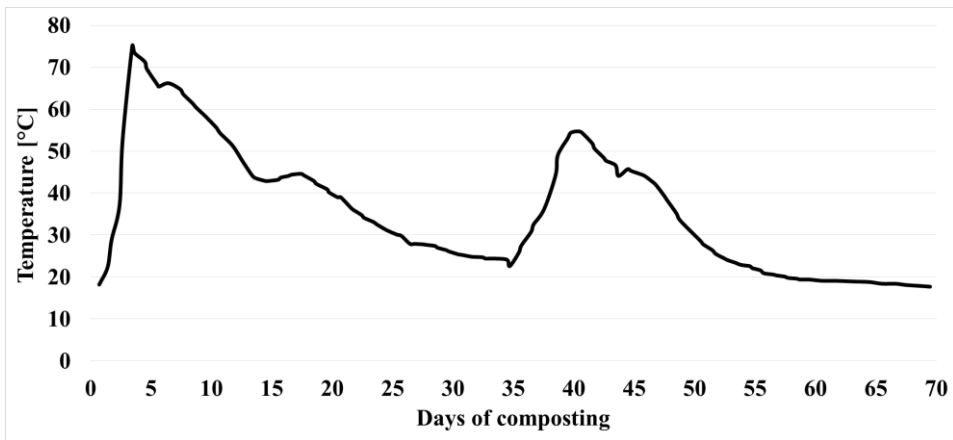


Figure 2. The temperature of the composted mixture during the experiment

3.3 Gaseous emission changes

The minimum concentration of oxygen at 9.1% level occurred on the third day of the study. Along with the compost being cooled down, the microbial activity has weakened, resulting in an oxygen increase to 17-20% level observed on the eleventh day, and lasted until the thirty-fourth. Decomposition of organic compost caused the decrease of oxygen content in the compost up to forty-first day. On forty-ninth day an oxygen stabilization started in chamber to the level of 20%, until the end of Stage I of the experiment.

Carbon dioxide is generally negatively correlated with the concentration of oxygen during composting process. The increase in its concentration causes a direct proportional loss of oxygen, and their sum should be close to that occurring naturally in atmospheric air. Maximum values of carbon dioxide concentration of 11.7% were reported with the highest compost temperatures.

Emission of ammonia from the compost heap reached its maximum of 989 ppm on the fourth day of the experiment, decreasing to less than 100 ppm only on the eleventh day of composting. At the same time, there was no effect of turning on ammonia emissions. Methane and hydrogen sulfide levels were also monitored. Emission of these gaseous proves the presence of anaerobic conditions. Hydrogen sulfide was observed in both compartments only in the first days of composting, but its level was marginal. H₂S maximum emission occurred on the third day, 28 ppm.

Composting of SL with SF is relatively new. Straw is the most popular substrate for composting with SL. In the study [8] the research on composting SF as monosubstrate was carried out. The addition of sewage sludge in own research allowed to achieve higher temperatures (fig. 2). This was due to the supply of SL with significant amounts of nitrogen and improved C/N ratio. Digestate was used in composting in research Franke-Whittle et al. [21]. The results of this authors also confirm the possibility of using digestate for composting.

4 Conclusion

Studies have shown that SL with a SF can be a suitable substrate for composting. The proof of that are for example change of parameters and temperatures during the process. This was proven among others by the reduction of organic matter from 93.45% at the beginning of the experiment to 78.32% after 69 days of the process. Knowing that sewage sludge is rich in nitrogen, it is important to keep in mind the appropriate proportions between components so as to avoid excessive ammonia emissions.

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