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Original Research

Application of a Natural Cover during Sewage Sludge Composting to Reduce Gaseous Emissions

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Abstract

Large amounts of sewage sludge are generated in the process of sewage treatment. Sewage treatment and sewage sludge treatment and handling inevitably cause the problem of gas emissions and unpleasant smells. Degradation of organic matter results in the emissions of gases with an unpleasant smell (NH_3, H_2S, etc.), as well as greenhouse gases (CO_2, CH_4, N_2O). The processes of biodegradation occur in nature and under artificial conditions, during composting. Our analysis covers the experimental results of sewage sludge composting by investigating NH_3, H_2S, CO_2, and VOC emissions. The experiment used surplus sludge from sewage treatment facilities that were dewatered with centrifuges (75.9% humidity). Additional materials applied included wood bark, sawdust, peat, and a grass layer (a lawn roll). Composting was performed in the "facilities" simulating a composting site.

Keywords: sewage sludge, composting, gas emissions, natural cover

Introduction

Large amounts of sewage sludge are generated in the process of sewage treatment. Sewage treatment, sewage sludge treatment, and handling inevitably cause the problem of evolving gases and unpleasant smells. Degradation of organic matter results in the emissions of gases with an unpleasant smell (NH_3, H_2S, etc.), as well as gases (CO_2, CH_4, N_2O) causing climate change. Ammonia (NH_3) emissions into the atmosphere not only cause problems related to unpleasant smells, but also are responsible for the loss of a valuable nutrient (N) from compost. The adequate handling of biodegradable waste has recently gained special importance as the products of decomposition of this waste make a big influence on climate change [1-5].

Composting is a natural process which is at the same time a controllable and supervised process, during which organic waste is converted into compost, i.e. a humus matter being the source of nutrients easily assimilated by plants. This process takes place naturally with the help of developed microorganisms. This is a continuous process in nature: when not raked up, leaves rot and nutrients return to the ground, thus feeding trees [6-10].

The greatest benefit of composting is the decrease of methane, greenhouse gas, and emissions. Composting and compost use reduce greenhouse gas emissions directly through the isolation of carbon dioxide and indirectly by improving the properties and composition of soil [1, 11]. When organic matter degrades naturally, CO_2 is emitted under aerobic conditions; however, when organic matter is degraded in the anaerobic environment carbon is emitted in the form of methane and other volatile organic compounds [12]. Greenhouse gas emissions from aerobic composting systems are lower than from anaerobic composting systems. Carbon dioxide (CO_2), methane (CH_4) and oxides of nitrogen (NO_x) are the by-products of the composting process. These three greenhouse gases contribute to global warming by absorbing radiation emitted to the ground [1, 13].

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Composting is one of the processes of biological stabilization intended for the treatment of dewatered sewage sludge.

The amount of ammonia released during composting, i.e. ammonia losses, depends on the pH, C/N ratio, temperature, and mixing of a composted mixture as well as air supply to it. The major problem of ammonia loss is the reduced amount of nutrients in a compost product as well as unpleasant smells in composting facilities [14]. One of the main conditions to be satisfied during composting is preservation of the largest possible amount of nutrients by reducing nitrogen losses. Decreased ammonia losses also alleviate the problem of unpleasant smells [15, 16].

Several factors, such as C/N ratio, temperature, mixing of initial materials, sludge mixing during composting, and air supply can have an influence on ammonia volatility during composting [17]. The gaseous losses of nitrogen are most frequently emitted during composting in the form ammonia, but also can take the form of nitrogen and NO_x [18]. According to Witter and Lopez-Real [21], total nitrogen loss can constitute up to 50% of the initial nitrogen in a composted mixture of sewage sludge and straw. Nitrogen losses grow to 33% of the initial nitrogen amount when composting domestic poultry manure [19].

Ammonia adsorption from compost can be ensured by the use of such materials as peat, natural zeolite, and basalt [20, 21]. Calcium and magnesium salts also have been added to precipitate ammonia with carbonate and to remove the alkalinity that could prevent a rise in pH [22]. It has been determined that peat and vermiculite have a positive impact on the management of ammonia emissions during composting [23]. Another effective way of reducing ammonia losses is blending of substances with large carbon content in a compost mixture, thus increasing the C/N ratio. As maintained by Eklind and Kirchmann [18], adding waste (materials) containing much carbon is not an effective way to reduce the loss of nitrogen from compost.

When a sufficient amount of Mg and P is added to composted materials, the ammonia loss is considerably reduced as a result of the process of crystallization. Therefore, the achieved share of ammonia-N in dry compost is up to 1.4%, while this value is by 3 to 5 times higher than in normal compost [14]. The aim of experiments is to determine the effectiveness of a natural compost cover in reducing gaseous pollutant emissions to the atmosphere.

Sewage Sludge Composting Methods

The surplus sewage sludge dewatered with centrifuges, tree bark, sawdust, peat, and a grass layer (a lawn roll) were used for the investigations of gaseous pollutant (NH_3, H_2S, VOC, CH_4) emissions during sewage sludge composting. Composting was carried out in the facilities imitating a composting site. A composting stand consists of a Perspex body with openings for taking gas samples and measuring compost temperature. Compressed air is supplied through a perforated pipe (PVC). The stand also is installed with an air compressor, and compost gas collection and off-take to the bio-filter pipe.

Composed materials are placed into 0.25 m^3 capacity boxes (250 l) (dimensions: 1000×500×500 mm) covered with leak-proof hoods. Composting boxes are filled with:

1. 15±0.1 kg of sewage sludge and 1.5±0.001 kg of wood sawdust (control)
2. 15±0.1 kg of sewage sludge and 1.5±0.001 kg of wood sawdust covered with a grass layer (40-50 mm)
3. 15±0.1 kg of sewage sludge and 1.5±0.001 kg of wood sawdust covered with a 5 kg layer of wood bark (40-50 mm) and grass (40-50 mm)
4. 15±0.1 kg of sewage sludge and 1.5±0.001 kg of wood sawdust covered with a 5 kg layer of peat (40-50 mm) and grass (40-50 mm)
5. 15±0.1 kg of sewage sludge and 1.5±0.001 kg of wood sawdust covered with a 5 kg layer of peat (40-50 mm)
6. 15±0.1 kg of sewage sludge and 1.5±0.001 kg of wood sawdust covered with a 2 kg layer of peat (40-50 mm) and grass (40-50 mm)

The surface of a compost pile is covered with natural materials (layers). Layers of the cover are composed of wood bark, sawdust and peat, which retain not only heat but also gas emissions during composting. The top layer of plants accelerates the humidification of sewage sludge (biodegradable waste). Through the process of nitrification plants assimilate nitrogen, which results in decreased emissions of gaseous compounds into the environment due to a decreased amount of surplus nitrogen in the sludge. With the concentration of CO_2, increasing both the photosynthesis activity and biomass production, the total amount of assimilated carbon is increasing and therefore carbon dioxide emissions to the environment are decreasing. The system of plant roots generates additional aeration for the compost pile.

Each of the composting facilities has two openings (Fig. 1) intended for taking gaseous pollutant samples: the concentration of ammonia (NH_3) is determined by the photometric method; the concentrations of hydrogen sulphide (H_2S), carbon dioxide (CO_2), oxygen (O_2), and methane (CH_4), are identified with the gas analyzer INCA 400; and the concentrations of volatile organic compounds (VOC) are recorded with a portable gas meter *MiniRae*.

The temperatures of the ambient air and inside the compost pile are measured every day. The experiments continued for 80 days. Gas samples are taken every 3-4 days. To aerate compost, air is supplied to the composting facility through perforated pipes at a rate of 50 l/min for 15 minutes. Gas samples (3 repeats) are taken after one hour from air supply to the facility.

This method helps us to determine ammonia (NH_3), volatile organic compounds (VOC), hydrogen sulphide (H_2S), methane (CH_4), waste humidity, pH, and total carbon. A gas analyzser INCA 400 with infrared sensor module and *Parox* sensor makes measurements with the following accuracy: ±5% for hydrogen sulphide, ±1% for carbon dioxide, ±1% for oxygen, and ±1% for methane. The concentration of ammonia (NH_3) is determined by the photometric method. The concentration of VOCs is recorded using a *MiniRae* 2000 device with a PID (photoionisation detector) sensor. The measurement accuracy at a pollutant concentration of 0-2,000 ppm is ±2 ppm. Compost humidity is determined by dewatering the sample at a temperature of 105±3ºC up to the constant mass, and is calculated taking account its mass before dewatering. pH is measured using a *MultiCal* 538 WTW pH meter with a glass electrode.

Results and Discussion

The experiment used surplus dewatered sewage sludge from the Vilnius city sewage treatment plant. The additional materials applied included grass, sawdust, cut bark, and peat. Wood sawdust increases compost porosity, reduces compression, and improves oxygen circulation within a compost pile. Compost piles were covered with natural materials of differing porosities and properties.

When mixed with wood sawdust, composted sewage sludge optimizes the C/N ratio of the compost.

The sewage sludge used for our investigations had the following parameters: pH 6.5-6.9, weakly acid-neutral; content of the total organic carbon in the dry mass – 57.1%; and humidity (the percentage of water in the material) – 75.9%. The humidity of additional materials used for investigations are 2.25% for sawdust, 1.35% for bark, and 48.6% for peat.

A stable ambient air temperature of 21.5±1.5ºC was maintained throughout the experiment. During biodegradable waste composting biochemical reactions take place in the course of which heat is released to the environment (exothermal reaction) and compost heats up. Heat accumulates in the composted mass, but when the amount of composted materials is small heat withdraws from the surface as radiation and together with the air, which is moving during "blow-offs." Compost temperature shows the ongoing heat exchange as well has an influence on microorganism activity. On the third day of the experiment the temperature in compost piles reached +33-38ºC. On the fifth and sixth days of the experiment compost piles reached the maximum temperatures of +32-42ºC. Throughout the experiments the internal temperature of compost piles corresponded to the temperature that is favourable for mesophilic bacteria (mesophilic bacteria are active in a temperature range of +20-40ºC).

Composting occurs in three successive phases: the mesophilic, thermophilic, and curing phases. In the initial mesophilic phase, the temperature of the composting pile increases from ambient temperature. In the thermophilic phase, the temperature increases to 40-70ºC. In the final curing phase (also known as the cooling phase), microbial activity is reduced and the composting process is completed [24].

Composting is a dynamic and biologically active process during which the temperature of composted materials as well as the humidity, acidity, and composition of materials and gases change.

Sewage sludge composting is an aerobic biothermal process during which organic components of the sludge degrade. This process can be described by the formula:

$$[C_{xl}H_{x2}O_{x3}N] + a_2[O_2] \rightarrow$$
$$\rightarrow a_2[CO_2] + a_3[H_2O] + NH_3 + Q_h$$

As the equation shows, degrading of the organic compounds of sludge produces carbon dioxide, water, ammonia, and energy in the form of heat.

Humidity management is a two-functions balance that stimulates microorganism activity and allows access of a sufficient oxygen amount. Water is the essential element for degrading processes and therefore an insufficient water amount is one of the main factors impeding microorganism activity in solid biodegradable materials (waste). Insufficient humidity can restrict the mobility of bacteria, and therefore the composting systems in which compost is mixed can operate in the presence of a lower amount of humidity in contrast to the static systems [25]. However, composted mixtures also can be too humid for aerobic composting, as excessive humidity fills minor pores among particles, thus restricting oxygen access.

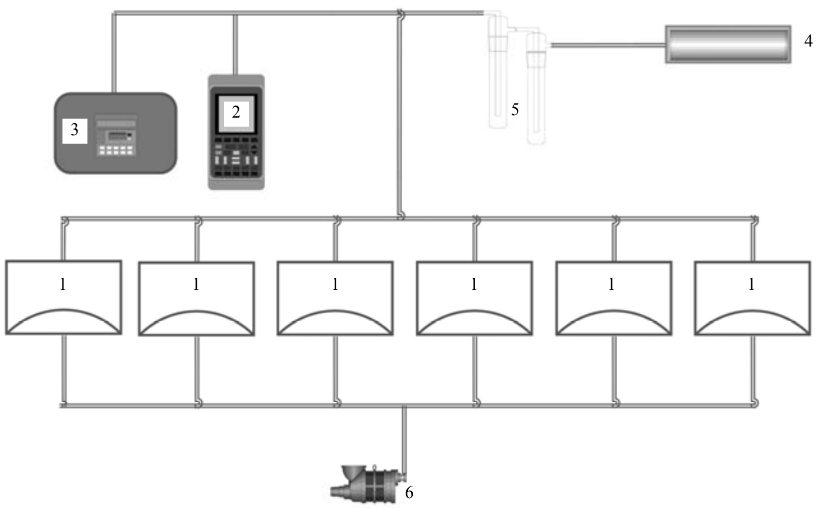

Fig. 1. Principle scheme of sludge composting research stand: 1 – sludge composting facilities with composted materials, 2 – VOC meter *MiniRae*, 3 – gas (H_2S, CO_2, O_2, CH_4) analyzer, 4 – air pump, 5 – Zaitsev adsorbents, 6 – compressed air compressor

For composting processes the optimum humidity is 50-60%, the limit – 30/70%. On the first day of composting the humidity of composted materials stood at 69.1%. As no additional humidification was envisaged, on the 80th day of composting the humidity of compost fell to 56-47%.

The optimum oxygen amount for the process of composting is 15-20% of the volume of organic waste; with oxygen amount decreasing below 10%, composting slows down and anaerobic processes start taking place (rot) [26].

Air supplied to the composting facilities contains 21% oxygen and 0.03% carbon dioxide (Fig. 2). During biological processes of composting, microorganisms consume oxygen for the maintenance of their vital functions, which also influences the formation of smaller amounts of CH_4.

During both aerobic and anaerobic composting of biodegradable waste, volatile organic compounds (VOC), as a product of biochemical reactions, are emitted into the environment. The experimental results show two peaks of VOC emissions: on experiment days 8–10 and experiment day 24 (Fig. 3). A comparison of VOC emissions obtained during experiments and presented by other authors shows similar tendencies – VOC emissions occur in "bursts." This is related to the phases of an aerobic process mechanism. For instance, the data presented by Cadenaa and others show the peaks of VOC concentration on day 14 and days 25-30, when compost piles are compulsively aerated in a composting plant [27].

The largest VOC emissions were recorded from non-covered (control) composted sewage sludge mixed with sawdust. The quality analysis of VOCs was not carried out. Lower amounts of VOCs were determined when composted materials were covered with one layer: either a grass or a peat layer. The biggest effect was achieved when composting materials were covered with two layers. The effectiveness of a peat layer applied on composted materials, compared to control (when composted materials were not covered at all), reached 20%; cover of a grass vegetation layer reduced VOC concentration 25%; cover of a sawdust and grass layer – 48%; a peat and grass layer – 62%; a bark and grass layer – 72%. According to the mechanism of composting VOC emissions into the environment, it is difficult to manage because they are almost all different composting times as an intermediate product. In addition, it has various compounds.

The major part of unpleasant smells during composting was produced by NH_3. However, H_2S emissions also significantly added to unpleasant odor. Hydrogen sulphide is a noxious gas causing corrosion. Hydrogen sulphide has the taste of a rotten egg. The value of the hydrogen sulphide odor threshold is 0.00076 mg/m^3, which means that man can smell its minor concentrations in the environment (according to the Republic of Lithuania hygiene norm HN 35:2007).

During the experiment the peaks of hydrogen sulphide were recorded on experiment day 4 and varied from 22 mg/m^3 to 86 mg/m^3. The highest concentration of hydrogen sulphide was identified when composting sewage sludge with sawdust covered with a peat layer of 86 mg/m^3. A lower concentration of hydrogen sulphide was recorded during composting of non-covered sewage sludge with sawdust – 70 mg/m^3. Starting from experiment day 8 no

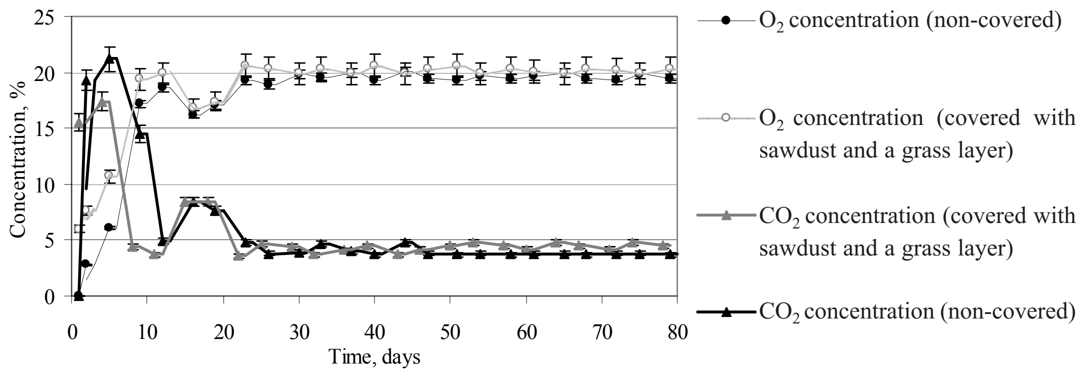

Fig. 2. O_2 and CO_2 concentrations (%) in composting facilities.

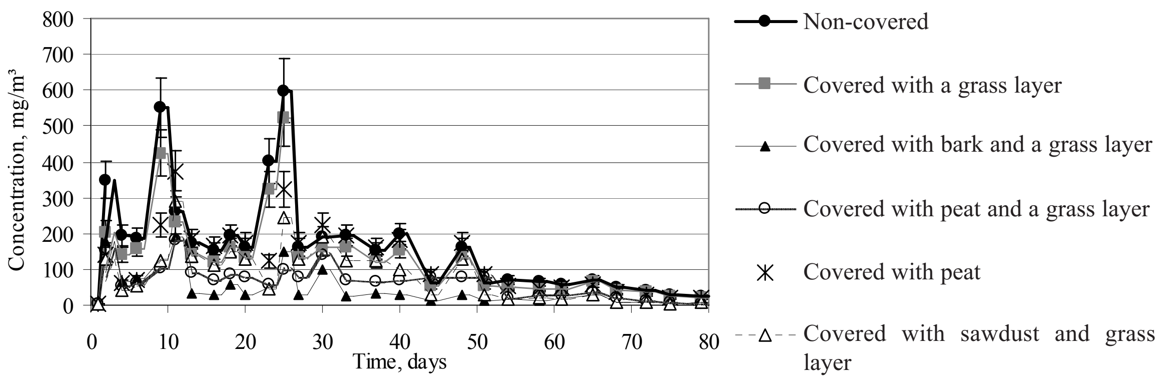

Fig. 3. VOC emissions (mg/m^3) from compost.

hydrogen sulphide was emitted in any compost pile except for the non-covered compost pile, which showed a concentration of 7 mg/m^3.

Ammonia emissions from compost are measured as their amounts (compared to the emissions of other gases) are big, and easy to identify. During municipal waste composting ammonia emissions vary from 18 to 1,150 g NH_3Mg^{-1} (from one ton of waste) [28], and the peaks of the ammonia concentration amount to 700 mg NH_3m^{-3} from sewage sludge composting facilities [26]. As indicated in the Air Pollutant Emission Inventory Guidebook of the European Environment Agency, 1 kg of spread sewage sludge, on average, emits 50 g NH_3, the lower and upper limits vary from 10 to 150 g NH_3 [29].

The performed experiment of sewage sludge composting shows from 0.56 to 41.41 g/kg NH_3 emissions from sewage sludge covered with different covers after 80 days (Fig. 4). The largest emissions of ammonia, 41.41 g/kg NH_3, were recorded during the composting of sewage sludge mixed with sawdust (10:1) when it was not covered. When composted materials were covered with a peat layer the emissions of ammonia decreased nearly threefold and reached 13.85 g/kg NH_3. When composted materials were covered with a grass layer the emissions of ammonia reached a mere 1.79 g/kg NH_3. The highest effectiveness in reducing ammonia emissions was achieved when using two-layer compost covers: a sawdust and grass layer – 0.29 g/kg NH_3, a peat and grass layer – 0.19 g/kg NH_3, and a wood bark and grass layer – 0.14 g/kg NH_3. A comparison of the experimental data and the rates of ammonia emissions from spread sewage sludge presented by the European Environment Agency shows that the data obtained from the experiment regarding sewage sludge composting without applying a compost cover is smaller than the lower threshold [29].

The highest concentration of ammonia, 575 mg/m^3, was recorded on experiment day 15 when sewage sludge was composted with sawdust without applying a compost cover, which is 18% less compared to the peaks of the ammonia concentration (700 mg NH_3/m^3) recorded from sewage sludge composting facilities [26].

When two-layer compost covers are used the internal layers of the compost cover composed of bark, peat or sawdust retain heat and the emissions of composting gases. The top layer of plants accelerates the humidification of sewage sludge (biodegradable waste). Through the process of nitrification plants assimilate nitrogen, which results in the decreased emissions of gaseous compounds into the environment due to the decreased amount of surplus nitrogen in the sludge. With the concentration of CO_2 increasing photosynthesis activity and biomass production of plants growing, the total carbon assimilated amount is increasing and therefore the atmospheric emissions of carbon dioxide generated during composting are decreasing. The system of plant roots generates additional aeration of the compost pile.

Conclusions

1. A methodology for the determination of emissions from sewage sludge composting with forced aeration has been developed and successfully applied.
2. A large specific surface area and porous structure of natural materials (bark, sawdust, peat) used for the absorption of odors has a positive impact on the process of adsorption, and at the same time these materials are suitable for the development of microorganisms participating in the process of composting, and therefore can be used as a natural tool of bio-filtration.
3. The highest effectiveness in reducing gaseous pollutant emissions is achieved by using compost covers consisting of two layers (bark, sawdust, peat, and a grass layer).
4. The effectiveness of a peat layer applied on composted materials, compared to control (when composted materials are not covered at all), reaches 20%; a cover of a grass vegetation layer reduces VOC concentration 25%; a cover of a sawdust and grass layer – 48%; a peat and grass layer – 62%; a bark and grass layer – 72%.
5. It has been determined during the experiment that sewage sludge covered with different covers emitted from 0.56 to 41.41 g/kg NH_3 over a period of 80 days. The largest emissions of ammonia, 41.41 g/kg NH_3,

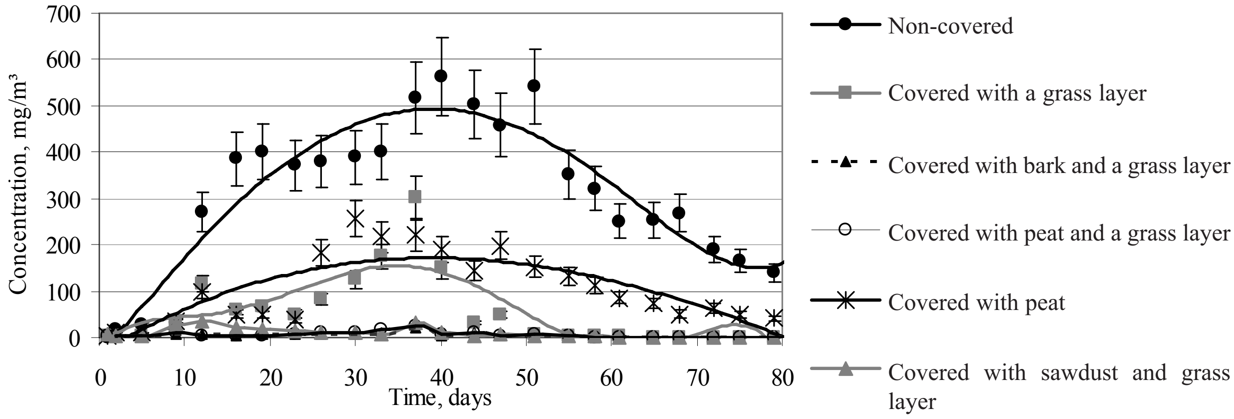

Fig. 4. Ammonia (NH_3) emissions (mg/m^3) from compost

were recorded from the composting of sewage sludge mixed with sawdust (10:1) when it was not covered. When composted materials were covered with a peat layer, the emissions of ammonia decreased nearly three-fold and reached 13.85 g/kg NH_3.

6. During the experiment the peaks of hydrogen sulphide were recorded on experiment day 4 and varied from 22 mg/m^3 to 86 mg/m^3. Starting from the eighth day of composting no hydrogen sulphide was emitted in any compost stand except for the non-covered compost pile, which showed a concentration of 7 mg/m^3.

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