Chemosphere 117 (2014) 33–39

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Technical Note

The effect of low-temperature transformation of mixtures of sewage sludge and plant materials on content, leachability and toxicity of heavy metals

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HIGHLIGHTS

- Thermal transformation of sludge without a plant component is not well-founded.
- Thermal transformation of materials decrease content of soluble form of the metals.
- Low toxicity of the materials for *V. fischeri* and *L. sativum*.
- *L. sativum* was higher sensitivity to metals occurring in materials than *V. fischeri*.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 12 December 2013
Received in revised form 7 May 2014
Accepted 8 May 2014

Handling Editor: O. Hao

Keywords:
Sewage sludge
Biochar
Heavy metals
Mobility
Toxicity

ABSTRACT

The aim of the study was to determine the influence of the process of low-temperature transformation and the addition of plant material to sewage sludge diversifying the content of mobile forms of heavy metals and their ecotoxicity. The experimental design included: sewage sludge + rape straw, sewage sludge + wheat straw, sewage sludge + sawdust, sewage sludge + bark and sewage sludge with no addition. The mixtures were subjected to thermal transformation in a chamber furnace, under conditions without air. The procedure consisted of two stages: the first stage (130 °C for 40 min) focused on drying the material, whereas in the second stage (200 °C for 30 min) proper thermal transformation of materials took place. Thermal transformation of the materials, caused an increase in total contents of heavy metals in comparison to the material before transformation. From among elements, the cadmium content changed the most in materials after thermal transformation. As a result of thermal transformation, the content of water soluble form of the heavy metals decreased significantly in all the prepared mixtures. Low toxicity of the extracts from materials for *Vibrio fischeri* and *Lepidium sativum* was found in the research, regardless of transformation process. *L. sativum* showed higher sensitivity to heavy metals occurring in the studied extracts from materials than *V. fischeri*, evidence of which are the positive significant correlations between the content of metals and the inhibition of root growth of *L. sativum*.

1. Introduction

The management of sewage sludge is currently one of Poland's most pressing environmental challenges. The need for the disposal

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http://dx.doi.org/10.1016/j.chemosphere.2014.05.032
0045-6535/

of sewage sludge is governed by legal, practical, and aesthetic considerations. Significant changes in the structure of municipal sewage sludge management have been taking place in Poland in recent years. The amount of sewage sludge deposited and stored temporarily at treatment plants or used in land reclamation or for agricultural purposes, has been decreasing. It is anticipated that technologies allowing for an increase in the amount of thermally transformed sludge will be introduced. By the year 2020, 30% of generated sewage sludge is to be disposed of using thermal methods, 25% will be used agriculturally and environmentally, and 20% will be used in reclamation.

The process of low-temperature transformation of sewage sludge might be a way of organically recycling these materials. Apart from liquids and gases, another result of the process carried out in anaerobic conditions is a product which is often called biochar. It is a material which is chemically stable and safe in sanitary terms, and it is rich in plant macronutrients. According to research conducted so far, the internal porosity of biochar is considerably more developed than in the case of untransformed materials, which influences soil hygroscopicity, its amount and sorptive capacity as well as its biological activity (Chan et al., 2007; Steiner et al., 2008; Karhu et al., 2011). Heavy metals occurring in organic material processed to biochar may be a factor limiting the use of biochar from, for example, sewage sludge. Once introduced to soil, these elements might constitute a threat to the environment, especially in favourable conditions, e.g. acidification (Melligan et al., 2012). The process of low-temperature thermal transformation of sewage sludge alone is not well-founded, considering the possibilities for the natural use of sewage sludge. A loss of organic matter during thermal transformation leads to condensation of the content of mineral components, including heavy metals (Hossain et al., 2010). Better effects, not only in terms of the environment, but also in terms of technology, can be achieved after mixing sewage sludge with plant waste materials, such as cereal straw, sawdust or bark. The addition of these materials leads to the dilution of the heavy metals content, and it also improves the conditions for conducting the process of thermal transformation by influencing the structure of mass being transformed.

Biochar obtained from the low-temperature thermal transformation of mixtures of sewage sludge and plant waste may be considered a fertilizing material or, due to its beneficial physical properties, may be used for the improvement of properties of degraded soils (Chan and Xu, 2009; Hossain et al., 2011; Kawano et al., 2012). However, before such a material is used for environmental purposes, one should evaluate the possibility of occurrence of adverse effects of its use, e.g. in terms of the dose of heavy metals introduced to soil as well as the activity of these elements in the soil. The process of thermal transformation of sewage sludge mixed with plant waste may lead to significant changes in the bioavailability of, for instance, heavy metals (released from organic bonds) which might, after application to soil, reach excessive levels in the soil and pose a potential threat to individual links in the food chain (Faithful, 2000; Chan and Xu, 2009; Hossain et al., 2011).

The aim of the research was to determine whether the process of low-temperature transformation as well as the addition of plant material to sewage sludge would diversify the content of mobile forms of heavy metals and their ecotoxicity.

2. Materials and method

2.1. Characteristics of sewage sludge and plant materials used in research

The sewage sludge used in the research came from two sewage treatment plants: a municipal-industrial plant (A) as well as a municipal plant (B). Both plants are located in the Malopolska region (southern Poland). Prior to sample collection, the sewage sludge was stabilized, but the technology and the stability time were different. After preliminary condensation, sewage sludge (A) was subjected to mechanical disintegration (cavitation with a sudden pressure fall) and directed back to biological reactors or to an intermediate reservoir. From there, the sludge was transferred to separated fermentation chambers where it was stirred with a stirrer and heated using heat exchangers. The sludge fermentation time in the separated fermentation chambers was 19 d. The fermented sludge was then dehydrated on a belt press. Sewage sludge (B) was subjected to aerobic stabilization in separated open chambers where continuous aeration was conducted. The aeration of the sludge lasted 5 d, and then the sewage sludge was dehydrated in filtration plots for 2 months. The final step in the sewage sludge (B) stabilization was its hygienization using hydrated lime in a dose of 0.15 kg $Ca(OH)_2$ kg^{-1} of sludge dry weight.

When selecting materials to be used as components for preparing mixtures with sewage sludge, the important factors were ease of material access as well as effectiveness in improving physical properties of sewage sludge. Rape straw as well as wheat straw used in the research came from a farmstead. Sawdust and bark from coniferous trees were obtained as sawmill waste. Selected chemical properties of sewage sludge and of plant waste materials are presented in Tables 1 and 2.

2.2. Preparation of mixtures and process of their thermal transformation

In order to improve physical properties and to dilute the content of heavy metals, sewage sludge was mixed with plant materials. Before mixing with sewage sludge, rape straw and wheat straw as well as the bark of coniferous trees were shredded and sieved through a sieve with a mesh size of 5 mm. Sawdust from coniferous trees was used in the same form as it had been obtained. Based on the dry weight content determined in the materials that were used for the research (Table 1), appropriate analytical samples were prepared and mixed at 1:1 weight ratio with respect to dry weight. The experimental design included: sewage sludge A + rape straw (SSA + RS), sewage sludge A + wheat straw (SSA + WS), sewage sludge A + sawdust (SSA + S), sewage sludge A + bark (SSA + B), sewage sludge A with no addition (SSA), sewage sludge B + rape straw (SSB + RS), sewage sludge B + wheat straw (SSB + WS), sewage sludge B + sawdust (SSB + S), sewage sludge B + bark (SSB + B), sewage sludge B without addition (SSB).

The process of thermal transformation of mixtures of sewage sludge with various materials was conducted under laboratory conditions. The mixtures were placed in porcelain containers and subjected to thermal transformation in a chamber furnace, under conditions without air access. The procedure of the process was as follows: 130 °C for 40 min → 200 °C for 30 min. After completing the procedure, the materials were left in the furnace to cool (ambient temperature). The procedure consisted of two stages: the first stage (130 °C for 40 min) focused on drying the material, whereas in the second stage (200 °C for 30 min) the proper thermal transformation of materials took place. The applied durations of individual stages were supposedly to minimize carbon losses and make it possible to obtain a product with the best possible structure. After cooling, the materials were placed in a desiccator, and then weighed in order to determine the loss of mass.

2.3. Chemical analyses

The starting materials (sewage sludge, rape straw, wheat straw, sawdust, bark) as well as the mixtures of sewage sludge with plant