Thermal decontamination of sewage sludge

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Abstract. Every year a huge amount of sewage sludge is formed at municipal wastewater
treatment plants. Sewage sludge contains a sufficient amount of biogenic elements and organic
components, which characterizes them as possible raw materials for the production of organic
fertilizers. However, direct incorporation of these sediments into the soil is impossible due to the
fact that, in addition to useful organic and mineral components, they contain pathogens, viruses
and helminth eggs. The aim of the study was to optimise thermal disinfection conditions for
preparing of safety sewage sludge fertilizer. Laboratory studies were carried out using sediments
from wastewater treatment plants of some cities. During laboratory experiments, the conditions
for thermal disinfection of sediments – the thickness of the sediment layer, the air temperature in
the disinfection furnace, and the treatment time of the sediment – were determined. When
conducting industrial tests of a conveyor-type sediment decontamination furnace, the operating
conditions of the furnace were determined, i.e., the temperature regimes of the sludge heating
zone, the decontamination zone and the cooling zone, and the optimum parameters of the sludge
layer thickness on the conveyor and the conveyor speed were determined.

Key words: layer thickness, movement speed, organic fertilizers, sewage sludge, thermal
disinfection, residence time.

INTRODUCTION

Every year, a huge amount of sewage sludge is formed at municipal wastewater
treatment plants, which are aqueous suspensions or sludges with a high content of
organic substances of different composition (Lukasevich & Barskaja, 2007). Significant
health hazard for sewage sludge relates to the wide range of pathogenic microorganisms
which could present in sludge from municipal or industrial wastewater. Therefore,
hygienic principles must be followed in processing, storage or agricultural use of sewage
sludge (Romdhana et al., 2009). The situation is exacerbated by the constant increase in
the population of the Earth and followed increased amounts of municipal sewage sludge.

On the other hand, population growth requires a significant increase in the
production of food products, including agricultural products, which is impossible

without increasing soil fertility. It is possible to increase soil fertility and reduce its degradation by use of organic fertilizers. The main source of organic fertilizers is livestock enterprises and poultry farms. However, these enterprises are not able to fully provide agriculture with high-quality organic fertilizers. The deficit can be compensated by fertilizers obtained from municipal sewage sludge (MSS) (Alaru et al., 2009, Raheem et al., 2018).

The content of biogenic elements in sewage sludge is comparable to their content in manure, commonly used as organic fertilizer. Municipal sewage sludge also contains valuable inorganic ingredients such as N, P, K, Ca, S and Mg. Bacterial constituents (proteins, lipids etc.) and their decay products coupled with inorganic matter and cellulose form the chemical structure of sewage sludge. In addition, the use of sludge as a fertilizer allows largely recoup the costs associated with wastewater treatment (Charnok, 1983, Raheem et al., 2018).

However, direct incorporation of these sediments into the soil is impossible due to the fact that, in addition to useful organic and mineral components, they contain pathogens, viruses and helminth eggs. Sludge is unstable and after its application into the soil, the biochemical processes continue, leading to the release of harmful odorous substances to the environment.

To use sewage sludge as fertilizer, it is necessary to solve the following tasks:
- to decontaminate sediments, i.e., to reduce the content of pathogenic microorganisms to the required standards;
- to neutralize sediments, i.e., detoxify sediments and reduce the content of harmful substances in them to the permitted limits;
- to eliminate the unpleasant smell of sludge, i.e., to ensure the complete flow of biochemical processes, accompanied by release of foul-smelling substances into the atmosphere;
- to achieve maturation of fertilizer, i.e. to transfer organic matter in the sediment into forms that are easily absorbed by plants (Romdhana et al., 2009, Kelessidis & Stasinakis, 2012, Lombardi et al., 2017, Raheem et al., 2018).

These tasks can be solved by subjecting sediments to a standard composting scheme, for example, having sustained sludge in piles for a long time (up to several months and even years). This solution of the tasks has a number of drawbacks, of which the most significant is environmental pollution (soil, atmosphere and groundwater) with harmful substances and pathogenic microorganisms, as well as the need for specially prepared areas for the composting (Alvarenga et al., 2015; Ciešlik et al., 2015; Raheem et al., 2018). According to Heiba et al. (2016) more efficient and safer use of sewage sludge could be achieved through development of novel and more efficient composting technologies to solve environmental problems related to sludge use in agriculture.

The aim of this study was to improve the treatment conditions of municipal sewage sludge as the first stage in the production of organic fertilizers.

MATERIALS AND METHODS

Laboratory experiments were conducted at the Laboratory of company 'Ecosoil' (1st set of experiments) and Latvia University of Life Sciences and Technologies (2nd set of experiments).

1st set of experiments at the Laboratory of company 'Ecosoil' were conducted to determine the optimal regime of heat treatment in the experimental heating chamber for determining the conditions for effective decontamination of sediments. Heating chamber was equipped with electric heaters, a thermocouple and a temperature controller.

The experimental procedure was as follows: sediments of 500–1,000 g were placed in a special basket; the basket was placed in a heating chamber. The temperature in the chamber and inside the sludge was recorded. Two treatment regimes, differed in temperature mode and the duration of heating after reaching the specified temperature, were tested:

1. Sewage sludge was preheated to a temperature of 70–80 °C, the sediment was kept 180 minutes;

2. Sludge was preheated to a temperature of 140–150 °C, the sediment was kept 15 minutes.

The efficiency of decontamination was controlled according to the results of the determination of *Escherichia coli* (expressed as colony-forming unit (CFU) per 1 g of dry matter of the treated sludge. Bacteriological studies were carried out in a specialized laboratory 'Bactochem' of Israel.

2nd set of experiments were carried out at Latvia University of Life Sciences and Technologies. Dehydrated sewage sludge (dry matter 15–17%) was obtained from two waste water treatment plants in Zemgale region, Latvia. Sewage sludge was placed on polypropylene trays (l : w : h = 40.0 : 29.0 : 3.0 cm). The sludge layer was 3 ± 0.5 cm thick. The trays were placed in a heating chamber with a temperature of 150 °C. Pasteurization was carried out for 15 minutes from the time when the layer temperature reached 70 °C. After pasteurization samples were placed in test tubes. Total amount of microorganisms (MAFAM) was tested according LVS EN ISO 6222:1999, CFU of *E. coli* according LVS ISO 16649-2, and *Salmonella* spp. according LVS EN ISO 6579-1 was determined at Laboratory of Biotechnologies Latvia University of Life Sciences and Technologies.

Industrial Testing

Industrial tests of thermal disinfection technology were carried out at the wastewater treatment plant of Odessa Vodokanal. For this, a conveyor oven with a total length of the heat-affected zone of 6 meters was designed and built. The furnace is designed to handle 25 tons of sediment with a humidity of 80% per day. The furnace has 3 zones (heating, disinfection, cooling zone), each of which has a length of 2 meters. The first and second zones of the furnace are equipped with electric heaters, each of the zones is equipped with temperature sensors allowing to control the temperature in this zone. Sediment enters the furnace through a special loading device, before entering the heating zone, it is distributed along the conveyor with a layer of thickness specified by adjusting the volume of the material supply and its distribution over the width of the conveyor. The rate of passage of sludge through the furnace is regulated by a special device and adapted to the thickness of sludge layer so that the residence time of the sludge in the zone of disinfection is 15 minutes.

RESULTS AND DISCUSSION

The 1<u>st</u> set of experiments showed that sediment in the basket (layer thickness was 1–5 cm), and the air temperature in the chamber 70–80 °C, even with a significant warm-up time up to 3 hours, the sediments were not disinfected (Table 1). The number of CFU reached an extremely high value, i.e., 1,100,000 CFU g_{dw}^{-1} in 5 cm sewage sludge layer. Decrease of layers thickness reduced CFU of *E. coli* (coefficient of correlation r = 0.995) (Table 1).

The results showed that holding the sediment at a temperature of 70–80 °C in a heating chamber even in a thin layer for 180 minutes does not provide disinfection, since the sediment does not warm up in its entirety. The heat consumption for heating the sediment, heating the water and its evaporation is determined by the heat capacity of the sediment and water, as well as the heat of evaporation of the water. The energy calculations showed that the greatest amount of heat is spent on heating the water and its evaporation from the sludge, it is obvious that the heat energy input to the sludge material under these conditions is not sufficient to ensure its heating to the temperature necessary for disinfection. Only after enough energy is supplied to the system for these processes, heating of the sediment begins, the effectiveness of which depends on the thermo–physical characteristics of the sediment – thermal diffusivity (a), heat capacity (c_p) and thermal conductivity of the sediment (λ).

Table 1. Sediment disinfection results with adjustable layer thickness at air temperature in the heating chamber 70–80 °C

Nr.	Time of exposition, min	Thickness of layer, cm	Temperature in heating chamber, °C	Temperature in sludge, °C	E.coli, CFU
1	180	5	70–80	40–45	1,100,000
2	180	4	70–80	45–50	123,000
3	180	3	70–80	45–50	24,000
			70–80	45–50	,
			70–80	50–55	

In accordance with the Fourier law (Antipov et al., 2001), the heat flux (Q) passing through the material is directly proportional to the temperature gradient (ΔT), the area S through which the heat flux passes, and the thermal conductivity coefficient λ.

$$Q = -\lambda \cdot \Delta T \cdot S \tag{1}$$

On the other hand, the thermal diffusivity of the sediment depends on its thermal conductivity, heat capacity and density, as well as on the thickness of the sediment layer and the time of exposure of thermal energy to the sediment and can be described by the equations:

$$a = \frac{\lambda}{c_p \cdot \rho} \tag{2}$$

$$a = \frac{R^2}{4 \cdot Z^2 \cdot \tau} \tag{3}$$

where a – thermal diffusivity; λ – coefficient of thermal conductivity; c_p – heat capacity; ρ – sludge density; R – sludge layer thickness; τ – time of thermal energy impact on the sludge; Z – coefficient determined experimentally.

From Eqs (2) and (3) it follows that the greater the thermal conductivity of the sediment, the greater the thickness of the layer can be heated to achieve the required temperature for a certain time.

According to Antipov et al. (2001), the coefficient of thermal conductivity of precipitation depends on its water content. Considering that the water content of the sediments was reduced by centrifugation to 80%, the temperature range was experimentally found to provide a heat flux sufficient to reach a temperature in the sediment layer of 70–80 °C and decontaminate the sediment for 15–20 minutes.

The 2nd set of experiments was carried out in the chamber where air temperature was maintained in the range of 140–150 °C. Other temperature ranges were also tested, but at lower temperatures, the results of disinfection were unstable, and the use of higher temperatures is impractical, as it will significantly affect the cost of fertilizer due to high energy costs. The indicators of bacterial contamination of the treated sludge fluctuated dramatically, i.e., *E.coli* appeared from ≤ 3 (no bacterial contamination) up to 11,000 CFU g_{dw}^{-1}. This effect was caused by uneven heating of the sludge due to different thickness of the sludge layer, which did not provide the conditions for disinfection. Therefore, in further experiments, the sediment was leveled in thickness with a special roller. The layer thickness was varied within 1–5 cm. The air temperature inside the chamber was maintained within 140–150 °C. After installing the basket with sediment in the chamber, a sharp drop in temperature to 90–100 °C was observed, since intensive evaporation of water from the sediment began, but after 15–20 minutes the temperature again reached 140–150 °C, while temperature control in the sediment showed that after the temperature in the chamber had risen to 140–150 °C, it was 70–80 °C in the sediment. The sediment was kept under these conditions for 15 minutes (Table 2).

Results showed that the selected temperature range in the heating chamber provides stable disinfection performance even at a layer thickness of 5 cm in 15 minutes. Increasing the thickness of the sludge layer to 7 or more centimeters led to unstable results. Therefore, it was recommended to vary the design of an experimental industrial disinfection furnace with a sediment layer 2–5 cm. A smaller layer thickness is impractical because it reduces the productivity of the heating chamber.

Table 2. Results of sediment disinfection with adjustable layer thickness at air temperature in the heating chamber 140–150 °C

Nr.	Time of exposition, min	Thickness of layer, cm	Temperature in heating chamber, °C	Temperature in sludge, °C.	*E.coli*, CFU
1	15	5	140–150	70–80	< 3
2	15	4	140–150	70–80	< 3
3	15	3	140–150	75–85	< 3
4	15	2	140–150	85–90	< 3
5	15	1	140–150	85–90	

Experiments done at Latvia University of Life Sciences and Technologies approved final experiments done in Ukraine. Thermal treatment for 15 minutes killed *E. coli* and *Salmonella enterica*, but CFU of MAFAM decreased 5.3 times (waste water treatment plant 1) and 12.1 times (waste water treatment plant 2) (Table 3).

During pasteurization the content of dry matter in the sludge from the 1st Waste water treatment plant increased by 4.8% (from 144.4 g kg^{-1} to 151.3 4 g kg^{-1}), whereas from Waste water treatment plant 2 – by 8.9% (from 158.0 g kg^{-1} till 172.1 g kg^{-1}), respectively.

Table 3. Sediment disinfection results of two waste water treatment plants in Zemgale region, Latvia

Microorganisms, CFU g_{dw}^{-1}	Sewage sludge 1		Sewage sludge 2	
	Before treatment	After treatment	Before treatment	After treatment
E.coli	1.4×10^5	0	2.8×10^4	0
Salmonella spp	*Salmonella enterica*	0	0	0
MAFAM	4.1×10^6	7.8×10^5	3.4×10^6	2.8×10^5

Industrial Testing

Results of industrial testing at the wastewater treatment plant of Odessa Vodokanal showed that in the heating zone, the sludge is heated from ambient temperature to 70 °C, in the disinfection zone, the sludge continues to warm to 80–90 °C and its disinfection, in the cooling zone, the sediment cools to 60–70 °C. The disinfected sediment from the furnace is fed into a special bunker, in which it is cooled to a temperature of 40–50 °C and transferred to further processing (Table 4).

Table 4. Performance indicators of industrial decontamination in pasteurization chamber

Thick-ness of layer, cm	Move-ment rate, cm min^{-1}	1st zone		2nd zone		3rd zone		Conta-mination *E. coli* CFU
		t entrance	t exit	t entrance	t exit	t entrance	t exit	
2	5	20	110	120	160	150	80	0
2	10	20	110	120	160	150	80	0
3	5	20	110	120	160	150	90	0
3	10	20	110	120	160	150	80	0
4	5	20	110	120	160	150	85	0
4	10	20	110	120	160	150	90	300
5	5	20	110	120	160	150	85	1,500
5	10	20	110	120	160	150	80	3,000

As can be seen from the presented data, stable indicators of sediment disinfection are achieved with a layer thickness of not more than 3 cm and a movement rate up to 10 cm min^{-1}. With a layer thickness of 4 cm and a rate of 10 cm min^{-1} disinfection does not occur completely, and with a thickness of 5 cm disinfection is not achieved even at a speed of 5 cm min^{-1}.

Thus, based on the required performance of the decontamination in pasteurization chamber, a layer thickness of no more than 3 cm can be recommended with a conveyor speed of 10 cm min^{-1}.

CONCLUSIONS

1. To ensure disinfection of the whole volume of sludge, it is necessary to maintain a temperature of 140–150 °C in the heating chamber, while the temperature reaches 70–80 °C in the entire volume of sediment, which ensures reliable performance in 15 minutes disinfection.

2. Complete disinfection of sediment occurs at a layer thickness of no more than 5 cm. Reduction of the thickness of the sludge layer increases microbiological quality of material.

3. An increase in the duration of temperature exposure without an increase in its intensity seems to be irrational, since a further increase in the thickness of the layer unnecessarily slows down the process of disinfection of large amounts of sludge.

4. Based on laboratory studies, a conveyor thermal disinfection furnace was constructed at the municipal waste water treatment facilities in Odessa, including a heating zone, a disinfection zone and a cooling zone with established optimum temperature conditions 20–110 °C, 120–160 °C and 150–80 °C respectively and with an optimum sediment layer thickness of 3 cm and conveyor speed of 10 cm min^{-1}, providing complete disinfection of the sediment.

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