

Disinfection of Dehydrated and Non-Dehydrated Domestic Sewage Sludge in Sustainable Development

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ABSTRACT

The article is devoted to a comprehensive consideration of various options for the disinfection of sewage sludge. It is noted that the processes of sludge disinfection are still insufficiently studied, it is difficult to choose the appropriate treatment method in accordance with the physicochemical properties of the treated sludge and activated sludge. A comparative analysis of sludge compositions of different wastewater treatment plants is made. The authors determined the optimal conditions for the thermal treatment of sediments - temperature regimes and processing time, providing guaranteed disinfection of the material at minimal energy costs. The possibility of disinfection of a suspension of domestic sewage sludge using the cavitation-acoustic method is considered.

Keywords: domestic sewage, sewage sludge, thermal disinfection, cavitation-acoustic effect.

INTRODUCTION

The resolution of the UN General Assembly, as one of the goals for achieving the environmentally friendly development of the planet, defines the transition to the development of technologies for a closed cycle of production and consumption [United Nations, 2017]. This goal can be achieved only if the waste generated both in the process of industrial production and human life is involved in the economic cycle. With the development of urban infrastructure, the creation of new production facilities, the amount of waste is growing, which requires changes and modernization of systems for their removal, storage, and processing. An important problem for regions with high population density is the formation of significant volumes of sewage sludge [Collivignarelli et al., 2019; Hoang et al., 2022]. The warehousing and storage of these wastes requires the allocation of significant areas for special landfills and poses a threat to the

environment [Gusiatin et al., 2018], in connection with which, in recent decades, there have been searches for ways to reduce the volume and recycling of this waste [Cao et al., 2020]. Processing of domestic sewage sludge is a difficult task, given the multicomponent, heterogeneous nature of these wastes, as well as their contamination with pathogenic microorganisms. The choice of a method for processing domestic sewage sludge depends on their composition, physical and chemical properties, as well as the costs of implementing the chosen processing method [Gherghel et al., 2019, Skórkowski et al., 2018].

One of the main operations in the treatment of sewage sludge is disinfection. Disinfection is the removal of pathogenic microorganisms, viable helminth eggs present in domestic sewage sludge. For the disinfection of organic waste, chemical, biological methods or their combinations are used, however, physical methods of disinfection are most widely used. Methods differ in terms of energy costs, equipment complexity,

safety and environmental impact. When analyzing various methods of disinfection, their positive and negative sides have been evaluated and a conclusion is made about the advisability of using one or another method for processing various types of organic waste.

Radiation decontamination and irradiation in microwave units [Vialkova et al., 2021] is a high-tech approach to SS treatment. At the same time, this method has its drawbacks associated, firstly, with the use of ionizing radiation and possible radiation contamination of the resulting fertilizers, and secondly, with the complexity of the equipment and the need to use specific means of individual and collective protection aimed at ensuring the safety of the operating personnel. Chemical methods are based on the use of various chemical reagents that affect pathogenic microorganisms and helminth eggs [Hawrlylik, 2020]. Table 1 gives a description of the chemical reagents used for the disinfection of domestic sewage sludge, their advantages and disadvantages.

As follows from the data in Table 1, the use of chemical disinfection methods in most cases has disadvantages associated with the use of expensive reagents that are hazardous to humans and the environment. In this regard, only lime is used quite often. The use of other chemicals is very limited. In addition, biothermal processes occurring in organic waste during composting can be used [Wang et al., 2022]. The main disadvantage of biological and biothermal disinfection

processes is the duration of the processes, resulting in the need to allocate significant areas for the construction of landfills for biological [Chang et al., 2023] and biothermal treatment of sediments. Recently, physical methods of disinfection have become more widespread, as they are faster and more technologically advanced.

Physical disinfection methods are based on changing the habitat of pathogenic microorganisms, which leads to their death. The most severe physical method of disinfection is the thermal drying of organic waste at a temperature of 600 °C and above. Under these conditions, the complete death of pathogenic microorganisms occurs [Zhen et al., 2017]. But this method requires high energy costs and, in addition, in the process a part of the organic component of the waste is lost, which significantly reduces their nutritional value as fertilizers.

Pasteurization – heating of waste at a temperature of 80–90 °C within 30–40 minutes – is a gentler way of thermal disinfection [Nordell et al., 2021]. However, this method also requires a significant amount of energy, and is not reliable enough, because when heating large masses of waste in a thick layer and for a limited time, it is not possible to achieve the desired temperature in the entire volume of waste. This leads to the fact that disinfection will not be stable, bio-pathogens remain in the waste, which, during the storage of fertilizer, will lead to an increase in the concentration of pathogens above acceptable levels. The main disadvantage of

Table 1. Characteristics of chemical reagents used for disinfection [Lazarev and Levina, 1976]

No.	Reagent	Time of processing	Advantages of the reagent	Disadvantages
1	Quicklime	Determined by mixing time	Cheap, prevents pathogen reactivation	Not recommended for further use of fertilizers on alkaline soils, calcareous dust irritates the mucous membrane, causes burns when contacting with wet skin
2	Thiazon (nematocide)	Mixing for 60 minutes and exposure under film in piles on hard-surfaced sites for 10 days	Prevents the reactivation of pathogens, destroys pathogens, mold, phytonematodes and weeds in the soil	High toxicity, requires the creation of special sites for processing, quite a significant investment of time for processing
3	Ammonia	Exposure for 10 days	Prevents reactivation of pathogens, maintains precipitation stability	Toxic, volatile, requires equipment to be sealed to prevent release into air, long lasting
4	Carbation	Exposure for 3 weeks	Neutralizes helminth eggs	Toxic, no data on the neutralization of bacteria and viruses, long
5	Formaldehyde	20 minutes	Removes pathogens and helminth eggs	Toxic, requires additional reagents
6	Bleaching powder	1 hour	No data	Toxic
7	Phenol	-	-	Expensive reagent, dangerous to use, no quantitative indicators, toxic, carcinogenic
8	Carbon dioxide	-	-	Suppresses pathogens, but no data on effects on helminth eggs

thermal disinfection is the high energy intensity of the process when using conventional methods of heating with heating elements or hot air. Efficiency can be improved by using heating in microwave ovens, microwave ovens or infrared elements [Guo et al., 2021].

Microwave drying is gaining more attention due to its energy efficiency [Kocbek et al., 2020]. However, the economic performance and efficiency of the process depend on many factors: the type of sludge, heating modes, power output, the initial mass of the treated sludge, evaporation rate, heat recovery efficiency. In addition, this method requires more sophisticated equipment than that one used in conventional thermal treatment.

As a rule, the processes of disinfection by physical methods should be preceded by the processes of sludge and activated sludge dehydration, which reduces the volume of sludge to be buried, processed, facilitates transportation, and significantly reduces energy costs. One of the promising directions for the disposal of this type of waste is their processing into organic and organomineral fertilizers, which is determined by the high content of biogenic components and organic matter in sediments [Rodrigues et al., 2021]. In addition, an increase in the use of organic fertilizers, caused by an increase in the cost of mineral fertilizers, their negative impact on the structure of the soil, makes it necessary to involve new raw materials in the production of organic fertilizers, such as sewage sludge.

To use domestic sewage sludge as a raw material for the production of organic fertilizers, it is necessary to solve the main problem aimed at disinfecting sludge, i.e. reducing the content of pathogenic microorganisms to the required standards. These problems can be solved by subjecting the sludge to a conventional composting scheme, for example, keeping the sludge in heaps for a long time (up to several months). This solution has several disadvantages, of which the most significant are seasonal prevalence, the duration of the process, pollution of the environment (soil, atmosphere and groundwater) by harmful substances and pathogenic microorganisms contained in sediments, as well as the need for specially prepared areas, which should be located far away from settlements due to unpleasant odors at such stations.

The disadvantages listed above can be eliminated because of the development of an accelerated method for processing sewage sludge (SS) into fertilizers.

RESEARCH METHODOLOGY

During the study, generally accepted scientific methods were used: methods of comparison, generalization, and systematization. The information-search stage included the study of scientific and methodological literature. At this stage, when analyzing information, the methods of grouping, comparison, methods of information retrieval, and constructive-critical analysis of special literature were used. The results of this stage provide a conceptual description and characteristics of the objects of study from the standpoint of the information field, knowledge, and elaboration of the object under study.

The descriptive stage of the study was carried out to systematize the collected information and present it in the form of a theoretical review. At this stage of the study, different methods were used: system methods, generalization, analysis and synthesis, structural-functional and other methods. The work of the international research group Earth Revival, which conducted research within the framework of the Innovative Technology for Fast Sewage Sludge Recycling into Biological Fertilizer project (supported by The European Regional Development Fund), presents an analysis of various ways to dispose of domestic sewage sludge.

During the analysis of existing methods for the disposal of domestic sewage sludge, various aspects of the considered models of SS handling were compared, and ways to optimize sludge utilization were determined. Particular attention was paid to the possibility of combining different methods, the formation of a flexible, integrated approach in determining the most rational, economical, and fast way to convert sludge into fertilizer. Under laboratory conditions, the necessary temperature conditions and the minimum preheating time of the precipitate were determined by modeling.

RESULTS AND DISCUSSION

In the course of long-term studies, the composition of different sludges of waste water treatment plants from Acra, Banjul, Dobeles, Jelgava, Jerusalem, Odessa, Ust-Kamenogorsk has been considered. As follows from the collected data, the composition of various sludges differs primarily in the level of organic matter concentration. Mineral composition also differs, which is important for agronomic potential. At the same

time, the identified differences are not significant enough to have a considerable impact on the technical component of the processing procedure.

According to the standard procedures adopted in wastewater treatment plants, the multi-day amount of sewage sanitation is collected in settling tanks, where primary stabilization and gravity separation of the effluent takes place. Thus, physical-chemical and biological properties of the generated sludge are averaged and do not depend on daily variations of effluent composition, seasonal humidity, and initial amount of water in the sewage. Comparative Table 2 summarizes the data obtained during sampling in Gambia, Israel, Latvia, Ukraine.

The data shows that heavy metal contamination of sewage sludge in different regions has its own specific features, but in each case it is a percent fraction of the processed sludge total mass. Comparing with the allowances of national regulations for sludge-based organic fertilizers, it can also be noted that the contamination level for each indicator is in most cases at a low hazard level, in the context of safe use in agriculture [Directive 86/278/EEC,1986; DSTU 7369-2013]. Sewage

sludge is a natural epidemic hotspot, which requires compliance with the norms of hygiene and biological safety when interacting with sewage sludge. [Romdhana M.H] In particular, during the studies conducted as a result of pandemic SARS-CoV-2 announcement in the detection of the virus in fecal masses and the lack of data on the period of inactivation of the virus in wastewater. However, the risk of infection in thermally disinfected sewage sludge was determined to be low to negligible [The French Agency for Food, Environmental and Occupational Health and Safety, 2020].

The effectiveness of the disinfection methods is assessed by bacteriological control of the treated sludge. The economic costs of the disinfection process include the cost of the equipment or reagents used and the energy costs. From this point of view, composting is the least costly method, as it does not require complex special equipment and reagents; however, this method is seasonal, requires a large area for the composting station, emits a large amount of foul-smelling substances into the atmosphere, and some substances dissolve and get into surface and ground waters under the influence of precipitation. Based on the

Table 2. Comparative chemical composition of sewage sludge samples

Samples	Mass (d.m.), %					Mass fraction (d.m.), mg/kg									
	pH	Org	N	P	K	Pb	Zn	Hg	Fe	Cd	Cr	Cu	Mn	Ni	
Latvia															
Dobele (sludge)						149	409	~0		0.15		81	188	25	
Jelgava (sludge)						49	94	0.12		3	315	181		41	
Gambia															
Banjul. Naweq (sludge)	6.4	20.4	0.92	0.48	0.008	0.1 ⁻²	0.04	~0	1.45	<1					
Israel															
Jerusalem (sludge)	9.0	50.2	0.5	<0.1	1.55	16	740							12	
Acre			0.4	0.2	2.4	42.	1250							52	
Ukraine															
Odessa (active silt 13.12)	7.4		1.44	0.33	0.59	127	770	0.23		7.4					
Odessa (treated sl. 26.01)	5.4	52.0	1.73	1.03	0.15	6.8	36.0	0.16 ⁻³		0.1				15.0	
Odessa (treated sl. 30.01)	7.8		1.73	1.88	0.15	6.4	58.0	0.14 ⁻³		0.15				25.0	
Odessa (sludge 17.02)	6.8	59.2	1.83	1.42	1.27	53.1	334	0.87		2.34					

data from the study of different approaches to treatment and utilization of sewage sludge, the hierarchy of economic efficiency of treatment methods based on the average complex costs for each of the methods is determined. Taking into account the large amount of sludge generated during domestic wastewater treatment, the use of radiation, microwave methods, as well as most chemical reagents is not reasonable and failed to find their widespread use Figure 1 [Milieu, 2008].

Various national legislation and EU directives regulate the principles of sewage sludge management. A retrospective evaluation of Directive 86/278/EEC on the use of sludge in agriculture in 2014 showed that its original objectives have been achieved, despite significant differences in the amount of sewage sludge used in agriculture in the Member States, ranging from zero to more than 50% [European Commission, 2014].

According to Eurostat data on sewage sludge disposal from 2014 to 2018, the use of sewage sludge in agriculture combined with composting was the main sludge disposal route in the EU with 44.58%, followed by incineration (32.70%) and other disposal methods (9.16%). Waste landfilling was at 7.81% [Collivignarelli et al., 2019].

It is important to note that organic fertilizers enable to reduce the load on the soil, which increases as a result of unbalanced use of mineral fertilizers. The use of organic fertilizers based on sewage sludge increases the microbiological activity of soil, which has a beneficial long-term effect on mineral nutrition of plants [Dubova et

al., 2020]. The temperature-time criteria for pasteurization are set by national standards. The US Environmental Protection Agency (US EPA) has developed formulas for determining temperature and time regimes for thermal treatment of sewage sludge [Carrington, 2001]. In the course of experiments and industrial tests, practical problems of sludge thermal treatment optimization within the specified requirements were solved.

To clarify the modes of heat treatment during the research, the necessary temperature conditions and the minimum preheating time of the sludge were determined, which are necessary to achieve a temperature that ensures complete disinfection of the sludge. Figure 2 shows a diagram of temperature changes in the furnace and in the thickness of the sediment layer depending on the processing time. As can be seen from the presented diagram, to achieve the required temperature in the sediment layer for two minutes, it is necessary to maintain a temperature of 120–150 °C in the furnace.

Various variants of thermal disinfection of sludge in furnaces with a vibrating conveyor, using heat sources built into the pasteurization chamber were proposed and tested [Patent EP3950646, 2022]. To increase the efficiency of reducing the energy intensity of the process of obtaining fertilizer, as an alternative to the method of thermal disinfection described above, the possibility of using the cavitation-acoustic method for treating domestic sewage sludge is considered. Based on the preliminary studies [Vaysman et al., 2022], a conclusion was made about the fundamental

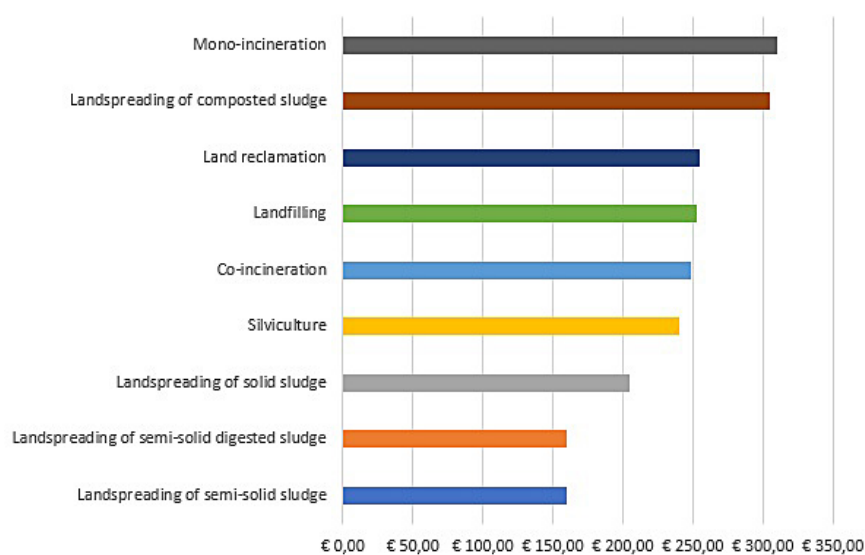


Fig 1. Average costs of sludge disposal and recycling, including operating and annualized investment costs for capital items (EUR/ t ·DM)

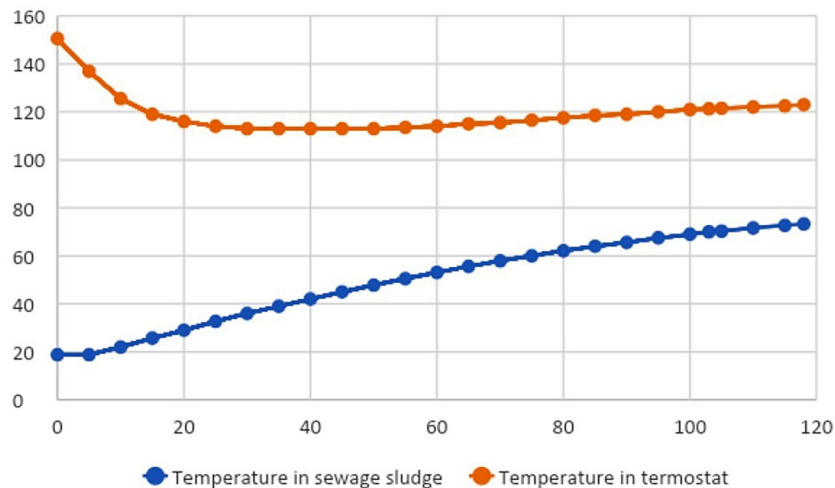


Fig. 2. Temperature in sewage sludge and thermostat

applicability of reagentless cavitation-acoustic disinfection to mechanically dehydrated SS. The possibility of implementing the proposed variant of cavitation-acoustic disinfection is confirmed by [Wolski, 2020; Zielinski et al., 2018; Widziewicz-Rzońca et al., 2023]. To increase the efficiency of disinfection, it is possible to offer a combined cavitation-acoustic effect with ozonation.

As an additional disinfecting effect, an electric pulse treatment of a suspension of domestic sewage sludge is recommended. Given the release of a large amount of energy in the process of hydrodynamic action in combination with electropulse processing will accelerate the transfer of the organic component of the resulting fertilizer into easily digestible products that are available to plants and do not inhibit their development in the process of using these fertilizers.

CONCLUSIONS

The analysis of methods of disinfection of domestic sewage sludge was carried out. The advantages and disadvantages of chemical, physical and biothermal disinfection methods are considered. A comparative analysis of sludge compositions of different wastewater treatment plants is made. It is shown that for accelerated disinfection of sewage sludge, thermal treatment of sludge at a temperature of 120–150 °C in the oven with preheating of sludge for 2 minutes. A variant of heat treatment in a chamber with a vibro-conveyor using heat sources built into it is considered. For disinfection of suspensions of domestic sewage sludge,

cavitation-acoustic treatment with electrical impulse action is proposed, which will ensure the transfer of the organic component of the resulting fertilizer into easily digestible products that are available to plants and do not inhibit their development in the process of using these fertilizers.

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