Technical and technological aspects of sewage waste management after amendments in legislation in Poland

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Abstract. Sewage sludge is generated in wastewater treatment plants as specific waste resulting from the processes of sewage purification and it requires the proper treatment. The growth in the number of people and use of modern more effective technologies of wastewater treatment results in an increase of amounts of produced sewage sludge. It would seem that municipal sewage sludge should enrich the soil with valuable elements (such as nitrogen, phosphorus, sulphur and magnesium) as well as organic matter due to its fertilizing and humus-generation facilitating features. However, the substance often contains excessive amounts of heavy metals and there is presence of organic pollution as well as pathogenic organisms and eggs of parasites. The introduction of prohibition of waste storage in 2016 as well as significant limitations to the use of sludge for agricultural purposes was a serious hindrance to the management of the waste. In order to verify the suitability of sludge for use in agriculture, samples of sewage sludge have been taken from one of wastewater treatment plants in the Malopolska province and an analysis of their elemental composition has been performed for better examination of the problem. Then the energy characteristics of the sludge have been checked.

1. Introduction

Sewage sludge is generated in wastewater treatment plants as specific waste resulting from the processes of sewage purification and it requires the proper treatment. The growth in the number of people and use of modern more effective technologies of waste treatment results in an increase of amounts of produced sewage sludge [1]. Costs related with its treatment and management also rise. The substance undergoes the operation of processing in order to make its properties stable and decrease its volumes. It is estimated that costs connected with processing of sludge and its further management comprise some 20 to 60 percent of the total expenditure related to functioning of waste treatment plant [2, 3]. The most frequent form of sludge on waste dumps and in the environment is initially stable (usually after oxygenic, non-oxygenic and calcium-based stabilization) [4, 5]. The substance poses yet quite a significant problem because of big hydration, mass and potential sanitary danger [6, 7]. The legislation of the European Union – so the directive of the Council number 86/278/EWG of 12th of June 1986 on the environment protection [8], the Directive of the European Parliament and the Council number 2008/98/WE of the 19th of November 2008 on waste [9] and the Directive of the Council number 1999/31/WE of the 26th of April 1999 on waste storage [10] – limits the storage of sewage sludge on waste dumps to a greater extent from 2013 and prohibits it completely
after the 1\textsuperscript{st} of January 2016. Simultaneously, there is a shift towards the annual increase of share of thermal methods of managing sewage sludge.

2. Legislation

The management of sewage sludge in Poland was largely influenced by legal requirements related with the membership of our country in the European Union. The result is the ban on the landfilling of sewage sludge (effective from the 1\textsuperscript{st} of January 2016) and annual growth of sludge generation as an outcome of expansion of sewerage systems and wastewater treatment plants [1, 5]. Due to all mentioned things, Poland faces a big problem of economic, technical and ecological nature. Until now, the final stage of neutralizing the sewage sludge was mechanical decalcifying and then dehydration and landfill [1, 3, 5, 11].

The changes in the manner of managing the sewage sludge arise from the following legal acts in force:

- The Act of the 14\textsuperscript{th} of December 2012 on waste (Journal of Laws of 2013, item 21 with further amendments) [12].
- The regulation of the Minister of the Environment of the 6\textsuperscript{th} of February 2015 on municipal sewage sludge (Journal of Laws of 2015, item 257) [13].
- The regulation of the Minister of the Economy of the 16\textsuperscript{th} of July 2015 on allowing waste to be placed at landfills (Journal of Laws of 2015, item 1277) [14].

The regulations above result from legal acts of the European Union:

- The directive of the Council number 86/278/EWG of the 12\textsuperscript{th} June 1986 [8] on the environment protection, especially the soil, in case of use of sewage sludge in agriculture. The directive restricts the possibilities of utilizing the sewage sludge for agricultural and environmental purposes by introducing quotas concerning the concentration of heavy metals in such substance.
- The directive of the Council number 91/271/EWG of the 21\textsuperscript{st} of May 1991 regarding the purification of municipal sewage [16] (prohibition of dumping the sewage sludge into the seas and oceans).
- The directive of the Council number 1999/31/WE of the 26\textsuperscript{th} of April 1999 on the waste storage [10]. The directive prohibits the storage of sewage sludge (on dumps other than dangerous and neutral) the combustion heat of which is over 6 MJ/kg of dry matter.
- The directive of the European Parliament and the Council number 2008/98/WE of the 19\textsuperscript{th} of November 2008 on waste [9].

3. Structure of generation and management of sewage sludge

According to the data of the Central Statistical Office [17] 3,273 municipal wastewater treatment plants were in operation in Poland in 2015. They serve over 27.9 million inhabitants (so around 73.2 percent of all people in Poland) and treat 1,756,898 thousand cubic meters of municipal sewage. Modern and high-performance systems of waste purification cause the generation of considerable amounts of sewage sludge. The prevailing direction of managing the municipal sewage sludge in 2015 in Poland was its neutralization through accumulated and collecting in the area of wastewater treatment plant (in stockyards, lagoons and tailing ponds). This method comprises even 45.7% of all cases. Other ways of managing are: use in agriculture (19.9%), utilizing for area reclamation (3.6%), use for cultivation of plants intended for compost production (8.7%) and thermal processing (14.7%).

The figure 1 presents the structure of sewage sludge management in Poland in 2015.
Through an analysis of the structure of sewage sludge generation (figure 2) in the years 2010-2015 one can note a successive increase in numbers of the produced sludge. There was a slight decrease in amounts of the substance utilized in agriculture – from 116.2 thousand Mg in 2011 to 107.5 thousand Mg in 2015. The quantity of sludge used for plant cultivation and compost production in the analyzed period of time grew significantly – from 30.9 thousand Mg (2010) to 47.1 thousand Mg (2015). The amount of sludge stored on waste dumps as well as collected in the area of waste treatment plant also fell significantly – from 58.9 thousand Mg in 2010 to 40.5 thousand Mg in 2015 and from 332.4 thousand Mg in 2010 to 246.9 thousand Mg in 2015, respectively. The utilization of sewage sludge – used for area reclamation – also decreased remarkably from 54.3 thousand Mg in 2011 to 19.2 thousand Mg in 2013 – by 35.4 percent. One can also pay attention to the fact that numbers of sewage sludge undergoing the thermal methods of neutralization rose significantly from 19.8 thousand Mg in 2010 to 79.3 thousand Mg in 2015. This is in line with targets of the municipal treatment of sewage sludge set in the domestic and the EU legislation. The most important aims are as follows [6]:

- total limitation of storing of sewage sludge.
- increase in amounts of municipal sewage sludge processed prior to the exposure to the environment and sludge transformed with the thermal methods.
- maximizing the grade of use of biogenic substances contained in the sludge while simultaneously fulfilling all requirements regarding the sanitary and chemical safety.
4. Logistics of sewage sludge

There is a number of possibilities of managing the sewage sludge. Each one of them, however, involves also some obstacles which means that there is no one good solution. There are different factors which influence the choice of the method: size of waste treatment plant from which the sludge comes, physical and chemical sludge properties. The figure 3 presents the division of processes connected with the logistics of sewage sludge. The processes are as follows: initial sludge processing (conditioning and final dehydration), thermal and biological processing, and final sludge treatment.

Figure 3. Processes of sewage sludge treatment [author’s own research based on [18]].
5. Research material
In order to perform the analysis, three samples of sewage sludge were taken separately in the month of January and June 2015. Sediments came from a wastewater treatment plant located in the area of Malopolska. The method of collecting those samples and the description of conduct of research are present in the publication [24]. During the physicochemical analysis, the content of dry residues, pH values, quantity of biogenic substances contained in sediments – that is total and ammoniacal nitrogen, total phosphorus, calcium and magnesium – were determined. The examinations also consisted in the determination of concentrations of heavy metals such as zinc, lead, copper, chromium, cadmium, mercury and nickel. They were all performed in accordance with reference methods for the examination of municipal sewage sludge defined in the appendix number 4 to the Regulation of the Minister for the Environment (Journal of Laws 2015, item 257) [13]. The obtained results and statutory limit values for contaminants have been compiled in tables 1, 2 and 3.

6. Biological use of sewage sludge
The selection of method of disposal of sewage sludge is based on its quality and in particular the presence of substances hazardous to the environment. The utilization of sediments in agriculture is considered as one of the best methods of recycling of municipal sewage sludge. Numerous fertilizing components present in the sewage sludge should be returned to the environment, especially that the shortage of organic substance in the soil is more and more frequently noticed.

The regulation of the Minister for the Environment of the 6th of February 2015 on municipal sewage sludge (Journal of Laws 2015, item 257) [13] states that the sewage sludge utilized for agricultural purposes must fulfill proper hygienic and sanitary requirements (table 1) and cannot exceed concentrations of heavy metals above the limit values defined in the regulation (table 2).

| Indicator                                                                 | Maximum level | Results obtained from tested sewage sludge |
|---------------------------------------------------------------------------|---------------|---------------------------------------------|
| Bacteria of Salmonella type in representative sample of sludge of weight of 100 g | 0             | 0 – 0.84                                    |
| Total number of live eggs of intestinal parasites Ascaris sp., Trichuris sp., Toxocara sp. in 1 kg of dry matter | 0             | 0 – 680 [pcs/kg of dry mass]                |
| soil pH value                                                             | Not less than 5.6 | 8 – 8.5                                      |

From the conducted research of physicochemical properties it appears that the pH value of examined sewage sludge is in a range from 8 to 8.5. The alkaline pH is influenced by the process of methane fermentation to which the sewage sludge is subject to in the process of its transformation. The research arising from the paragraph 2.1. of the regulation of Minister for the Environment of the 6th of February 2015 (Journal of Laws 2015, item 257) [13] covers the identification of pathogenic bacteria of Salmonella type and tests for the presence of live eggs of ATT intestinal parasites (of Ascaris sp., Trichuris sp. and Toxocara sp. type). Sanitary properties of sewage sludge are changeable in nature, but in the majority of cases the content of examined microorganisms has been detected. The obtained results clearly disqualify the use of sludge produced in a treatment plant as a fertilizer for agricultural purposes.
Table 2. Amount of heavy metals in used municipal sewage sludge [own research on the basis of: (Journal of Laws 2015, item 257) [13], Appendix 1 and [24].

| Metals       | Content of heavy metals in mg/kg of dry mass of sludge not more than: | Obtained results of examined sewage sludge [mg/kg dry mass] |
|--------------|---------------------------------------------------------------------|----------------------------------------------------------|
|              | In agriculture and for reclamation of lands for agricultural purposes | For reclamation of lands for non-agricultural purposes | For cultivation of plants intended for compost production. For cultivation of plants not intended for human consumption and for feed production |
| Pb           | 750                                                                  | 1,000                                                  | 1,500                                                  | 26 – 81 |
| Cd           | 20                                                                   | 25                                                     | 50                                                     | 1.5 – 5.18 |
| Hg           | 16                                                                   | 20                                                     | 25                                                     | 0.33 – 3.8 |
| Ni           | 300                                                                  | 400                                                    | 500                                                    | 36 – 105 |
| Zn           | 2,500                                                                | 3,500                                                  | 5,000                                                  | 1,300 – 2,288 |
| Cu           | 800                                                                  | 1,200                                                  | 2,000                                                  | 238 – 365 |
| Cr           | 500                                                                  | 1,000                                                  | 2,500                                                  | 25 – 720 |

The examination of sewage sludge has also shown significant fluctuations of metal concentrations. Variable chemical composition of the examined sludge can be influenced by the type of incoming sewage water, applied processes of sewage purification and conditions of the run of particular processes.

Among metals it is the chromium content which is characterized with the highest variability and exceeds the maximum values. The high content of chromium can be a result of the inflow of industrial waste.

Quantities of other elements in the examined sludge are low and do not exceed the maximum values defined by the regulation of Minister for the Environment of the 6th of February on municipal sewage sludge (Journal of Laws 2015, item 257) [13]. In case of use for agricultural purposes, the sludge can be a valuable source of nitrogen, phosphorus, carbon, organic matter and macro-elements essential for the correct growth of plants. The advantage of such managing is undoubtedly a relatively low cost. However, there are yet serious limitations connected with the utilization of sewage sludge arising from the necessity of fulfilling the requirements of the regulation of Minister for the Environment (Journal of Laws 2015, item 257) [13] as to the quantity of heavy metals and the presence of bacteria. Moreover, the agricultural utilization of sludge depends on the seasons and vegetation periods.

The examined sewage sludge can be used for the reclamation of lands for non-agricultural purposes and the cultivation of plants intended for the compost production because of low contents of heavy metals.

7. Thermal methods of sewage sludge management

The most frequent method which allows to use the sewage sludge in an energetic way is the combustion in incineration plants and the co-incineration in industrial equipment, for example in rotary furnaces and waste heat boilers [20-22]. The process requires the proper processing of sewage sludge (removal of moisture to a level lower than 20 percent) which assures at least the auto-thermal combustion (Wd> 6.5 MJ/kg) [23, 24].
Another way of the energetic utilization of sewage sludge can be the incineration in a cement rotary kiln [25]. High temperatures of gas streams (above 2,000 Celsius degrees) and burnt substances (around 1,450 Celsius degrees), turbulence and relatively long time (7 to 10 seconds) of gas and substance flow in a zone of high temperatures (above 1,200 Celsius degrees) make the sewage sludge combustion process in the cement rotary kiln fully compliant with all requirements included in the Regulation of the Minister of Economic Development of the 21st of January 2016 on requirements concerning the conduct of process of thermal transformation of waste and ways of proceeding with waste resulting from that process (Journal of Laws 2016, item 108) [14]. Conditions present in the furnace make the decomposition and burning of organic combustible matters inserted there complete [24]. An important advantage of the cement rotary kiln against the waste incinerator and other similar equipment is the waste-free disposal. The output of combustion – the ash – is totally absorbed and permanently attached to the clinker without posing any danger to the environment [23, 25, 26].

The table 3 below presents a comparison of the composition and net calorific value of the sewage sludge and conventional fuels.

**Table 3.** Comparison of selected properties of sewage sludge with conventional fuels [author’s own research based on [24, 27].

| Designator | Sewage sludge total | Examined sewage sludge | Coal sludge | Black coal | Brown coal | Waste wood |
|------------|---------------------|------------------------|-------------|------------|------------|------------|
| Net calorific value [MJ/kg] | 8 – 21.5 | 14.7 | 8 – 16 | 25 – 30 | 8 – 16 | 13 |
| Ash [%] | 30 | 21.7 | 30 – 60 | 5.3 | 10 – 20 | 0.8 |
| Carbon [%] | 50 | 37.4 | 31 | 88 | 66 | 50.7 |
| Hydrogen [%] | 6 | 6.1 | 3.7 | 6 | 5 | 5.9 |
| Sulphur [%] | 1 | 0.8 | 1 – 1.5 | 0.8 | 0.7 – 7 | 0.04 |

Sewage sludge has a similar net calorific value to the coal sludge, brown coal and waste wood. The ash content is big and it is only the coal sludge which can be characterized with bigger content of ashes. The amount of carbon element included in the sewage sludge is close to the coal sludge and waste wood, while the volume of hydrogen is similar to that in conventional fuels. The sewage sludge has large amounts of sulphur in comparison to other fuels. It is only the brown coal and coal sludge which contain bigger volumes of that element.

8. Sewage sludge landfilling

The sewage sludge is most frequently drifted to waste dumps and to the environment in an initially stable form (usually after oxygenic, non-oxygenic and calcium-based stabilization). The substance is yet quite problematic due to big hydration, mass and potential sanitary danger. It appears that municipal sewage sludge should enrich the soil with valuable elements (such as nitrogen, phosphorus, sulphur and magnesium) as well as organic matter due to its fertilizing and humus-generation facilitating features [6]. However, there are many factors limiting and even excluding its use for agricultural and environmental purposes. These are often excessive amounts of heavy metals [28, 31] presence of organic pollution (PAH – Polycyclic Aromatic Hydrocarbons, PCB – Polychlorinated Biphenyls, AOX – Adsorbable Organic Halogens [29, 30] and occurrence of pathogenic organisms and eggs of parasites [7].

The criteria for granting permission for the sewage sludge to be stored on waste dumps of other than hazardous and neutral type are presented in the table 4.
Table 4. Criteria for storing the sewage sludge on waste dump of other than hazardous and neutral type [Journal of Laws of 2015, item 1277 [15], appendix 4].

| Parameter                  | Limit value                                      |
|----------------------------|--------------------------------------------------|
| Total Organic Carbon (TOC) | 5 % of dry matter                                |
| Loss on ignition (LOI)     | 8 % of dry matter                                |
| Combustion heat            | Maximum of 6 MJ/kg of dry matter                 |

The last parameter – the heat of combustion – limits the possibility of storing unprocessed sewage sludge on waste dumps after the year 2016.

9. Costs of managing sewage sludge
The figure 4 presents average costs of various ways of managing the sewage sludge in Poland. Unit costs of the mono-incineration in big wastewater treatment plants are at about 1,750 PLN/Mg of dry matter which makes the method one of the most expensive. However, incurring high costs for the sludge neutralization seems to be unavoidable as much cheaper agricultural methods of managing the sludge are not always possible due to ecological and legal reason. Because of the ban on storing the sludge effective from the 1st of January 2016, this option is also much limited. Despite the fact that methods of co-incineration are much cheaper than the mono-incineration (by some 200 PLN/Mg of dry matter on average), energy producing industry is not interested in that kind of cooperation for the time being.

![Figure 4. Costs of management of sewage sludge (PLN/Mg of dry matter) [author’s own research based on [18].](image)](image)

10. Summary
In the coming years in Poland we will note a sharp increase of sewage sludge stream due to bigger and bigger possibilities of development and modernization of existing domestic wastewater treatment plants and building new objects of that type. The management of the increased sewage sludge will be a real challenge. The current legal rules treat the problem of sewage sludge storage on overcrowded municipal waste dumps more tougher. Moreover, quite popular natural methods of managing the sewage sludge also become less attractive because of high contents of compounds (heavy metals) in
the municipal sewage sludge coming especially from large urban areas. Those compounds are detrimental to the environment. This is why it appears that the main direction of sludge management will mainly become methods of thermal utilization.

The possibility of energetic use of the sewage sludge depends only on its physical and chemical properties. Those features namely arise from the content of processed sewage and its stabilization processes.

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