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Evaluation of dewatered sludge properties from a selected municipal sewage treatment plant

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ABSTRACT

An incorrectly maintained sludge management in wastewater treatment plants, may cause a major threat to the natural environment. Sewage sludge and supernatant, as by-products of the sewage treatment process, generate various chemical substances, including toxins. The aim of the study was to determine the physicochemical characteristics of sludge, sampled from a selected municipal wastewater treatment plant of a throughput of 9000 m^3/d. The supernatant and water extract of tested sludge were also determined. The tests were carried out in compliance with the accredited methods for municipal sewage sludge. The heavy metal content of tested sludge does not exceed the amounts specified for their use in agriculture and for land reclamation. Taking into consideration the use of polyelectrolytes in the sludge conditioning process, some examinations were performed using a gas chromatography electron-capture detector to determine the polyacryloamide content. Thus the concentration of this compound in the water extract from the sludge after the press was 1.62 μg/L, while in the supernatant from the pressed sludge it was at a level of 0.98 μg/L. In the examined water extract from the pressed sludge, a very high level of dissolved organic carbon was found (TOC = 128.5 mg C/L) as against the permissible value (TOC = 30 mg C/L). For this reason, the waste (pressed sludge) should not be disposed on a landfill site other than the one designed specifically for non-hazardous and neutral wastes.

Keywords: Sewage sludge; Thickening; Supernatant; Water extract; Polyelectrolytes

1. Introduction

The treatment, stabilization, dewatering, neutralization and utilization of sewage sludge constitutes a crucial part of the processes taking place in sewage treatment plants, which is,however, a constant source of various unresolved problems for the operators. All technical, technological and economic factors contribute to this [1–3].

Sewage sludge forms itself at various sewage treatment stages [4]. Its form and nature depends on the type of sewage getting to the sewage treatment plant

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Table 1
Comparison of the pressed sewage sludge supernatant properties with permissible impurity concentrations in cleaned industrial wastewater discharged into the surfacewater or soil

No.	Impurity index	Pressed sewage sludge supernatant	The highest permissible impurity index values for cleaned industrial wastewater[a]
1.	pH	7.5 ± 0.2	6.5–9.0
2.	Chlorides, mg/L	83.1 ± 1.7	1,000
3.	Sulphates, mg/L	106.0 ± 21.2	500
4.	Fluorides, mg/L	<0.1	25
5.	TOC, mg/L	7.93 ± 1.6	30
6.	Zinc, mg/L	0.062 ± 0.006	2
7.	Lead, mg/L	<0.010	0.5
8.	Cadmium, mg/L	<0.0005	0.4
9.	Copper, mg/L	0.251 ± 0.025	0.5
10.	Total chromium, mg/L	<0.003	0.5
11.	Nickel, mg/L	0.007 ± 0.0007	0.5
12.	Mercury, mg/L	<0.0005	0.06
13.	Arsenic, mg/L	<0.0010	0.1
14.	Selenium, mg/L	<0.0010	1
15.	Barium, mg/L	0.0037 ± 0.0003	2
16.	Molybdenum, mg/L	0.0046 ± 0.0004	1
17.	Antimony, mg/L	<0.05	n.s.
18.	Dissolved solid compounds, mg/L	626 ± 62.6	n.s.
19.	Acrylamide[c], μg/L	0.98 ± 0.36	0.1[b]

Notes: n.s.—non-standardized value. <—value below the lower detectability limit of the measuring method used.

[a]As per Appendix No. 3 "The highest permissible impurity index values for cleaned industrial waste water" (Tables I and II—The highest permissible values for the other impurity indices) to the Regulation of the Minister of the Environment of 24 July 2006 on the conditions that shall be met when discharging wastewater into the surfacewater or soil and on substances particularly harmful to the aquatic environment. (Dz. U. No. 137, Item 984, with subsequent amendments).

[b]The value relates to the water monomer residue concentration calculated in accordance with the specifications for the maximum liberation from the respective polymer in contact with water.

[c]Requirements of the Regulation of the Minister of Health of 20 April 2010 (Item 466), Appendix No. 1, basic chemical requirements to be met by water.

and on the applied sewage treatment technology [5,6]. It has been proved that in reality there are no two identical sewage sludges [7,8]. With an increase in amount of sewage directed to treatment, the amount of sludge also grows . Thus, the scale of the sludge management issue is constantly increasing [9–11]. Sludge formed as a result of sewage treatment is a multiphase, polydispersion system, in which the liquid (water together with substances dissolved in it), or the supernatant water, makes a dispersing phase, while solid particles (mineral and organic) and occassionally gas bubbles, constitute a dispersed phase. The proportion between the solid phase and the liquid determine the hydration of the sludge, which is the most characteristic feature of sewage sludge. The most important operations in the sludge treatment process includes the removal of the water contained in the sludge, that is, the separation of the solid phase from the supernatant, whereby a considerable reduction in the sludge volume can be achieved and the stabilization of the sludge, which results in reduction of its odour-related nuisance [12,13]. In large sewage treatment plants, the following sludge treatment processes are distinguished, among others: mechanical thickening, anaerobic stabilization, mechanical dewatering, drying or liming [14,15]. In the thickening process, only free water (either "originally free" or liberated from the conditioning process) can be removed from the sludge [16,17]. In most of the devices, preliminary flocculating of the sludge with polyelectrolytes is necessary in order to achieve the proper phase-separation degree and the thickening effect. The consumption of the polymer is within 2–8 g/kg dm [4,18].

The most common practice is to use chemical conditioning of sludge by adding polymers or coagulants (calcium, iron, aluminium compounds and polyacryloamide) to improve the properties of the sludge [19,20]. A properly selected polymer increases the purity of effluents and reduces the hydration of the sludge. An incorrectly chosen polyelectrolyte may increase the operational costs and also lower the sludge dewatering

Table 2
Comparison of the pressed sewage sludge water extract properties with permissible impurity concentrations in cleaned industrial wastewater discharged into the surfacewater or soil

No.	Impurity index	Pressed sewage sludge water extract	The highest permissible impurity index values for cleaned industrial wastewater[a]
1.	pH	7.8 ± 0.2	6.5–9.0
2.	Chlorides, mg/L	49.8 ± 10	1,000
3.	Sulphates, mg/L	<10.0	500
4.	Fluorides, mg/L	<0.1	25
5.	DOC, TOC, mg/L	128.5 ± 25.7	30
6.	Zinc, mg/L	0.260 ± 0.026	2
7.	Lead, mg/L	<0.010	0.5
8.	Cadmium, mg/L	<0.0005	0.4
9.	Copper, mg/L	<0.004	0.5
10.	Total chromium, mg/L	<0.003	0.5
11.	Nickel, mg/L	<0.004	0.5
12.	Mercury, mg/L	<0.0005	0.06
13.	Arsenic, mg/L	<0.0010	0.1
14.	Selenium, mg/L	<0.0010	1
15.	Barium, mg/L	0.0037±0.037	2
16.	Molybdenum, mg/L	0.0046±0.005	1
17.	Antimony, mg/L	<0.05	n.s
18.	Dissolved solid compounds, mg/L	2039±204	n.s
19.	Acrylamide[c], μg/L	1.62±0.60	0.1[b]

Notes: n.s.—non-standardized value. <—value below the lower detectability limit of the measuring method used.
[a]As per Appendix No. 3 "The highest permissible impurity index values for cleaned industrial waste water" (Tables I and II—The highest permissible values for the other impurity indices) to the Regulation of the Minister of the Environment of 24 July 2006 on the conditions that shall be met when discharging wastewater into the surfacewater or soil and on substances particularly harmful to the aquatic environment. (Dz. U. No. 137, Item 984, with subsequent amendments).
[b]The value relates to the water monomer residue concentration calculated in accordance with the specifications for the maximum liberation from the respective polymer in contact with water.
[c]Requirements of the Regulation of the Minister of Health of 20 April 2010 (Item 466), Appendix No. 1, basic chemical requirements to be met by water.

effect. Unfortunately, using polyelectrolytes in water treatment, sewage treatment and in the manufacture of adhesives, plastics, paper or cosmetics causes this mutagenic and carcinogenic compound to penetrate into the environment. Physical methods, which may eliminate or reduce the chemical reagents used in some environmental engineering applications, include ultraviolet light [20] and ultrasonic field [21–23].

The aim of the investigation was to establish the physicochemical characteristics of sewage sludge and effluents (supernatant) and to determine their contents of toxic substances, including heavy metals and organic compounds.

2. Experimental

2.1. Testing methodology and quality control

The substrate for the tests was sewage sludge originating from a municipal sewage treatment plant with a throughput of 900 m^3/d. The waste of the code 19 08 05, represented by municipal sludge after the press, contained 7.40% dm of total nitrogen (determined by the Kjeldahl method EN 13342) and 1.66% dm of total phosphorus. The organic matter content (determined as the loss on ignition at a temperature of 600˚C) in the representative sample was very high, around 83.7% dm The dry matter content of tested sludge was 15.0%. The sludge contained 1.53% dm of calcium and was characterized by the reaction close to neutral (pH 6.9). It was slimy, with a strong rotten odour and brown colour.

The laboratory tests of the sludge were carried out in an accredited testing laboratory. This laboratory has all qualifications necessary for conducting sewage quality analyses in compliance with the requirements of the provisions of the Act on wastes of 14 December 2012 (Dz. U. 2013, Item 21).

This certification confirms that the laboratory meets the requirements of the standard PN-EN ISO/IEC 17025. The testing scope was selected to conform

Table 3
Comparison of sludge water extract testing results with limiting leaching values, which have been determined for wastes disposed of on non-hazardous and neutral waste landfill sites and on hazardous landfill sites

No.	Impurity index	Sludge water extract	Permissible limiting leaching values Basic test: Non-hazardous and neutral waste landfill site	Permissible limiting leaching values Basic test: Hazardous waste landfill
1.	pH	7.8 ± 0.2	–	–
2.	Chlorides, mg/kg dm	498 ± 99.6	15 000	25 000
3.	Sulphates, mg/kg dm	<100	20 000	50 000
4.	Fluorides, mg/kg dm	<1.0	150	500
5.	DOC, mg/kg dm	1,285 ± 128.5	800	1 000
6.	Zinc, mg/kg dm	2.60 ± 0.26	50	200
7.	Lead, mg/kg dm	<0.10	10	50
8.	Cadmium, mg/kg dm	<0.005	1	5
9.	Copper, mg/kg dm	<0.04	50	100
10.	Total chromium, mg/kg dm	<0.03	10	70
11.	Nickel, mg/kg dm	<0.04	10	40
12.	Mercury, mg/kg dm	<0.005	0.2	2
13.	Arsenic, mg/kg dm	<0.010	2.0	25
14.	Selenium, mg/kg dm	<0.010	0.5	7
15.	Barium, mg/kg dm	0.750 ± 0.075	100	300
16.	Molybdenum, mg/kg dm	<0.040	10	30
17.	Antimony, mg/kg	<0.50	0.7	5
18.	Dissolved solid compounds, mg/kg	19 400 ± 1940	60 000	100 000

Note: <—value below the lower detectability limit of the measuring method used.

to the analytical scope of the above-mentioned regulations. The polyacryloamide content test, on the other hand, was performed on account of the use of polyelectrolytes in the sludge conditioning process.

Characteristics tested and testing/measurement methods: the pH determination was made in accordance with the standard PN-EN ISO 10523:2012 by the potentiometric method, the chloride concentrations were determined according to the standard PN –EN ISO 10304–1: 2009 by the ion chromatography method and fluorides were assayed according to the standard PN-78/C-04588/03 by the potentiometric method. The total organic carbon (TOC)/dissolved organic carbon (DOC) was determined by the infrared spectrophotometry method in accordance with the standards PN-EN 12457-4: 2006 and PN-EN 1484:1999. The concentration of the elements: antimony, barium, total chromium, zinc, total phosphorus, cadmium, copper, molybdenum, nickel and lead was determined by the inductively coupled plasma-optical emission spectrometry (ICP-OES) method according to the standard PN-EN ISO 11885; 2009. Mercury was determined by the cold vapour-atomic absorption spectrometry (CV-AAS) method according to the standard PN-EN 1483:2007; arsenic was determined by the hydride-generation atomic absorption spectrometry (HG-AAS) method; and polyacryloamide was determined using gas chromatography with an electron capture detector, method 8032A.

Measurement uncertainty was defined as expanded uncertainty, with the expansion factor $k = 2$ and probability of 95%.

2.2. Analysis of the testing results

2.2.1. Analysis of the supernatant from the pressed sewage sludge

The results of the analyses with the measurement uncertainty of the pressed sewage sludge supernatant are presented in Table 1.

The analysis of the supernatant from the sludge after the press showed a slightly alkaline reaction (pH 7.5) and this value falls within the range of its permissible values (pH 6.5–9.0) as specified for the cleaned industrial waste water discharged to the surface water or the soil. A low level of DOC (TOC = 7.93 mg C/L) was also observed, as against the allowable value (TOC = 30 mg C/L). The tests carried out did not reveal any metal contents exceeding the permissible standard values. The effluent from the sludge tested was characterized by low salt concentration, as

Table 4
Heavy metal concentrations in pressed sewage sludge—evaluation of the possibility of agricultural utilization

Heavy metal	Pressed sludge sample	Heavy metal level in mg/kg of sludge dry mass not higher than, when using the sewage sludge[a]		
		in agriculture and in land reclamation for agricultural purposes	in land reclamation for non-agricultural purposes	for adapting the land to suit specific needs resulting from waste management plans, land management plans or land development and management decisions; for growing plants intended for compost production; for growing plants not intended for consumption or feed production
1	3	4	5	6
Zinc, mg/kg dm	902 ± 180	2,500	3,500	5,000
Lead, mg/kg dm	73 ± 15	750	1,000	1,500
Cadmium, mg/kg dm	1.41 ± 0.28	20	25	50
Chromium, mg/kg dm	18.6 ± 3.7	500	1,000	2,500
Copper, mg/kg dm	181 ± 36	1,000	1,200	2000
Nickel, mg/kg dm	15.0 ± 3.0	300	400	500
Mercury, mg/kg dm	0.37 ± 0.09	16	20	25

Note: dm— dry mass.
[a]Acc. to the Regulation of the Ministry of the Environment (Dz. U. No. 137, Item 924, 2010).

evidenced by the small amounts of chlorides (Cl = 83.1 mg/L) and relatively small amounts of sulphates (SO_4 = 106 mg/l) and dissolved solid compounds (626 mg/L). Besides, some tests for polyacryloamide were made, whose content was found to be 0.98 μg/L, being more than ten times the permissible concentration of this compound in potable water, as specified by the above-mentioned Regulation [12].

2.2.2. *Analysis of the water extract from the sewage sludge after the press*

Table 2 contains a summary of analysis results for the water extract from examined sewage sludge after the press.

The analysis of the extract from the sludge (after the press) showed a slightly alkaline reaction (pH 7.8), which fell within the range of its permissible values (pH 6.5–9.0) as specified for the cleaned industrial wastewater discharged to the water or soil. Whereas, a very high level of dissolved solid organic (TOC = 128.5 mg C/L) relative to the permissible value (TOC = 30 mg C/L) was observed. The tests on the water extract did not show any metal contents exceeding the permissible standard values. The water extract from the examined waste is characterized by a low salt concentration, as evidenced by trace amounts of chlorides (Cl = 49.8 mg/L) and a relatively trace of sulphate amount. Also, tests for polyacryloamide were made, whose content was found to be 1.62 μg/L, being more than fifteen times the permissible concentration of this compound in potable water, as specified by the aforementioned Regulation.

2.2.3. *The analysis of the water extract—evaluation of the possibility of landfilling the sludge*

The water extract testing results were also used for the evaluation of the possibility of landfilling the sludge. Given below is a summary of the concentration of the examined sludge water extract components together with the limiting leaching values for wastes permitted to be disposed of on non-hazardous and neutral waste landfill sites and on hazardous waste landfill sites (Table 3). The permissible limiting values for granular waste with small grain sizes of individual elements are determined by the ratio of the liquid to the solid phase being equal to 10 L/kg–the basic test.

The summary provided in the table above shows that the water extract from the pressed sludge does not meet the requirements specified in Appendices 1 and 2 to the Regulation of the Minister of the Economy of 8 January 2013 on the criteria and procedures for permitting wastes to be disposed of on a specific type waste landfill site (Dz. U. 2013, Item 38) due to the very high level of DOC. For this reason, the waste 19 08 05 (municipal sewage sludge) may not be disposed of on a non-hazardous and neutral waste landfill site. The water extract does not comply with the requirements of Appendix No. 2 of the aforementioned Regulation of the Minister of the Economy of 8 January 2013 in respect of the DOC level, which means that the sludge after the press may not be disposed of on a hazardous waste landfill. The provisions of the Regulation in question implement the provisions of the Council Decision No. 2003/22 CE establishing criteria and procedures for the acceptance of waste at landfills.

2.2.4. Permissible heavy metal contents of municipal sewage sludge

Table 4 provides pressed sludge heavy metal analysis results as against the Regulation of the Minister of the Environment of 13 July 2010 on municipal sewage sludge (Dz. U. No. 137, Item 924, 2010) complying with European Standards.

The interpretation of the testing results given in the table above was made based on the rules set out in Appendix No. 1 and in art. 2 of the Regulation of the Minister of the Environment of 13 July 2010 on municipal sewage sludge (Dz. U. No. 137 Item 924). The concentrations of the analysed metals in the representative pressed sludge sample did not show any values in excess of the levels permitted under the aforementioned Regulation.

3. Conclusions

In accordance with the Regulation of the Minister of the Environment of 13 July 1010 on municipal sewage sludge (Dz. U. of 2010, No. 137 Item 924) from a municipal sewage treatment plant, as represented by the pressed sludge sample, meets, in respect of heavy metal contents, the quality requirements for sludge to be utilized (subject to recovery R-10—spreading on the soil surface for the purpose of soil fertilization or improvement) in compliance with the quoted Regulation.

Numerous toxins contained in sewage flowing into the treatment plant might accumulate in the sewage sludge. According to the legislator, the basic chemical indicator of the quality of sludge is its content of heavy metals. The high class of toxicity of the samples of both sewage sludge and supernatant, found in the tests, largely limits the possibility of utilizing the sewage sludge for agricultural purposes (e.g. acrylamide, lack of permissible values). This will not be possible, however, without preparing the relevant legal acts. Tests will undoubtedly play an important role in the process of complementing the evaluation of the quality of sewage sludge and effluent, especially if they are to be utilized in agriculture. It is necessary, however, to conduct those tests in order to assess toxicity of inflowing sewage and to establish the analytical ranges and precise assessment criteria.

To sum up, the examination of the composition of the water extract from the pressed sludge originating from the sewage treatment plant under study has shown that this sludge could be used in the R-10 process; however, this might contaminate the surface and underground waters with organic compounds (TOC, polyacryloamide). For this reason, the waste (pressed sludge) should not be disposed of on a non-hazardous and neutral waste landfill site.

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