

## EFFECT OF DIFFERENT METHODS OF TREATMENT OF MUNICIPAL SEWAGE SLUDGE ON THEIR PHYSICOCHEMICAL PROPERTIES AND THEIR AGRICULTURAL UTYLIZATION

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### ABSTRACT

In the study the physicochemical properties of selected municipal sewage sludge were compared using the reports on waste generation from the years 2007–2012 in the Mazovia voivodship. The selection was done on the basis of different methods of sludge processing and the number of equivalent inhabitants (NEJ) supported by sewage. Physical and chemical properties of municipal sewage sludge were significantly dependent on the method of purification and treatment methods. These sludges were characterized by a high content of organic matter and macronutrients. The amount of heavy metals (Pb, Cd, Cr, Cu, Ni, Hg and Zn) were within acceptable standards for municipal sewage sludge used in agriculture. Municipal sewage sludge treated by biological method with higher nutrients removal did not create bacteriological danger and were used in agriculture, generally to the cultivation of all agricultural products. Sewage sludge sanitized with lime and subjected to anaerobic digestion did not meet bacteriological standards, which eliminated their use in agriculture.

**Keywords:** municipal sewage sludge, physicochemical properties, agricultural utilization.

### INTRODUCTION

The chemical composition of sewage sludge is very varied, dependent on the season of year, the city's infrastructure and the quantity and quality of effluents discharged by the industry to municipal wastewater treatment plants. Processes in sewage directly or indirectly affect the sediment, changing its properties. The processes selection of sludge treatment has a significant influence on the subsequent their utilization [Simonetti et al. 2014]. Most often municipal wastewater in treatment plants are mechanically and biologically treated. In this process significant amounts of soluble organic substances, difficulty sedimenting suspensions and colloids, reducing the amount of viruses and bacteria are removed from the waste water. From the inorganic substances only those absorbed by microorganisms the nitrogen and phosphorus com-

pounds are removed. The stream of municipal sewage sludge in Poland are increasing rapidly, as is the effect of dynamically running modernization and the introduction of more advanced wastewater treatment technology or the construction of new wastewater treatment [Stypka, Flaga-Maryańczyk 2013]. The approach to the sludge from the technology site of little or no waste is at the moment one of the most important aspects [Leszczyński, Brzychczyk 2007, Pawłowski et al. 2000]. Municipal sewage sludge, in accordance with the legislation in force in Poland can be used for fertilizer, as evidenced by the operating law regulations, including the Act on Waste [2012] and the Regulation of the Minister of Environmental Protection [2002, 2010]. The suitability of sewage sludge to agricultural utilization is determined by such factors as: the content of organic matter, nutrients for plants, content of permanently damaging (undegradable

and degradable very difficult) to the environment, the presence of pathogenic organisms, consistency [Simonetti et al. 2014].

The aim of the study was to evaluate the physicochemical properties of municipal sewage sludge treated by various methods from selected wastewater treatment plants with different throughput mass of Mazovia voivodship.

## MATERIAL AND METHODS

The paper presents the results of studies from the reports on waste generation in the years 2007–2012 in the Mazovia voivodship [Report of the production of waste]. Of the 598 municipal wastewater and industrial treatment plants exploited in Mazovia - as in 2012 [<http://wios.warszawa.pl>], four municipal sewage treatment plants using different methods of treatment were selected. On the basis of the wastewater load the treatment plant was expressed by a number of equivalent inhabitants (NEJ) tested treatments were classified to II, III, IV and V group. Group I – treatment support up to 2 thousand of NEJ, II – 2–10 thousand of NEJ, III – 10–50 thousand of NEJ, IV – 50–100 thousand of NEJ V - over 100 thousand of NEJ. Most of the selected wastewater treatment uses biological method of sludge treatment. Administrative policy of the community and the activities of exploiter can significantly affect the quality of the produced sludge, as well as its quantity. Two of the selected treatment plants belonging to II and III group purified and wastewater by biological method with increased nutrient removal (MB). Wastewater treatment by this method allows an increased reduction of nitrogen and phosphorus. Sludge from wastewater treatment plants belonging to the second group is subjected to further composting (MB-K). This process ensures the stabilization of organic compounds, natural disinfection, reducing the weight of sludge and production of a stable final product. In the largest wastewater treatment plants (group V) in Warsaw sewage sludge is disposed in the anaerobic process (fermentation) (MB-F). In the next wastewater treatment (group IV) chemical method for treatment of waste water is used by the addition of quicklime (MCh-CaO). The estimation of sewage sludge includes such parameters as pH, content of viable eggs of parasites, the dry matter, organic matter content, macronutrients, except for potassium, and the content of heavy metals. Reports

show that the sediments produced by the selected treatment in Mazovia province were not always clean in bacteriological terms (Table 1).

**Table 1.** Number of live eggs of parasites in municipal sewage sludge treated by various methods in Mazovia voivodship in the years 2007–2012

Sewage sludge	Year		
	2007	2009	2012
MB-K (G II)	0	0	0
MB (G III)	0	0	0
MCh-CaO (G IV)	0	198.0	0
MB-F (G V)	0	93.0	155.0

Data on the content of macronutrients and heavy metals were compared statistically using Statistica program, Version 10.0 StatSoft, for a detailed comparison of the mean values Tuke'y test at  $p < 0.05$  were used.

## RESULTS AND DISCUSSION

Physical and chemical properties of municipal sewage sludge are variable, depending primarily on the type of sewage, method of purification and processing methods [Maćkowiak 2000]. The analysis (table 2) shows that the lowest pH average 6.16 was characterized by sludge from sewage treatment plants applying biological treatment associated with composting, and almost twice higher pH value = 12 was recorded in the sludge from wastewater applying lime stabilization. Deacidifying activity of sewage sludge used in agriculture is confirmed by the research of many authors [Speir et al. 2003]. The dry matter content in sewage sludge ranged from 22.63 to 51.5%. The highest content of dry matter was characterized by sludge from a biological treatment plant with increased nutrient removal and the least sludge subjected to fermentation. Municipal sewage sludge contain diverse content of organic matter, which ranged from 16.7% to 51.7%. Most of organic matter was observed in the sediment subjected to composting. Maćkowiak [2000], based on eight years of research gives an average of 50.62% of organic matter in municipal sewage sludge and agri-food sewage in Polish. Sanitary characteristics of sewage sludge are variable and are based on many factors, among others, dependent on the quality of life and health status of residents in the area, the type of treated wastewater and process-

**Table 2.** Mass and selected parameters of municipal sewage sludge

Sewage sludge	Mass of sewage sludge (Mg / years)		Aim of application	pH			D.M. (%)			Organic material (% D.M.)		
	F.M.	D.M.		min.	max.	average	min.	max.	average	min.	max.	average
	2007											
MB-K (G II)	756000	227000	1	5.30	6.80	5.80	21.5	32.0	26.0	41.3	57.8	51.7
MB (G III)	1309000	261880	3	8.27	8.07	7.90	49.9	64.3	51.5	13.3	17.9	16.7
MCh-CaO (G IV)	1843000	626900	5	11.2	11.7	11.4	28.2	38.9	34.0	17.0	26.5	20.5
MB-F (G V)	1329000	342000	5	8.50	12.0	11.0	16.5	33.8	22.6	38.1	65.5	53.4
2009												
MB-K (G II)	807000	242000	1	6.10	6.50	6.30	31.8	42.3	37.1	32.0	45.3	38.7
MB (G III)	1317000	263000	1	7.47	8.46	7.86	24.8	50.7	35.2	18.1	33.5	28.0
MCh-CaO (G IV)	3750000	1200000	5	12.0	12.5	12.2	27.8	36.6	32.0	23.3	40.5	31.8
MB-F (G V)	56810700	16313000	5	7.80	12.5	8.80	22.5	45.9	28.5	20.7	54.4	45.6
2012												
MB-K (G II)	696000	209000	1	5.70	6.76	6.37	35.1	37.8	36.7	43.2	45.8	44.6
MB (G III)	1217000	245000	1	7.00	8.25	7.82	15.3	32.9	21.6	29.0	64.4	44.9
MCh-CaO (G IV)	3160000	742000	5	12.5	12.5	12.5	18.5	28.1	23.5	36.2	50.9	43.6
MB-F (G V)	3731000	836750	5	10.1	13.2	11.9	20.4	27.2	23.3	23.4	42.7	35.0
Average of the years												
MB-K (G II)	753000	226000		5.70	6.69	6.16	29.5	37.4	33.3	38.8	49.6	45.0
MB (G III)	1281000	256629		7.58	8.26	7.86	30.0	49.3	36.1	20.1	38.6	29.9
MCh-CaO (G IV)	2917000	856300		11.9	12.2	12.0	24.8	34.5	29.8	25.5	39.3	31.9
MB-F (G V)	20623000	5830583		8.80	12.6	10.6	19.8	35.6	24.8	27.4	54.2	44.7

**Table 3.** Content of selected macroelements (g · kg<sup>-1</sup> D.M.) in municipal sewage sludge

Sewage sludge	N			P			Ca			Mg		
	min.	max.	average	min.	max.	average	min.	max.	average	min.	max.	average
	2007											
MB-K (G II)	18.4	19.0	18.7	19.0	49.5	36.2	25.2	37.3	32.7	4.61	4.50	4.60
MB (G III)	48.0	84.0	70.0	8.50	9.70	9.10	1.20	20.5	10.1	0.60	3.60	2.30
MCh-CaO (G IV)	22.0	30.0	27.0	11.0	18.0	14.0	179.0	300.0	247.0	3.00	4.30	3.80
MB-F (G V)	26.0	51.0	39.3	21.0	37.5	29.8	45.2	100.7	76.4	5.10	8.26	6.50
2009												
MB-K (G II)	16.2	25.4	20.8	34.2	38.3	36.3	39.9	44.3	42.1	4.80	5.00	4.90
MB (G III)	11.1	15.7	13.3	8.50	17.3	12.4	8.60	31.2	17.4	2.70	6.50	4.90
MCh-CaO (G IV)	19.1	31.0	24.1	1.40	22.3	8.15	81.3	246.0	153.0	2.50	5.70	3.70
MB-F (G V)	11.3	40.0	30.3	13.2	27.2	21.8	9.80	19.0	14.6	3.30	5.30	4.20
2012												
MB-K (G II)	20.8	23.4	22.3	28.1	37.6	33.8	33.6	41.4	37.3	3.90	4.50	4.10
MB (G III)	30.2	42.6	36.5	25.3	51.1	41.6	38.7	59.5	46.3	6.90	24.4	16.0
MCh-CaO (G IV)	26.2	49.9	34.5	13.5	21.1	18.2	155.0	263.0	209.5	3.90	5.00	4.40
MB-F (G V)	20.3	33.0	28.2	9.80	19.0	14.6	150.0	239.0	191.3	4.78	5.93	5.47
Average of the years												
MB-K (G II)	18.5	22.6	20.6	27.1	41.8	35.4	32.9	41.0	37.4	4.44	4.67	4.53
MB (G III)	29.8	47.4	39.9	14.1	26.0	21.0	16.2	37.1	24.6	3.40	11.5	7.73
MCh-CaO (G IV)	22.4	36.9	28.5	8.63	20.5	13.5	138.4	269.7	203.2	3.13	5.00	3.97
MB-F (G V)	19.2	41.3	32.6	14.7	27.9	22.1	68.3	119.6	94.1	4.39	6.50	5.39
LSD <sub>0.05</sub> for:												
A-methods of sludge treatment	1.60	4.41	3.81	0.898	0.733	0.724	3.84	8.02	1.44	0.277	0.745	0.543
B-years	1.25	3.46	2.98	0.704	0.575	0.568	3.01	6.29	1.13	0.217	0.584	0.426
A/B- interaction	2.51	7.46	6.60	1.56	1.27	1.25	6.66	13.9	2.49	0.479	1.29	0.940
B/A - interaction	2.77	6.92	5.98	1.41	1.15	1.14	6.03	12.6	2.26	0.434	1.17	0.851

ing methods [Sahlström et al. 2004, Bagge et al. 2005, Walczak, Lalke-Porczyk 2009]. The data show that smaller wastewater treatment plants produce sludge bacteriological safe, which can be used in agriculture, in general, to the cultivation of all agricultural products (Table 1, 2).

The content of biogenic elements (essential in plant nutrition) in the presented sewage sludge was significantly varied and depends on the method of wastewater treatment (Table. 3). Sludges are very rich in nitrogen, phosphorus, magnesium. The amounts of these macronutrients are usually much higher than in manure [Rosik-Dulewska 2000, 2001, Skorbiłowicz 2002]. The nitrogen content ranged from 20.6 to 39.9 g·kg<sup>-1</sup>, with variations from 11.1 to 84 g·kg<sup>-1</sup>. Phosphorus content was on average from 13.5 to 35.4 g·kg<sup>-1</sup>, magnesium from 3.97 to 7.73 g·kg<sup>-1</sup>. Very large amounts of calcium in the sludge hygenized with CaO have been reported. The average content of the element was 203.2 g·kg<sup>-1</sup>, and in the remaining sewage sludges it was much lower, up to 5-fold. The contents of macronutrients in these

sludges are comparable with the results of many authors [Mazur 2000, Jakubus 2005, 2006, Malinowska, Kalembasa 2013].

In the sludge the main criterion for their eligibility for the natural use is the content of heavy metals [Czechowska-Kosacka 2007]. In these sludge did not exceed the permissible content of heavy metals [Regulation 2010] (Table 4, 5).

The average lead content in sewage sludge ranged in each year on average from 9.80 to 42.8 mg · kg<sup>-1</sup> (Table 4). As follows from the data content of this metal in the sludges stabilized by different methods did not exceed 35 mg · kg<sup>-1</sup> D.M. It was reported that sludges analyzed in 2012 contained much less lead than in previous years. Maćkowiak [2000] obtained similar content of lead in municipal sewage sludge in eight years of research. The average cadmium content ranged from 0.420 mg · kg<sup>-1</sup> in sewage sludge stabilized with lime to 11.7 mg·kg<sup>-1</sup> in sludges subjected to fermentation, from sewage treatment plant with the largest throughput mass. The chromium content in sewage sludge was significantly varied and

**Table 4.** Contents of selected heavy metals (mg · kg<sup>-1</sup> D.M.) in municipal sewage sludge

Sewage sludge	Pb			Cd			Cr		
	min.	max.	average	min.	max.	average	min.	max.	average
2007									
MB-K (G II)	25.0	53.0	42.8	1.80	2.37	2.03	209.0	392.0	293.0
MB (G III)	15.7	19.9	17.8	0.910	1.19	1.02	7.38	17.2	13.5
MCh-CaO (G IV)	6.30	50.4	23.7	0.840	2.00	1.58	0.100	46.6	28.1
MB-F (G V)	24.4	42.8	33.4	8.66	16.3	11.7	103.4	195.0	150.1
2009									
MB-K (G II)	29.6	32.6	31.1	1.24	1.30	1.27	109.0	145.0	127.0
MB (G III)	13.6	48.8	30.5	0.990	2.79	1.81	7.17	15.8	12.8
MCh-CaO (G IV)	4.22	8.08	6.11	0.220	0.710	0.420	9.84	19.7	14.8
MB-F (G V)	21.0	71.9	43.7	0.574	4.13	1.99	74.8	153.0	112.0
2012									
MB-K (G II)	23.2	29.2	27.2	0.990	1.16	1.09	272.0	498.0	388.0
MB (G III)	22.9	32.0	27.8	1.04	1.33	1.19	21.3	27.2	23.8
MCh-CaO (G IV)	6.68	12.7	9.80	0.720	1.55	1.05	13.6	23.1	18.7
MB-F (G V)	17.6	22.7	19.9	1.60	2.41	1.98	20.0	46.6	29.9
Average of the years									
MB-K (G II)	25.9	38.3	33.7	1.34	1.61	1.46	196.7	345.0	269.3
MB (G III)	17.4	33.6	25.4	0.980	1.77	1.34	12.0	20.1	16.7
MCh-CaO (G IV)	5.73	23.7	13.2	0.593	1.42	1.02	7.85	29.8	20.5
MB-F (G V)	21.0	45.8	32.3	3.61	7.61	5.23	66.1	131.5	97.3
LSD <sub>0.05</sub> for:									
A – methods of sludge treatment	0.823	1.38	0.770	0.064	0.422	0.295	1.66	3.16	2.93
B – years	0.645	1.09	0.604	0.050	0.331	0.232	1.31	2.48	2.33
A/B- interaction	1.43	2.40	1.33	0.111	0.732	0.511	2.88	5.48	5.15
B/A - interaction	1.29	2.18	1.21	0.101	0.663	0.463	2.61	4.96	4.66

**Table 5.** Contents of selected heavy metals ( $\text{mg} \cdot \text{kg}^{-1}$  D.M.) in municipal sewage sludge

Sewage sludge	Cu			Ni			Hg			Zn		
	min.	max.	average	min.	max.	average	min.	max.	średnia	min.	max.	average
2007												
MB-K (G II)	124.0	176.0	144.3	23.5	32.3	27.6	0.880	1.28	1.04	900.0	1026.0	956.3
MB (G III)	53.4	67.3	59.9	7.40	62.7	26.6	0.210	0.420	0.330	395.0	493.0	444.3
MCh-CaO (G IV)	79.8	233.0	148.0	1.00	17.9	10.1	0.280	0.500	0.370	485.6	985.0	785.9
MB-F (G V)	201.2	274.0	244.9	23.4	53.8	34.5	3.50	4.21	3.85	1619.6	2567.0	2054.5
2009												
MB-K (G II)	122.0	133.0	127.5	20.4	31.6	26.0	0.630	0.730	0.680	763.0	818.0	790.5
MB (G III)	59.9	41.0	162.0	10.1	18.6	13.0	0.400	3.66	1.50	256.0	852.0	606.7
MCh-CaO (G IV)	11.3	79.3	49.7	8.57	14.8	11.9	0.130	0.190	0.150	335.0	381.0	359.0
MB-F (G V)	141.0	361.0	256.0	37.1	91.8	66.5	0.170	1.74	0.780	521.0	1212.0	973.0
2012												
MB-K (G II)	112.0	128.0	121.0	28.0	33.5	30.0	0.360	0.660	0.520	652.0	877.0	777.3
MB (G III)	159.0	270.0	222.3	14.2	16.5	15.6	0.140	0.660	0.450	823.0	1092.0	956.7
MCh-CaO (G IV)	97.3	258.0	155.3	5.39	10.6	8.80	0.160	1.51	0.540	589.0	819.0	658.0
MB-F (G V)	89.1	134.0	113.7	10.5	13.3	11.7	0.690	1.06	0.890	569.0	1070.0	783.0
Average of the years												
MB-K (G II)	119.3	145.7	130.9	23.9	32.5	27.9	0.623	0.890	0.746	771.7	907.0	841.4
MB (G III)	90.8	126.1	148.1	10.6	32.6	18.4	0.250	1.58	0.760	491.3	812.3	669.2
MCh-CaO (G IV)	62.8	190.1	117.7	4.99	14.4	10.3	0.190	0.733	0.353	469.9	728.3	601.0
MB-F (G V)	143.8	256.3	204.9	23.7	52.9	37.6	1.45	2.34	1.84	903.2	1616.3	1270.2
LSD <sub>0.05</sub> for:												
A – methods of sludge treatment	1.87	5.88	1.12	0.542	6.77	0.959	0.205	0.061	0.071	37.7	32.0	29.6
B – years	1.47	4.61	0.879	0.425	5.31	0.752	0.161	0.052	0.059	29.6	28.3	25.4
A/B- interaction	3.24	10.2	1.94	0.938	11.7	1.66	0.355	0.104	0.121	65.3	56.2	51.3
B/A- interaction	2.93	9.22	1.76	0.849	10.6	1.50	0.321	0.093	0.109	59.2	48.3	45.2

ranged on average from 12.8 to 388  $\text{mg} \cdot \text{kg}^{-1}$ . The highest content of this element was observed in the biologically stabilized sludges and subjected to a process of composting.

The content of other heavy metals (copper, nickel, mercury and zinc) in the sludge was significantly dependent on the processing method (Table 5).

The copper content was on average from 49.7 to 244.9  $\text{mg} \cdot \text{kg}^{-1}$  and was highest in sludge from wastewater plants applying fermentation, with the exception of 2012. A similar correlation was observed for the other heavy metals. The nickel content ranged from 8.80 to 66.5  $\text{mg} \cdot \text{kg}^{-1}$ . The average content from six years did not exceed 40  $\text{mg} \text{Ni} \cdot \text{kg}^{-1}$  D.M. of sludge and was more than 8-fold lower than that allowed for municipal sewage sludge for use in agriculture. Mercury is a highly toxic element which forms common environmental pollution [Gochefeld 2003, Wang et al. 2004]. It was observed decrease in the content of this metal in these sludge in the period considered. The average mercury content ranged from 0.330

to 1.50  $\text{mg} \cdot \text{kg}^{-1}$  and Hg standard for sludge is 16  $\text{mg} \cdot \text{kg}^{-1}$ . Toxicity of zinc is much lower than of mercury, cadmium or lead, the metal presents the highest toxic risk for biomass in the soil. The high content of this element in the sludge used in agriculture may pose a threat to soil microorganisms. The zinc content in these sewage sludges ranged from 359.0 to 2054  $\text{mg} \cdot \text{kg}^{-1}$ , the average from six years did not exceed 1300  $\text{mg} \cdot \text{kg}^{-1}$ . According to Wardas et al. [2002] the source of this metal in municipal sewage sludge can be galvanized water pipes, as well as large amounts of chlorine regulating the bacteriological state of water.

Based on the evaluated parameters was found that municipal sewage sludge produced by different methods in the Mazovia voivodship in the years 2007–2012 in terms of chemical composition are valuable waste, which can be used in agriculture for the cultivation of all agricultural products. Sanitary standards were only one parameter that limited agricultural use of sewage sludge stabilized chemically and biologically under anaerobic conditions.

## CONCLUSIONS

- Physical and chemical properties of municipal sewage sludge were dependent on the method of purification and methods of their processing and load of sewage treatment plant.
- These sewage sludges contain a significant amount of organic matter and nutrients but heavy metals did not exceed acceptable standards for municipal sewage sludge used in agriculture.
- From the analysis of reports on waste generation in the years 2007–2012 in the Mazovia voivodship resulted that assessed municipal sludge treated biologically derived from small sewage treatment plants do not endanger bacteriological. Sewage sludge treated by other methods from wastewater treatment plants serving more than 50 thousand of equivalent number of residents did not meet sanitary standards.

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