Environment Protection Engineering

Vol. 41 2015 No. 2

DOI: 10.5277/epe150209

JAROSŁAW GAWDZIK[1], JOANNA DŁUGOSZ[1], MARIUSZ URBANIAK[2]

GENERAL CHARACTERISTICS OF THE QUANTITY AND QUALITY OF SEWAGE SLUDGE FROM SELECTED WASTEWATER TREATMENT PLANTS IN THE ŚWIĘTOKRZYSKIE PROVINCE

Five wastewater treatment plants from the Świętokrzyskie Province have been briefly described, and a general analysis of the composition and quantity of sewage sludge from the data objects has been conducted. The paper also presents various ways of management of sewage sludge. The authors analyzed sediments from the wastewater treatment plant for PE in the range of 15 000–99 999 located in Ostrowiec, Opatów, Starachowice, Skarżysko-Kamienna, and in Sandomierz. The sludge was characterized in terms of its quantity and quality, the content of heavy metals, total nitrogen, total phosphorous, and organic solids.

1. INTRODUCTION

According to the Waste Law of December 14, 2012, a municipal sewage sludge means sludge from wastewater treatment plants (WTPs), sludge from fermentation chambers and other installation for waste water treatment and also from any other plant with a similar composition to municipal wastewater [1]. Wastewater treatment is closely related to formation of sewage sludge whose amount increases with increasing requirements for wastewater treatment [2]. Therefore the sludge treatment is an important issue which should be considered during the construction and operation of wastewater treatment plants. Until recently, the sludge management was secondary to wastewater treatment but now it becomes equally important. Sewage sludge treatment

[1]Kielce University of Technology, Faculty of the Environmental Engineering, Geomatics and Energy, al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland, corresponding author J. Gawdzik, e-mail: jgawdzik@tu.kielce.pl

[2]The Jan Kochanowski University in Kielce, Faculty of Mathematics and Natural Sciences, ul. Świętokrzyska 15, 25-406 Kielce, Poland.

can be carried out using inter alia compaction, conditioning, stabilization, dewatering, hygienization and drying. The choice of process depends on many factors, including the character and amount of sludge and final application (used in agriculture and forestry, combustion, deposited at the landfill, etc.).

The paper presents a brief description of five wastewater treatment plants from the Świętokrzyskie Province together with a general analysis of sewage sludge from the data objects.

2. GENERAL CHARACTERISTICS OF THE OBJECTS

According to data of the Central Statistical Office, at the end of December 2010, there were 108 municipal sewage treatment plants in the Świętokrzyskie Province, including 71 biological sewage treatment plants and 37 with enhanced nutrient removal technology [3]. We analyzed sediments from the wastewater treatment plant located in Ostrowiec (O1), Opatów (O2), Starachowice (O3), Skarżysko-Kamienna (O4) and in Sandomierz (O5).

The O1 plant is a mechanical-biological treatment plant. According to the project data, the load expressed in PE (population equivalent) is 88 060. The actual PE value for the O1 facility, based on the maximum average weekly load, for the calendar year 2011 was 87 150 PE. Currently, the maximum capacity of the plant $Q_{d\max}$ is 20 200 m^3/d, while the capacity specified in the water permit $Q_{d\text{avrg}}$ amounts to 20 000 m^3/d. Treated effluent from the wastewater plant is discharged through the measurement flume to the Kamienna River. Different pollution indicators for the O1 facility show a very high degree η of pollutant reduction (BOD_5 – 97.6%, N_t – 83.6%, P_t – 75.0%, COD – 93.9%, total suspension – 96.5%).

Technology of the plant O2 is based on activated sludge process. Removal of nutrients from raw wastewater using biological processes can be supported by dosing of PIX 113 formulation. The average daily flow for this facility currently amounts to 1200 m^3/d, its capacity being the smallest one of these plants. Municipal and industrial sewage is delivered by combined sewer and road tanker vehicles. Treated effluent is discharged into the receiver, which is the Opatówka River. The population equivalent for real values (the maximum average weekly load) PE amounts to 15 240. The sewage treatment plant O2 achieved very high degree of pollutant reduction complying with the requirements of the Minister of the Environment [4]. The degree of pollutant reduction η for the facility amounts to: BOD_5 – 98.5%, COD – 97.1%, P_t – 82.4%, N_t – 93.9%, total suspension – 98.5%.

The wastewater treatment plant O3 has been in service since 1962 and is a mechanical-biological treatment plant based on activated sludge process. Biological treatment lines consist of a biological reactor, secondary settling tank, recirculation pumping station, and the blowers station. The firstt biological reactor receives 45% of sewage, the rest is directed to the second process line. Over the past fifty years, facility has been repeatedly upgraded. A recently developed concept assumed the introduction of new wastewater treatment process and increase of the capacity to 33 000 m^3/d. Due to significant reduction of the amount of industrial waste, in the late 90's it was decided that the expansion should be gradual. The O3 will have the capacity of 14 000 m^3/d and quality parameters of treated waste water. The first stage was completed in 2000, and the facility achieved the following pollutant reduction degree η: BOD_5 – 98.6%, COD – 94.8%, P_t – 88.5%, N_t – 77.8%, total suspension – 98.2%. The population equivalent for real values PE amounts to 95 000 M.

The wastewater treatment plant O4 was put into operation in 1962. Initially it was a mechanical biological treatment plant with the capacity of 5032 m^3/d. At present, its technology is a hybrid system of biological treatment plant with the activated sludge. The separation of the sewage is carried out in the screening building which is a combined building for both process lines. The designed capacity of the plant $Q_{d\text{avg}}$ is 24 000 m^3/d and $Q_{d\text{max}}$– 30 000 m^3/d. The degree of pollutant reduction η amounts to: BOD_5 – 97.7%, COD – 92.7%, P_t – 98.3%, N_t – 65.4%, total suspension – 98.1%. According to the design assumptions, population equivalent for the O4 facility PE is 50 000 M. The population equivalent for real values PE amounts to 59 500 M.

The sewage treatment plant O5 is a mechanical-biological treatment plant with the nominal capacity of 7500 m^3/d. The actual average daily capacity is over half of that planned and amounts to 3132 m^3/d. In spite of this, the facility achieves very high levels of pollutant reduction degree η (BOD_5 – 96.0%, COD – 94.1%, P_t – 97.3%, N_t – 82.1%, total suspension – 98.7%). The biological method is based on activated sludge with the enhanced removal of nutrients. Basic elements of this part are two integrated multi-function circular bioreactors comprising a centrally located secondary clarifier and activated sludge chambers located along the circumference. The plant operation has continued without interruption since 1998. As a result of the constantly increased requirements for the sewage treatment and the increase of the sewer coverage from 76.12% in 2007 to 77.35% in 2013, upgrading of this facility is planned. According to the guidelines [4] population equivalent was calculated for the facility and amounts to 29 550 M.

3. CHARACTERIZATION OF THE AMOUNT OF THE SEWAGE SLUDGE

In the wastewater treatment plant, the sewage sludge is produced in the municipal wastewater treatment process. According to the Ordinance of the Minister of Environment of September 27, 2001 on waste catalogue, the sewage sludge is classified in group 19 (screenings – code 190801, solids sludge from grit chamber – code 190802, dry sludge – code 190805) [5].

The amount of produced sewage sludge depends, among others, on [6]: contaminants in wastewater, treatment technology, stabilization of the sludge, reduction of the weight and volume of the sludge and reagents used in the treatment process (e.g. reagents for phosphate precipitation causes increase of the sludge by approximately 25–35%). According to the data contained in [7], the amount of sewage sludge produced in municipal wastewater treatment plants in 2001 was 397 200 Mg d.m. As a result of operation of the 108 wastewater treatment plants in the Świętokrzyskie Province, 14 963 Mg d.m. of the sewage sludge were produced in 2010 [3]. Municipal sludge generation forecast for 2022 based on the data [8] is shown in Fig. 1.

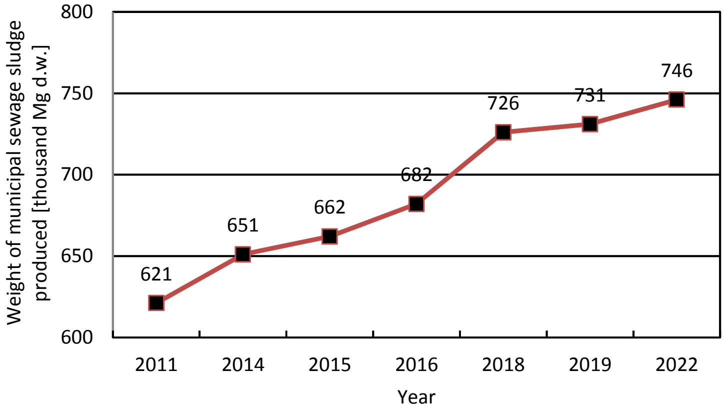

Fig. 1. Forecast production of municipal sewage sludge [8]

A continuous increase of generated sewage sludge is predicted. It is directly related to the extension of the sewage system and thereby to the increasing number of wastewater treatment plants [9, 10]. The sewage sludge accounts for only 2%, but its stabilization costs represent 33% of the wastewater treatment [11].

Unitary average rate of the amount of stabilized sludge generated in domestic wastewater treatment plants is 0.247 kg d.m./m^3, while (unitary) average rate of the sludge amount for the Świętokrzyskie Province is smaller and amounts to 0.176 d.m./m^3. This index is calculated as the quotients of the total amount of sludge dry mass and the quantity of the treated sewage (wastewater) for 24 h and expressed in kg d.m./m^3 [7].

In the analyzed period, the largest amount of the sewage sludge was produced in the wastewater treatment plant O3 (9993 Mg of waste with code 190805), slightly less in the facilities O5 and O1 (6997.1 Mg and 4468 Mg, respectively).The smallest amount of the sewage sludge was generated in wastewater treatment plant O2 (less than 500 Mg). The wastewater treatment plants also produced waste with codes 190801 and 190802 which after hygienization with lime were removed to a landfill.

4. CHARACTERISTICS OF THE QUALITY OF THE SEWAGE SLUDGE

The sewage sludge is a two phase system. One phase consists of water with dissolved additives whereas the other (called dispersed phase) is a solid insoluble in water [12]. The properties of the sludge depend on the type of sewage and the treatment technology [13]. The composition of sewage sludge, confirmed by laboratory tests, is the basis for selection methods of their disposal and for its further use [6]. The soil formation and fertilizing qualities of sewage sludge result from content of organic matter, nitrogen, phosphorus, microelements and harmful heavy metals, as well as pathogenic organisms. Before application, both the sludge and the land where they are to be applied, must be tested [14, 15]. Basic indicators of sewage sludge from wastewater treatment plants O1–O5 are presented in Table 1.

Table 1

Selected indicators in sewage sludge [4, 5, 9]

Indicator	Wastewater treatment plant				
	O1	O2	O3	O4	O5
pH	7.9	7.5	12.6	6.9	12.4
Dry mass, %	18.3	15.0	50.6	–	18.2
Dry mass of organic matter, % d.m.	43.1	59.1	31.1	49.2	40.2
Total phosphorus, % d.m.	2.52	1.59	1.14	1.7	1.42
Total nitrogen, % d.m.	1.81	1.20	<0.1	1.8	1.55
Calcium, % d.m.	2.83	3.63	45.5	–	14.55
Magnesium, % d.m.	0.31	0.44	0.62	–	0.45

The sludge from wastewater treatment plants O1–O5 has a wide range of pH values. pH of the sewage sludge usually ranges from 5 to 8 but when they are digested or in the methanogenic phase pH is 7–7.5. The values of pH for an initial sludge and sludge in the fermentation process are close to 6 or lower. The sludge from wastewater treatment plant O4 has the lowest pH (6.9). In the case of the sludge from wastewater treatment plants O1 and O2, pH is within the range of 7.5–7.9. The highest pH of the sewage sludge from facilities O3 and O5 was about 12.5 (after CaO).

The total amount of organic compounds is determined by the dry mass of organic matter. Unstabilized sludge contains 60–85% d.m., while a stabilized one contains 30–50% d.m. In the case of the sludge from wastewater treatment plants O1–O5, the contents of dry matter is in the range from 31.1% d.m. (O3) to 59.1% d.m. (O2). This clearly indicates that the sludge is stabilized.

The fertilizer value of the sludge is determined by the concentration of biogenic elements (N, P, Mg, Ca). The nitrogen content depends primarily on the method and the degree of stabilization. Nitrogen in the sewage sludge may be present as organic nitrogen, ammonium ions and nitrates. The content of nitrogen in the stabilized sludge is in the range of 2.5–4% d.m. The sludge from wastewater treatment plants O4 and O1 has the highest N_t value (about 1.8% d.m.) and from the facility O3 has the lowest N_t value (below 1% d.m.). In the case of phosphorus, it may be present as organic phosphorous, polyphosphates and orthophosphates. The sludge from the facility O3 has the lowest value of P_t (1.14% d.m.) and from the facility O1 has the highest value of N_t (2.52% d.m.). In the case of other facilities content of P_t was in the range of 1.42÷1.70% d.m.

The use of sewage sludge in agriculture requires compliance with requirements on heavy metals. The permissible and maximum load of heavy metals applied to soil on a 10-year period must not be exceeded [16]. The concentration of heavy metals in the sludge depends on the ratio of industrial waste water (Table 2) in the total amount of treated waste water.

Table 2

Industries as sources of emissions of selected heavy metals to the environment [17]

Metal	Industries
Cd	electroplating plants, production of dyes, batteries, paints, plastics, stabilizers for polymers, chemical industry, plant protection, graphics and printing industries
Pb	production of dyes, batteries, fertilizers, motorization, power industry, plant protection, electrochemical industry
Cr	electroplating plants, tanneries, wood impregnation, textile industry, production of dyes and plastics, graphics and printing industries
Cu	metallurgy, dyeing, textile industry, production of pesticides and fertilizers
Hg	production of batteries, phosphoric acid, caustic soda, pulp mills industry, production of pesticides and metallic mercury
Ni	galvanizing industry, paper industry, refinery, steel plant, production of fertilizers
Zn	production of batteries, paints, plastics and plastics stabilizers, textile industry, graphics and printing industries

High concentrations of heavy metals are a limiting factor for the wide use of sewage sludge including also agriculture. The content of heavy metals should not exceed a specified limit (Table 3). The increase of heavy metal content can lead contamination to groundwater, adversely affecting biological properties of the soil, causes changes in the food-chain and are toxic to plants. Toxic metals, in concentrations exceeding permissible levels, significantly reduce soil fertility, inhibiting enzyme activity and changing soil acidity [18].

Table 3

Maximum amount of heavy metals in sewage sludge for various purposes [19]

Metal	Heavy metal content in the sludge [mg/kg d.m.] not more than in applying municipal sewage sludge		
	Agriculture and land reclamation for agricultural purposes	Land reclamation for non-agricultural purposes	Adaptations of the land[a]
Pb	750	1000	1500
Cd	20	25	50
Ni	300	400	500
Zn	2500	3500	5000
Cu	1000	1200	2000
Cr	500	1000	2500
Hg	16	20	25

[a]Adaptation to the specific needs of waste management plans, zoning plans or land development decision, plants to produce compost, plants for non-food or non--feed purposes.

The contents of some heavy metals in the examined sewage sludge are presented in Table 4.

Table 4

Content of heavy metals [mg/kg d.m.] in sludge from wastewater treatment plants O1–O5

Metal	Wastewater treatment plant				
	O1	O2	O3	O4	O5
Pb	62.1	68.2	50.8	31.26	45
Cd	2.6	3.6	6.18	12.13	4.17
Ni	35.5	20.0	26.5	28.5	21.2
Zn	1387.4	696.8	2420	5351	384
Cu	186.7	85.0	22.2	21.8	59.0
Cr	85.6	41.2	26.0	2759.8	13.26

In the analyzed sewage sludge from facilities O1–O5, significant differences are observed in the amount of heavy metals. There are sewage sludge with small amount of heavy metals and also sludge with increased and high concentration of one or more elements. The highest amounts of heavy metals (Cd, Zn, Cr) were found in the sludge from wastewater treatment plants O4, while the concentration of Pb and Cu in this sludge are the lowest. This is possibly caused by type of industry within the area served by the treatment plant. The highest concentration of nickel and copper was determined in the sludge from wastewater treatment plants O1 and the highest concentration of lead found in sludge from facility O2. The comparative analysis of Tables 3 and 4 shows that some of the heavy metals are present in concentrations significantly exceeds the standards for agricultural purposes. This conclusion applies to concentration of Zn and Cr in the sludge from wastewater treatment plants O4.

The level of heavy metals in sewage sludge may be subject to fluctuations, therefore dynamics of its chemical composition and also biological parameters should be analyzed [20]. Despite heavy metals, undesirable component of the sewage sludge are also pathogenic organisms. These are mainly bacteria and eggs of intestinal parasites but these organisms were not observed in the analyzed samples.

5. MANAGEMENT OF WASTE SLUDGE FROM THE WASTEWATER TREATMENT PLANTS O1÷O5

The selection of methods of sludge disposal should take into account the results of technical and economic analysis and community and regional waste management plans [21]. Processes of treatment and disposal of sewage sludge are presented by the block diagram in Fig. 2.

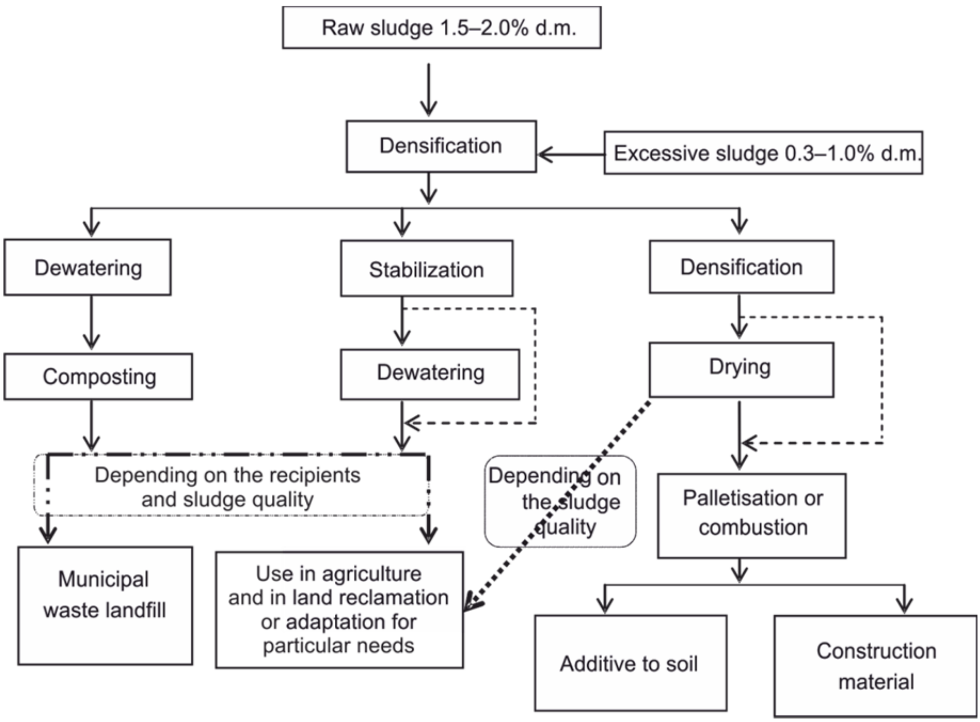

Fig. 2. Processes of a treatment and disposal of sewage sludge [21]

The analysis of the survey data collected in 2003 [7] showed that 36% of the sludge was used for land reclamation, more than 17% was dumped in landfills and 14% was used to produce compost and fertilizers. Nearly 7% was used in agriculture, while only 4% was burned. The remaining 22% of the sludge was managed in different ways depending on the local requirements and capabilities. According to forecasts, in 2018 more than 50% of the sludge will by thermally utilized, 20% will be composted, about 10% will be used in agriculture and in nature and about 10% will be used for land reclamation [22]. Due to the planned prohibition of storage of waste containing more than 5% of the organic compounds, storage of most of the sludge cannot be the final stage of treatment.

The sewage sludge from the wastewater treatment plant O1 is used in agriculture, when quarterly results of research allow such use. The facility O1 provides the sewage sludge to ca. 15–20 farms. The dosage is individually determined for each farm based on tests of the soil [23].

The recipients of the sewage sludge from the wastewater treatment plant O2 are farmers from around Opatów county. In all area where the sludge is used, the influence of application of the sewage sludge on the soil was checked. In recent years, limitation of sludge application in nature was presence pathogenic bacteria in the genus Salmonella. In that case, hygienization with lime was recommended. According to the guidelines of waste management plan of Opatów county for 2014, amount of the sludge used as fertilizer without composting will be at the level of 26%. In 2014, in agriculture should be used from 49 to 94 Mg d.m. of the sludge.

The sewage sludge produced in the wastewater treatment plant O3 is transported by the RAFIT Ltd and managed in localities of the Świętokrzyskie Province (Rzepin Pierwszy, Rzepin Drugi) and in localities of the Mazowieckie Province (Krzyżanówka, Boska Wola, Brzozówka). The ground on which sludge was used belongs to light soils (sand or loam-sand) and medium soils (sandy dust). The plants grown there are cultivated in order to be used only as biomass.

The sewage sludge from wastewater treatment plant O4 is moved to the municipal landfill and used as insulating layer. The unique solution carried out in the plant O4 is drying the sludge in special tunnel made of plastic. It is dried with solar energy assisted by heat from the combustion of biogas, not used in technology process. Increasing of air flow in the dryer is achieved by the use of mechanical ventilation. Drying the mechanically dewatered sludge results in a product with a dry matter within the range of 80–95%.

Under the contract from 2009, the sewage sludge from wastewater treatment plant O5 is received by BIO-MED Ltd., and managed by natural recycling for growing willow for energy in localities of the the Śiętokrzyskie Povince (Ublinek, Romanów, Czynów Szlachecki). The sewage sludge is also used to produce compost, pellets and mineral-organic fertilizer.

6. CONCLUSIONS

Characteristics of the sewage sludge originating from five wastewater treatment plants have been given. All the facilities belong to the treatment plant with PE ranging from 15 000 to 99 999. The smallest PE value for analyzed facilities amounted to 15 240, whereas the highest PE one was equal to 95 000. The WTPs under study have been characterized by very good efficiency in wastewater treatment.

The tested sewage sludge was characterized by large variation of the composition. Therefore, sludge from individual treatment plants should be considered separately in order to determine the extent of continued use in agriculture and nature.

The National Waste Management Plan 2014 predicts increase of the amount of municipal sewage sludge. Therefore, it is necessary to consider all available methods of sludge management from all analyzed facilities (existing methods may not be sufficient).

Considering the content of biogenic substances in the above described sewage sludge, it would be appropriate to use them for agricultural and natural purposes. However, not in all cases conditions for heavy metal concentrations are met. The characteristics of the sludge show significant differences of concentrations of heavy metals in sludge from different facilities. In the case of agricultural and natural use of sewage sludge, lack of pathogenic organisms is important (in the sewage sludge taken from analyzed WTPs, pathogenic bacteria or parasite eggs were not detected).

REFERENCES

[1] *The Waste Law of December 14, 2012* (uniform text: Journal of Laws, No. 00/2013, item 21); http://isap.sejm.gov.pl/DetailsServlet?id=WDU20130000021

[2] BIEŃ J., KOWALCZYK M., KAMIZELA T., *Influence of conditioning methods of sludge from water treatment on the effectiveness of its mechanical dewatering*, Environ. Prot. Eng., 2007, 33 (2), 61.

[3] *Statistical Yearbook of the Regions. Poland 2011*, GUS, Warszawa, December 2011, http://www.stat.gov.pl/gus/5840_2176_PLK_HTML.htm

[4] *The Ordinance of the Minister of Environment of July 24, 2006 on conditions to be met for the introduction of sewage into the water or soil, and on substances particularly harmful to the aquatic environment* (OJ 2006 No. 137, item. 984, as amended. change OJ 2009 No. 27 pos. 169), http://isap.sejm.gov.pl/DetailsServlet?id=WDU20061370984

[5] *The Ordinance of the Minister of Environment of September 27, 2001 on waste catalogue* (OJ 2001 No. 112, item. 1206), http://isap.sejm.gov.pl/DetailsServlet?id=WDU20011121206,

[6] SADECKA Z., WEISS E., MYSZOGRAJ S., *Processing of sewage sludge with energy recovery in a wastewater treatment plant*, Environ. Prot. Eng., 2012, 38 (3), 97.

[7] *National Program of Municipal Wastewater Treatment*, The Minister of Environment, Warszawa, December 2003, http://kzgw.gov.pl/pl/Krajowy-program-oczyszczania-sciekow-komunalnych.html

[8] *Resolution of the Council of Ministers*, No. 217 of 24.12.2010, *National Plan for Waste Management 2014*, Journal of Law, No. 101, item 1183, http://www.abc.com.pl/mp-akt/-/akt/m-p-10-101-1183

[9] PALICKA M., SAŁAGAN P., DUSZA E., *Changes in management of municipal sewage sludge in Poland in 2000–2006 and utilization forecast for the next years*, Biotech. Środ., Wyd. Politechniki Śląskiej, 2008, 9 (12) (in Polish).

[10] HALICKA A., SUSZYŃSKA A., *Management of sewage sludge from small municipal wastewater treatment plants on the example of the Ciasna community*, Gaz, Woda, Techn. Sanit., 2008, 3, 39 (in Polish).

[11] MAŁACHOWSKA-JUTSZ A., *Assessment of physicochemical and microbiological parameters of sewage sludge depending on the stabilization method*, Inż. Ochr, Środ., 2006, 9 (4), 395 (in Polish).

[12] KARVELAS M., KATSOYIANNIS A., SAMARA C., *Occurrence and fate of heavy metals in the wastewater treatment process*, Chemosphere, 2003, 53, 1201.

[13] WASIAK G., *Production, properties and management of sewage sludge in Poland compared to Western Europe and USA*, Proc. Sci. Tech. Seminar, Warsaw 1994, IOŚ, AG-CHEM EQ CO. INC., 11–23 (in Polish).

[14] SMERNIK R.J., OLIVER I.W., MERINGTON G., *Characterization of sewage sludge organic matter using solid state carbon-13 nuclear magnetic resonance spectroscopy*, J. Environ. Quality, 2003, 32, 1516.

[15] USMAN K., KHAN S., GHULAM S., KHAN M.U., KHAN N., KHAN M., KHAN KHALIL S., *Sewage sludge. An important biological resource for sustainable agriculture and its environmental implications*, Am. J. Plant Sci., 2012, 3, 1708.

[16] *Council Directive 86/278/EEC of June 12, 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture*, http://cc.cdr.gov.pl/pliki/PRAWO_UE/A_3_Dyr_278_86_os_sciek.pdf

[17] BORUSZKO D., MARGEL L., WIERZBICKI T., *Effect of some heavy metal ions in static fermentation processes of sewage sludge*, B.J. Bień (Ed.), *Problems of sludge management in sewage treatment plants*, International Scientific-Technical Conference, Wyd. UNi-Serwice Sp. z o.o., Częstochowa 1995 (in Polish).

[18] KHALILZADEH SHIRAZI E., MARANDI R., *Evaluation of heavy metals leakage from concretes containing municipal wastewater sludge*, Environ. Poll., 2012, 1 (2), 176.

[19] *The Ordinance of the Ministry of the Environment of 13rd July 2010 on municipal sewage sludge*, Journal of Law, No. 137, item 924, http://isap.sejm.gov.pl/DetailsServlet?id=WDU20101370924

[20] LATOSIŃSKA J., GAWDZIK J., *Effect of incineration temperature on the mobility of heavy metals in sewage sludge ash*, Environ. Prot. Eng., 2012, 38 (3), 31.

[21] HALICKA A., HEIDRICH Z., *The range of use of aerobic and anaerobic digestion of municipal wastewater sludge*, Inż. Ochr. Środ., 2008, 11 (2), 163 (in Polish).

[22] *Strategic of Environmental Assessment for National Program of Municipal Wastewater Treatment. Preliminary report*, Warsaw, April 2009, http://kzgw.gov.pl/pl/Krajowy-program-oczyszczania-sciekow-komunalnych.html

[23] DŁUGOSZ J., GAWDZIK J.I., *Validation of the operations of wastewater treatment plant in Starachowice*, Archiwum Gospodarki Odpadami i Ochrony Środowiska, 2011, 1 (in Polish).