Towards sustainable sludge management in Poland: the current status and perspectives

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Abstract: The status of sewage sludge management in Poland is presented. Current management practices are reviewed, and the problems associated with them evaluated, including technological aspects, as well as institutional issues, such as enforcement of legislation and problems with utilization. Perspectives for more sustainable sludge management practices are outlined and briefly discussed.

Keywords: biological treatment, legislation, pre-treatment, sewage sludge, thermal treatment, utilisation

Introduction

Above 2200 wastewater treatment plants (WWTP) that operate in Poland (2004) serve over 20 millions inhabitants and treat over 1.7×10^6 km^3 of municipal wastewater. Majority of WWTP is relatively new, and in more that 500 plants nutrients (N, P) are removed by means of two- or three- phase systems, hybrid cyclic and/or semi cyclic systems, as well as in one phase systems with chemical phosphorus precipitation (KPOSK, 2003). The amounts of sewage sludge formed mainly after coagulation and sedimentation processes at WWTPs do not usually exceed 2% of wastewater inflow to a plant (Kempa, 1997). However, due to chemical and physical properties and threats for humans and ecosystems, sludge must be subjected to proper treatment and ultimate neutralization. In WWTPs designed before 1990 the sludge management was limited mainly to deposition in lagoons and sludge beds. As a result of social-economic changes in Poland, access to western technologies and increased concern of environmental protection, the WWTPs have been designed or modernised taking into account the proper sludge management. The newly realized plants have independent technological lines of sludge treatment, while modernized plants are supplied with additional sludge treatment equipments. The investment and running costs of sludge treatment installations amount to 40-50% of the total operation costs of the WWTP. Such high costs are the rationale for carrying out extensive studies on optimizing sludge treatment and ultimate neutralization. To make a decision about the specific sludge management option one has to consider technical, economical and ecological aspects, as well as site-specific conditions.

The paper discusses the status of sewage sludge management in Poland, including current practices and associated problems. The perspectives for more sustainable sludge management are outlined and briefly discussed, as well.

Polish Legislation

The basis for waste and sewage sludge management in Poland is given by the Act on the Waste (Dz.U.2001.62.628 with further changes). It is accompanied by number of specific regulations:

- Decree of the Minister of Environment on waste catalogue (Dz.U.2001.112.1206),
- Decree of the Minister of Environment on municipal sewage sludge (Dz.U.2002.134.1140 and Dz.U.2002.155.1299),

- Decree of the Minister of Economy on types of waste different than hazardous and installations, in which thermal treatment is allowed (Dz.U.2002.18.176 with further changes),
- Decree of the Minister of Economy on requirements for thermal treatment of waste (Dz.U.2002.37.339, with further changes),
- Decree of the Minister of Environment on emission standards from installations (Dz.U.2005.260.2181).

The Act on the Waste defines municipal sewage sludge as coming from closed fermentation tanks (CFT) at WWTP, and from other installations used for communal and communal-like wastewater treatment. The owner of the sewage sludge is obliged to handle it according to the waste management principles and programs, with respect to environmental protection and a special emphasis on sludge recycling and re-use. If it is not feasible ecologically and/or economically, sewage sludge should be treated, and only then deposited at controlled landfills.

According to the decree on waste catalogue, stabilised sewage sludge is classified in the waste stream group 19.08, with a code: 19.08.05. The decree on communal sewage sludge defines conditions to be fulfilled if agriculture utilisation of municipal sewage sludge is considered. It gives limits of sewage sludge loads to fertilised soils by defining dosage, range, frequency of application, as well as the reference testing methods of sewage sludge and soils. The decrees on requirements for thermal treatment of waste and on emission standards from installations define how to perform the treatment, what the emission standards are, and how to deal with waste generated during thermal treatment.

Amounts and Quality of Sewage Sludge

The amounts of generated sludge depend on wastewater composition and treatment methods. According to the National Program of Wastewater Treatment (KPOSK, 2003), the amounts of sewage sludge generated in WWTPs in Poland in 2001 were evaluated as 397.2×10^3 tons d.m. These amounts are estimated to reach of ca. 642×10^3 tons d.m. until 2015, when 58% of sludge will be generated in 76 agglomerations with inhabitants' equivalent of above 100,000. Agglomerations are defined as areas, on which population density or human activities are so concentrated that it is visible to collect wastewaters by sewerage systems and direct them to WWTPs. These evaluations were based on a sludge indicator defined as a ratio between the total mass of generated sewage sludge and the total volume of treated wastewater during 24 hours. The mean value of this indicator was calculated as 0.247 kg d.m./m^3. These amounts of sludge are similar to the value of 700×10^3 tons d.m. estimated for 2014 in the National Programme of Waste Management (KPGO, 2002). Referring to this document, the amounts of sludge generated that requires utilisation will increase in 2015 by ca. 62% as compared to 2001.

The properties of wastewater entering WWTP and the treatment processes determine the physical-chemical characteristics of sewage sludge. Most of the municipal sewage sludge has high water contents from above 99% in the case of fresh (primary) sludge to 80-55% (for dewatered sludge), and to 10% for sludge dried thermally. Contents of biodegradable organic matter may vary from ca 70% d.m. (fresh sludge) to 45-55% d.m. (sludge after fermentation). The chemical composition of sludge is a derivative of the chemical composition of wastewater.

In KPOSK (2003), the quality of sewage sludge is considered from the potential use point of view without taking into account biological indicators. It is assumed that sludge used in agriculture and for land reclamation purposes fulfil the requirements concerning sanitary aspects. In most cases the presence of heavy metals is the limiting factor of sewage sludge application in agriculture. The results of sludge evaluation with respect to heavy metals made for 5 WWTP of different size is presented in Tab. 1 (Bernacka *et al*., 2002). Sludge with heavy metal contents higher or exceeding standards came from WWTP of different size. The contribution of wastewater from industry or workshops to the total amounts of wastewater entering the WWTP was postulated to be the most important factor influencing the content of heavy metals.

Table 1 Minimum, maximum and (average) contents of heavy metals [mg/kg d.m.] in sewage sludge in 2001-2002 (Bernacka *et al*., 2002).

Pb	Cd	Cr	Cu	Ni	Hg	Zn
12-279 (79)	1,6-83,8 (11,2)	47-1279 (249)	135-483 (233)	14-275 (56)	0,61-9,11 (2,6)	801-5124 (2071)

The statistical analysis of data from 1998-2002 allowed for estimating heavy metals contents at 50 and 90% probability of their occurrence in sludge (Tab. 2). Taking into account 90% probability of occurrence of individual heavy metals in sludge, one should consider some limitations of agricultural application. In particular, the agricultural application may be excluded due to exceeded contents of Cd, Zn, Pb and Ni. However, sludge can still be used for land reclamation and for growing plants for industrial purposes.

Table 2 Heavy metals content at 50 and 90% probability of occurrence in sewage sludge (Bernacka *et al*., 2002).

Element [mg/kg d.m.]	Probability of occurrence			
	50%		90%	
	1998-1999	2001-2002	1998-1999	2001-2002
Pb	100	63	255	123
Cd	4.6	4.6	24.6	20.5
Cr	270	195	782	730
Cu	222	210	783	349
Ni	43	29	197	142
Hg	2.02	2.19	4.21	4.25
Zn	2240	1817	3350	3298

Similar to heavy metals, contents of organic contaminants are independent on the size of WWTP, but depend on the types and contributions of different wastewater streams. The content of chlorinated organic compounds (AOX) was relatively low and rather stable within the tested period. Changes were observed in the case of polycyclic aromatic hydrocarbons (PAH). Within 2001-2002 their contents in sewage sludge decreased by ca. 30%. Similar behaviour was observed for polychlorinated biphenyls (PCB). However, in most of samples, the contents of individual congeners did not exceed 0.01 mg/kg d.m. Statistical analysis of data set from 1998-2002 allowed for estimating contents of organic contaminants at 50 and 90% probability of occurrence (Tab. 3).

Table 3 AOX, PAH and PCB contents at 50 and 90% probability of occurrence in sewage sludge (Bernacka *et al*., 2002).

Substance [mg/kg d.m.]	Probability of occurrence	
	50%	90%

	1998-1999	2001-2002	1998-1999	2001-2002
AOX	225	232	300	304
Σ16 PAH	7.6	6.5	16.4	11.6
Σ7 PCB	0.13	0.03	0.32	0.09

Sludge Management Practices

Stabilisation

Aerobic and anaerobic stabilisation is the most common method of organic mass reduction in sewage sludge. Aerobic stabilisation is usually carried out in open pits, closed chambers with air supply, or simultaneously along with wastewater treatment in the activated sludge tanks with an extended aeration. Aerobic stabilisation is usually applied in small WWTP with the simplified treatment system (without primary settlers) (Oleszkiewicz, 1998). Although there are some examples of aerobic stabilisation in big WWTP, but this usually results in only partial stabilisation of sludge. Aerobic stabilisation as the exclusive process is applied in 54.5% out of 800 WWTP analysed within the frame of KPOSK (2003). In big WWTP the anaerobic stabilisation by means of methanogenic fermentation is commonly applied (currently in 94 WWTP).

Dewatering

In 80s, gravitational sludge thickening was commonly applied as a first step of dewatering of primary and secondary sludge mixtures (Kempa, 1998). Currently, particularly at big WWTP, it has been replaced by mechanical thickening of excess sludge. Commonly used installations include: filter-belt, drum, drum-worm and centrifuge thickeners. Thickening may be enhanced by polyelectrolytes properly selected and dosed to sludge. At present sludge dewatering is also realized by use of mechanical devices. Lagoons commonly used in 80s and in the beginning of 90s for natural dewatering are only used in small WWTP, and even there they are often replaced by sack-filling machines (e.g. DRAIMAD® system). In bigger plants, filter- and filter-belt presses, as well as sedimentation centrifuges are used. Mechanical dewatering can also be significantly improved by applying selected polyelectrolytes. Drying of sludge as a third step of dewatering becomes more popular. At present, in many cases thermal drying is considered. An interesting approach that has recently been used in small plants is based on solar drying in greenhouses. In June 2004, the first solar drying installation was started at WWTP in Rzeszow with an area of 4704 m^2 and a capacity of 6000 tons of sludge (23% d.m.) per year (Luboschik, Trojanowska, 2005).

Methods of Ultimate Treatment and Neutralisation

Fertilizer characteristic of sewage sludge is well known. Also agricultural reuse of sewage sludge for soil reclamation at degraded areas is successfully and practically applied (Wierzbicki, 2003). However, due to the presence of heavy metals, toxic organic compounds, and pathogens, recycling of sewage sludge as a fertilizer and disposal on agricultural land pose potential threats to ecological sustainability, including the possibility of long-term contamination of agricultural soils and increased levels of contaminants in the food chain. One of the management approaches is an increasing interest in recycling sewage sludge as a source of energy. It can be achieved by number of treatment processes and relevant unit operations, including: anaerobic digestion, incineration, gasification, pyrolysis, oil from sludge, sub-critical and supercritical oxidation, hydrothermal treatment, sludge dewatering, sludge drying, and integrated use of sludge as an energy and valuable material resource (Rulkens, 2003).

To-date, the final sludge neutralization practices in Poland include (Tab. 4): (i) agricultural/horticultural reuse, (ii) land and landfill reclamation, (iii) storage at WWTP (in lagoons and ponds), (iv) composting, (v) disposal at sanitary landfills, (vi) thermal utilization, (vii) treatment in installations located at large WWTP.

Table 4 Final neutralization practices [%] of sewage sludge in Poland (2000-2002)

Years	Utilization		Composting	Thermal methods	Disposal		Other methods
	industrial	agricultural			Total	at WWTP	
2000	8	14	7	2	42	-	27
2001	6	12	7	2	50	33	23
2002	8	20	8	2	58	41	4

In 2003, a detailed questionnaire was circulated for comments directly among a number of WWTP operators to estimate the contribution of different methods to final neutralisation practices (KPOSK, 2003). Results showed that 36% of sludge were used for land reclamation, 14% for production of compost and fertilizer's preparations, 17% deposited at landfills, 4% treated thermally, and only 7% used in agriculture The remaining 22% of sludge were neutralised depending on local demands and possibilities. Data from the questionnaire do not represent all WWTP, however, if comparing them with the data presented in tab. 4, one can observe increased amounts of sludge composted and decreased amounts landfilled. It is in accordance with the KPGO (2002), where composting is assumed to be the preferable direction of sludge treatment prior to application for land and landfill reclamation. This direction should be particularly suitable in the case of WWTP cooperating with composting plants and plants generating big amounts of organic waste (bark, sawdust). It may allow for an increase of composted sludge even up to 20% of the total amounts generated.
In 2010, the amounts of sludge treated thermally are prognosed to increase to ca. 5% (currently ca. 2%), and to 8% by 2015. On the other hand, the contribution of deposited sludge is to increase from 42,14% (2004) to 45% in 2010, and then to drop to 39% in 2014 (Fig. 1). It is also prognosed that by 2014 a direct application of sewage sludge in agriculture will drop to 12%.

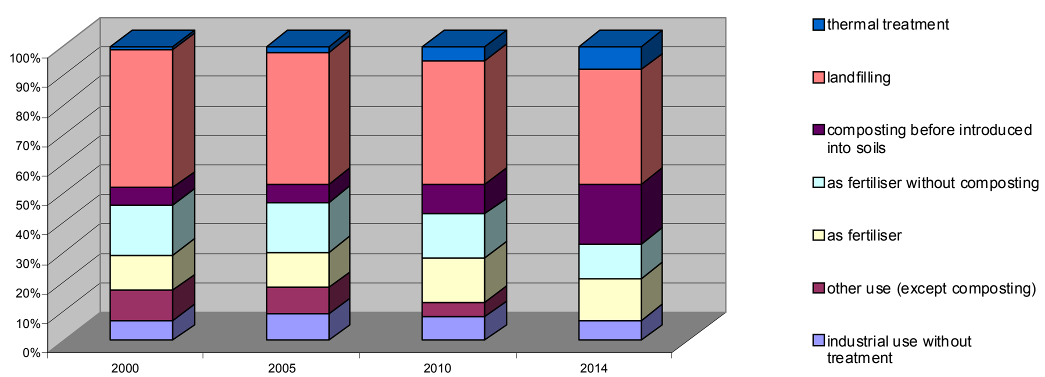

Figure 1 Options of sewage sludge treatment and utilisation in Poland (KPGO, 2002).

Application in agriculture. This method of sludge neutralisation allows for using their fertility properties, and is cost effective though limited due to chemical composition, sanitary aspects and the season of the year. It requires sludge storage and market. Due to dispersed farming in

Poland and the logistic problems, the application of sludge in agriculture is rather low although highly demanded, according to the postulate of returning organic substances and nutrients into the cycle of elements and matter in nature. According to the regulations, sewage sludge can only be used as a fertilizer for land reclamation and for growing industrial plants if heavy metals contents do not exceed the standards (Tab. 5). Sludge is usually treated prior to application in agriculture/horticulture, and the most common treatment methods include composting and stabilisation with liming.

Table 5 Permissible contents of heavy metals (mg/kg d.m.) in sludge and soil (Dz.U.2002.134.1140; Dz.U.2002.155.1299)

Element	Sewage sludge used as fertiliser or for soil reclamation purposes	Top soils (0-25 cm) used for agriculture and for reclamation of agriculture soils
Pb	500	80
Cd	10	3
Hg	5	1,5
Ni	100	50
Zn	2500	180
Cu	800	75
Cr	500	100

Composting. Composting of biodegradable solid waste and sewage sludge is governed by the Act on the Waste (Dz.U.2001.62.628), and the conditions of using compost material are controlled by the Act on fertilisation and fertilisers (Dz.U.2002.134.1140). Composting of sewage sludge is a multifunctional process that assures: sludge stabilisation, destruction of pathogens, reduction of mass and water content. Adding structural materials, such as straw may enhance significantly the process efficiency by keeping water and oxygen contents during aerobic biodegradation. Compost may be used as a fertiliser, material for land reclamation and in forestry. It may improve soil structure, replace manure and other organic fertilisers in gardening, particularly in urban and sub-urban areas. It can also be useful in developing, conserving and preserving urban green areas. Sewage sludge of high quality and not containing hazardous substances should only be composted. Any compost introduced to the market has to be certified based on the results of tests indicating that it can be useful for fertilisation of agriculture soils, or for land reclamation purposes, and that it is not harmful for humans and ecosystems.

Authors could not present the number of composting installations for sewage sludge that currently operate in Poland as such statistics are not carried out yet by the local and regional administration that is authorised to do so. Based on available data from regional waste management programs, it was estimated that in 2001 in Poland over 40×10^3 tons d.m. of sewage sludge were composted.

Anaerobic digestion with biogas production. Biogas generation from sewage sludge in CFT at WWTPs is a 4-phase process of: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The amounts and composition of biogas depend on: contents of fats, lipids, etc., anaerobic biodegradability of sludge and the hydrolysis process. Biogas usually consists of CH_4 (60-70%), CO_2 (26-36%), N_2 (1-10%), O_2 (0-1.7%), H_2 (0-1%) and H_2S (0-1%) (Malina, 2003). The amounts vary, depending on the fermentation time, process temperature and organic matter content, from 0.5 to 1.0 Nm^3 per CFT unit volume, per day. The biodegradation rate is limited by the rate of hydrolysis, which is responsible for liquefaction of organic matter. Hydrolysis determines the performance of other phases and, consequently, the composition and amounts of produced biogas. Biodegradability increases as bioavailability of sludge (related to the degree of granulation) increases. Intensifying of the fermentation process requires initial mechanical disintegration of sludge particles by thermal hydrolysis or sonification (Bień *et al.*, 2004). Organic matter and enzymes released from dead aerobic cells are substrates for anaerobic microorganisms. As a WWTP requires relatively much heat and electric energy, biogas utilization may significantly increase its effectiveness. Since 1994 in Poland more than 30 biogas installations equipped with power units have been installed and new plants are under constructions. To-date 32 biogas systems are in operation, with the total power of 61.5 MW. Electric energy production is estimated at 38 GWh, while thermal energy as 447,3 TJ (ECEO, 2002).

Thermal treatment. Due to limitations in agricultural applications thermal treatment of sludge is getting more interest. It may include: incineration, co-incineration and, the so-called alternative methods: gasification, pyrolysis and wet oxidation (Rulkens, 2003). Incineration is regarded as a proven technology, also with respect to off-gases treatment and by-products utilisation (Pająk, Wielgosiński, 2003; Krawczyk, 2003). It can be performed in incinerators for both: hazardous and/or municipal solid waste. Suitability of sludge for thermal treatment is mainly determined by chemical composition of flammable and mineral fractions, contents of volatile fractions and water, as well as ash content and composition (Ostojski, Kowalik, 2003). These are key parameters for a proper thermal process selection, with respect to minimal emissions and to avoid problems of process performance. Currently, in Poland only few thermal installations for treatment of sewage sludge are in operation. First Polish installation for thermal utilisation of sewage sludge has started in 1997 in Gdynia – Dębogórze, with a capacity of 55-60 tons of sludge (water content of 65-75% ww.) per day. Sludge is incinerated in a fluidised-bed furnace at 800-880°C. High initial water content and low calorific value of sludge caused problems, but after introducing biogas to the boiler, the process has significantly improved. Another thermal installation is operating in Warsaw, with the capacity of 17 tons of sludge per hour. Sludge is incinerated in a kiln with a moving grate at 850-1150°C. Co-incineration in power boilers and cement industry is still in the phase of testing and not practically implemented in practice, so far.

Perspectives of Sludge Gasification. The gasification process has been used commercially with coal, wood chips and municipal solid waste in the USA in the 1970s, but those plants have been shut down because of technical and financial problems (Wiltowski, 2003). It is thermo-chemical conversion of solid or liquid organic substances into gas with a specific calorific value. It is conducted under deficit of oxygen using a gasifying factor (air, pure oxygen, steam) that catalyses the process leading to faster conversion into gas by means of heterogenic reactions (Di Blasi, 2000). The composition of generated gas depends mainly on chemical composition of gasified substances, and consists of: CO_2, CO, CH_4, H_2, H_2O, trace amounts of higher hydrocarbons and inert gases. Besides, the flammable gas that can be used as a fuel for heat and/or thermal energy production, the so-called ballast substances are generated (e.g. coke and coke tar). Contribution of the components depends on: temperature, time, humidity, particles size and air composition. Direct gasification takes place when the gasifying factor is partially used to oxidize the materials. Energy obtained during oxidation allows for keeping the process temperature. Indirect gasification requires the external energy source, and takes place if steam is used as the gasifying factor. Steam is commonly applied due to simple generation and the positive effect on the hydrogen content in obtained gas. Heat of combustion of generated gas depends on the chemical composition, mainly the content of nitrogen. As a result of indirect gasification, increased volumetric efficiency can be obtained at adequately higher heat of combustion. In Poland, there is no practical use of the sludge gasification process, so far. However, number of studies is currently running, where diverse thermal processes, including sludge gasification, are investigated.

Concluding Remarks

The volumes of municipal or industrial waste and sewage sludge continuously increase, so does the need to find environmentally acceptable methods for their management, and to develop more efficient and more sustainable treatment technologies.

Depending on sewage sludge properties, local conditions and legal issues, several sludge management options are considered to be applied in Poland that are similar to trends observed in other EU countries. These trends include: application for land reclamation and in agriculture, composting, thermal treatment and disposal at controlled landfills.

In coming years composting seems to become dominant, particularly in WWTP that cooperate with composting plants for solid biowaste located at sanitary landfills. As it was not possible to obtain information about numbers of operating sewage sludge composting installations, it is highly recommended to develop a register with continuously updated databases.

Application of sewage sludge in agriculture will be most probably limited due to legal aspects, problems with sludge storage, as well as public acceptance and market demands for this product. Current practice shows that due to dispersed farming in Poland and problems with logistics, the sludge application in agriculture is rather small.

At present thermal treatment is not popular, though it seems that this approach will become more important and applied more widely, particularly in the case of thermal drying to decrease masses and volumes of sludge. Dried sludge is odourless, free from pathogens, more easy to store and transport. Thus, dried sludge may be used in agriculture, or as an alternative energy source.

Sludge deposition at landfills that is at present the most common practice will become limited, according to the requirements of the EU directives to avoid the greenhouse effect.

It should be emphasised that sludge management in Poland will be highly dependant on public acceptance, decision makers and the properties of generated sludge. Most probably, it will be based on several alternative methods rather than on one common approach.

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