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Review of sewage sludge management: standards, regulations and analytical methods

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a b s t r a c t

This article presents the most popular methods of sewage sludge management and associated unit operations and processes referring to them. The most popular methods are: Reclamation and adaptation of lands to specific needs; plant cultivation not intended for consumption or for production of food; usage in agriculture; usage in building; recovery of phosphorus, rare earth metals or fats and usage in industry; producing combustible pellets, granulates or other usable materials such as absorbents; and storage on territory of treatment plant and landfills. Processing connected with stabilization leads to generation of materials which might be contaminated with variety of organic compounds. Since this type of management generally assumes introduction of processed sludge to the ground, it can cause soil contamination with unknown compounds of organic origin. However, thermal processing of raw sewage sludge essentially excludes such possibility. Majority of organic matter is transformed into simple, mineralized form. In this case the most problematic issue is sewage sludge ash contamination with heavy metals. Although, determination of heavy metals in ashes is much simpler than determination of organic compounds. Chemical analysis can be very useful to asses environmental safety of processed and managed sewage sludge. That is why there is a significant quantity of used analytical techniques which are likely to support the processes of designing and implementing new economically and environmentally reasonable ways of re-using sewage sludge. Further, the process of technological utilization of sewage sludge conducted in Wastewater Treatment Plant "Wschód" in Gdańsk is described. Recently technological line was upgraded. Now excessive sewage sludge is anaerobic digested with biogas recovery. Fermentation residues are incinerated in fluidized bed furnace. Ashes are cemented and land filled. Gdańska Infrastruktura Wodociągowo-Kanalizacyjna, which is owner of the treatment plant "Wschód" is planning development strategy for the implementation of a pro-ecological management method connected with production of light construction materials and phosphorus recovery. Manage-ment of thermal treated sewage sludge is simpler and cheaper than non-thermal management, espe-cially in case of large amounts of treated sewage sludge like in Wastewater Treatment Plant "Wschód". Management in smaller installations of treatment plants collecting sewage sludge from less industrial-ized agglomerations is also less complicated. Sewage sludge management process should be developed separately for each treatment plant. Only then all management methods will be ecologically and economically justified.

Keywords: Sewage sludge, Sewage sludge ash, Sewage sludge management

1. Introduction

The management of sewage sludge is becoming an issue of growing importance. In all countries of the European Union, directives are introduced on the basis of which each member state has to create relevant. According to European regulations management methods involving storage are now being replaced by methods leading to waste stabilization and safe recycling. legislation, programs and developmental strategies. Their aim is, amongst

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other things, to promote pro-ecological management of sewage sludge. Management methods involving storage are now being replaced by methods leading to its stabilization and safe recycling. These methods may consequently lead to the recovery of valuable raw materials from potentially dangerous materials, processing them in order to enable their use in agriculture, various branches of industry or heat and energy recovery (Bartkiewicz and Pierścieniak, 2011). At each stage of sewage sludge processing, its characteristics change. During the disinfection process, the microflora of sludge is changed; the methane fermentation process leads to a decrease in overall carbon content, while thermal processing, depending on the temperature, may result in densification of sludge or even transformation of all organic matter into inorganic compounds. Therefore, many various kinds of processed sewage sludge are generated and each of them have a different chemical composition. They may also vary in the physical properties, consistency or even parameters such as toxicity or stability of pollutants. All those factors may decide whether the particular material will be classified as safe or unsafe. Determined values of parameters, mentioned above, may influence on changes in processing technology in order to develop other methods of management. Therefore, it is important that at every stage of processing of this type of waste, the resulting material should be subjected to a comprehensive chemical analysis. Due to their diversity, other methods and analytical techniques will be useful in each case. Therefore, the choice of a suitable analytical method depends on the planned method of sewage sludge management, which to some extent determines the technology used for processing them.

2. Methods and scope

This study focuses on describing sewage sludge management methods and showing advantages and disadvantages of many approaches. Analytical methods are described as powerful tool supporting management process. The review is based on literature from the entire world, and since the subject is still developing in some countries, and there is a great number of legislation including European Union directives and many countries ordinances, we have included not only management methods reported in peer-reviewed journals but also acts connected to raw and processed sludge management. Discussed legal aspects also recall maximum allowable concentration of contaminants and critical parameters.

Studies published in technical journals and books are also mentioned. As-build documentations, specifications and flow sheets were used to describe current applied technology in Sewage Sludge Treatment Plant "Wschód" in Gdańsk. This facility is used as an example of developing treatment plant, implementing modern technologies in order to create environmentally friendly and economically justified raw sewage sludge management methods.

3. Methods of sewage sludge management

Even today, there are situations in which raw sewage is discharged into bodies of water. This happens most often in small and less developed countries. The Federated States of Micronesia, where almost 30% of produced sewage goes into the waters of the Pacific Ocean without prior purification are good example here (Rouse, 2013). Problem is greater when countries are bigger, like India where only about 30% of the wastewater generated from major cities is being processed (Kapshe et al., 2013). Treated sewage, from which often only a part of the solid fraction has been removed, is also released into the water, which increases the carbon content in coastal waters and causes excessive growth of local fauna and flora. Fortunately, as the ocean is a large body of water and coastal waters mix with the waters from the ocean, eutrophication is not usually a big problem. The situation is different in bodies of water that do not have direct access to the ocean such as the Baltic Sea. It is separated from the Atlantic Ocean by two straits: Skagerrak and Kattegat, which prevent seawater from mixing freely water from the ocean. The introduction of raw sewage into such a relatively small body of water, would result in eutrophication progressing at a very fast pace. Therefore, it is very important to improve wastewater treatment processes so that sewage introduced into surface waters and then brought to lakes, marine and ocean waters is devoid of biogenic compounds such as phosphates. In order to limit environmental degradation caused by eutrophication and the introduction of harmful substances into the waters such as heavy metals, the European Union established relevant directives, such as the Council Directive of 21 May 1991 concerning municipal wastewater treatment. It assumes that in all areas sensitive to eutrophication, such as the Baltic Sea catchment area, it is required that wastewater should be treated more thoroughly (Council Directive, 1991; Winkler et al., 2013). This directive also applies to Poland, which is a member state of the European Union. As a result, more and more wastewater treatment plants are being built and the old ones are still being modernized. Regulations on the requirements for sewage discharged into water or soil are increasingly restrictive (Ordinance of Minister for the Environment on the conditions to be fulfilled while releasing sewage into water or soil & on substances particulary harmful to the environment, 2006). Thus, purification processes still need to be improved. An increasing amount of impurities, not only organic ones, is accumulated in excess sewage sludge. Therefore, its utilization is now becoming a greater problem. More than half a million tons of dry weight of sewage sludge was produced only in Poland in 2011. It should be taken into account that these sediments are usually hydrated in more than 90% so the problem of their management is very complex. Currently, on the areas of landfills and sewage treatment in Poland a two-year excess sludge is stored (Bartkiewicz and Pierścieniak, 2011), because until recently the storage method was the most frequently used way of its management. This is due to the fact that in order to be re-used for example for broadly understood agrochemical treatments, sewage sludge must meet restrictive standards. They will be different depending on the country and the specificity of the method of management. Moreover, according to Directive 2008/98/EC of The European Parliament and The European Council (Council Directive 91/271/EWG, 2008), all recycling and management methods should be preferred approaches involving the use of landfills. Landfilling must be reduced to 35% of biodegradable content by 2020 (Valderrama et al., 2013). Also, it is recommended that the best available technologies should be used to cope with all kinds of waste and with the production of new alternative products. Those products must meet all legal requirements for broadly understood environmental safety. Using them may not pose a risk to waters, soils, air, plants, animals and cannot generate odors or other kind of environmental pollutants.

3.1. The use of sludge in agriculture and soils reclamation

In 2012 over 10 million tons of dry solid sewage sludge was produced. About 40% of excess sludge was speeded on land for agriculture use. If sludge is used as a fertilizer for growing crops for both human consumption and feed production, a strong emphasis is placed on biological and chemical safety of this material (Roig et al., 2012). When waste is used for soils reclamation to the specific needs, its physical parameters may play a more important role. However, in both cases, you cannot afford to too large, uncontrolled amounts of potentially harmful chemicals seeping into the soil or groundwater (Houillon and Jolliet, 2005). Compounds such as heavy metals, grease, phenolic compounds and polycyclic aromatic hydrocarbons can cause drastic changes in the flora and fauna of the soil reducing its fertility and changing the other parameters. It is possible to prepare the sludge prior to its use, meet with legal regulations and also to be adequate regarding desired end-use, by different technological procedures such as disinfection, stabilization on the sludge drying beds or stabilization using earthworms and its combinations and/or modifications (Suthar, 2010).

3.1.1. Stabilization on the sludge drying bed

Processes of disinfection and stabilization on drying bed are designed, apart from the removal of pathogenic bacterial flora, to prepare the sludge for use as a fertilizer or for other treatments such as soil reclamation. Beside hygenisation this process cause dewatering of the sludge. In contrast to thermal processing investment and operating cost are significantly lower. Drying is very important operation despite the fact excess sludge is generally 97–99 % hydrated. Omission of simple drying process would result in drastic physical changes in the soil into which unprocessed sludge would be introduced (Uggetti et al., 2009).

3.1.2. Stabilization using earthworms

When earthworms are used for stabilization of sewage sludge, the amount of organic carbon is reduced, while the amount of bioavailable phosphorus increases. Due to that, after about 100 days of stabilization, the carbon to nitrogen ratio is reduced, which improves its quality as a fertilizer. During this process, the content of potentially dangerous compounds like heavy metals is also reduced (Suthar, 2010). This is probably due to the fact that these compounds are accumulated in the bodies of earthworms, which at the end of the process are removed from the finished product. This is an advantage of this alternative process over the conventional stabilization one, because the content of heavy metals in wastewater, especially from industrial and large agglomerations, may pose a serious problem often precluding the use of sludge for such treatments.

3.1.3. Anaerobic stabilization with biogas recovery

Anaerobic stabilization may be an alternative to aerobic stabilization. In this case, in addition to the previously mentioned limitation of development of pathogenic fauna, the content of organic carbon in the sludge is also reduced and as a result, a product with a lower C:N ratio is obtained. The sludge after fermentation may also be suitable for use in agriculture and soil reclamation. In addition, biogas with a high methane content is produced (Mills et al., 2014). Formerly, biogas was treated as waste and burned in a torch flame as methane. Now, as a greenhouse gas with a greenhouse potential twenty-five times higher carbon dioxide, it cannot be released directly into the atmosphere. However, it can be used as fuel and burned in gas turbines, thereby recovering energy (Xu et al., 2014). The energy obtained in this process is energy from a renewable source so such waste management is one of the most desirable. It may be used in the facility or sold to the grid (Mills et al., 2014). Moreover obtaining energy from biomass or other renewable sources contributes to reduction CO_2 emission (Lag-Brotons et al., 2014). Still, this method of sewage sludge management has some limitations. To ensure effectiveness of the methane fermentation process, fermentative microorganisms must have appropriate conditions for development. Optimal and limit parameters of this process are presented in Table 1. Choice of the most suited technology for energy recovery depends on available technologies, countries economical conditions and geographical location.

Additionally, sludge should not contain process inhibitors such as pesticides and other plant protection products. In some situations, it is advisable to add excipients, such as enzymes, or to mix excess sludge with other waste of plant origin to improve the efficiency of the process. The limitation is the fact that the methane fermentation process is cost-effective for relatively large sewage treatment plants, several dozen thousands population equivalent (PE). One can collect sludge from several smaller wastewater treatments but it reduces the profitability of the methane fermentation process due to the cost of transport. The precipitate of the fermentation process can be used not only for agriculture and soils reclamation, but can also be processed further, for example thermally.

Table 1
Optimal and extreme conditions of methane fermentation process (Heidrich, 2010).

Parameter	Optimal parameters	Limit parameters
Temperature, [°C]	33–37	20–57
Reaction, [pH]	6.8–7.4	6–8
Oxidation-Reduction Potential	−520 to −530	−490 to −550
Volatile organic acids, [mg CH_3COOH/dm^3]	50–500	More than 2000
Alkalinity, [mg $CaCO_3/dm^3$]	1500 (2000) - 3000	1000–5000

3.2. Thermal processing

There are many technologies of sewage sludge thermal treatment. Most of them need special pre-treatment. Processing of raw sewage sludge before thermal treatment is often necessary in technological and economical point of view.

3.2.1. Drying

Drying is a relatively simple technological operation of delivering energy to the system to evaporate the water resulting in its densification. This process can be applied prior to further thermal treatment:

- conventional incineration,
- co-incineration with coal or other fuels,
- vitrification,
- or pyrolysis,

or may be the final step the product of which can be further handled in agriculture as in the previous described methods for sludge stabilization. Drying does not always require an additional supply of energy. Thus, it does not need to generate extra costs. Biodrying is an alternative in which the process is carried out with the use of heat produced by microorganisms. Such technologies allow for cutting operating costs (Winkler et al., 2013). A prior step to drying may be methane fermentation that was mentioned earlier. When the final product, e.g. pellet, appears to be low-caloric, it may find application in the construction industry e.g. as the road ballast or other practical applications described further. However if it is high-caloric, dried sewage sludge may be used as fuel in variety kinds of processes (Mills et al., 2014).

3.2.2. Conventional incineration

Thermal utilization is the most popular way used for the processing and management of sewage sludge. Incineration is also widely used for treating other kinds of waste, such as medical or municipal. This is due to the fact that the incineration process is one of the best known waste treatment processes. Incineration significantly reduces volume of disposed sewage sludge. It is important in densely populated regions like Japan where people have to deal with problem of high quantities of sludge production and low land availability. Amount of sludge being incinerated there already reached the percentage of 55% (Samolada and Zabaniotou, 2014). Conventional incineration usually must be preceded by pre-drying of sewage sludge to 18—35 % dry solid content (Donatello and Cheeseman, 2013), usually about 25% (Houillon and Jolliet, 2005). When it is designed properly, this operation does not have to generate large additional costs (Winkler et al., 2013). Biodrying, as mentioned above, is an example of such a procedure. Another alternative is the use thermal energy generated during the incineration process for heating amenity buildings on the premises of sewage treatment plants or for pre-drying of the incinerated material. Alternatively heat from combustion of sewage sludge could be use in clinker production (Valderrama et al., 2013; Rodríguez et al., 2013). Waste products of all incineration processes are ashes which must then be recycled or utilized in another way. It should be mentioned that ashes from first and second sets of filters (generally electrostatic precipitators and wet scrubber, cyclones, two sets of bag filters etc.) (Donatello and Cheeseman, 2013) could differ, so management methods should be designed separately. However there could be a case in which management methods of both types of ashes can be linked.

3.2.3. Co-incineration

Sometimes, when prepared for incineration sludge has a low calorific value, it is necessary to design co-incineration process with other energy utilities (coal, fuel oil or natural gas). The biogas produced in the plant can be an alternative energy source. In this case, it is important to check whether incinerating it in turbines for combined cogeneration of heat and electric energy will be more economically viable. Then electric energy can be used in the treatment plant or sold to the grid, while the heat can be used for social purposes, or for heating process utilities or initial preparation of raw materials, as described above. During selection of an energy utility, in addition to the economic aspects, it is important to draw attention to energy demand, depending on the calorific value of the sludge subjected to incineration and, more importantly, to the possibility of introducing additional contaminants into the final product. It is also possible to transmit the sewage sludge to a heat and power plant in which it can be used for co-incineration of combustible utilities as an admixture (Donatello and Cheeseman, 2013) (about 10% of sewage sludge). In such cases industrial synergy may be profitable. Building sewage sludge treatment plants, or other facilities producing calorific waste near power plants or different incinerators could be economically viable (Liu et al., 2011). In some cases co-incineration with municipal solid waste would be economically and ecologically justified (Lin and Ma, 2012). Then also ash from all kinds of incineration facilities running such process must be analyzed, both chemical and ecotoxicological (Barbosa et al., 2011; Magdziarz and Wilk, 2013; Hong et al., 2013). Management methods could differ due to the fact that coal ash generally contains less nutrients than pure sewage sludge ash (Donatello and Cheeseman, 2013).

Both in the case of conventional incineration and co-incineration, the products of the process will be exhaust gases, fly ash and slags. Exhaust gases must meet relevant criteria to prevent environmental pollution from incineration products such as polycyclic aromatic hydrocarbons, adsorbed on the surface of dust and heavy metals. Other dusts and slags should be properly utilized. They often contain significant amounts of bioavailable phosphorus so that they can be used, just as combustionless stabilized sludge, in agriculture or soils reclamation. In the case of sludge coming from wastewater treatment plants collecting waste from industrialized areas, obtained ash can contain large amounts of heavy metals which may then enter the environment causing its degradation. Equally important is the fact that too much phosphate may be deleterious due to the already mentioned eutrophication. Additionally it should be stressed that, polycyclic aromatic hydrocarbons may adsorb onto the surface of the ash, thereby increasing its toxicity. It is therefore necessary to control the products of sewage sludge processing not only when they leave the production line but also their subsequent fate in the environment, if used for different agrochemical treatments.

3.3. The use of processed sewage sludge in construction industry

There is a possibility of another pro-ecological management of sewage sludge rather than as a fertilizer or medium for soil reclamation. In this case, initial raw materials to the process are mostly ash remaining after incineration. However, there is a possibility to produce safe and durable brick using sewage sludge ground with crushed granite rock. After addition of gravel that pulp is fired to obtain crystalline phases (Wolff et al., 2014). Other approach is mixing sewage sludge with biomass ash and recycled aggregates to obtain “Controlled Low-Strenght Materials” which can reach compressive strength within the range between 0.5 and 2.5 MPa or ever higher (Pavsic et al., 2014).

3.3.1. Cementing

Ashes may be subjected to the solidification process together with cementitious materials. These operations are performed to immobilize contaminants contained in the processed sewage sludge which may be environmentally deleterious. In addition, cementitious materials can be given concrete form and shape in this way. Ash cement properties depend on the reactants used for the cementation process and their proportions (Wu et al., 2011). The most appropriate rations of ashes were found to be 10% substitution of cement and 2% substitution of sand (Chen et al., 2013). However, sometimes strength of material prepared in such way is unsatisfying (Donatello and Cheeseman, 2013). It is often required that ashes coming from the energy industry should be added to a cementation process in order to improve the degree of immobilization of contaminants such as heavy metals. In this form solidified blocks can be stored in the wastewater treatment plants or waste landfills posing no threat to the environment. Ash consists of about 40% of dry mass of waste (Wzorek, 2008) so after the incineration and solidification process, despite the mass increases by adding the cementitious factors and other additives, stored materials occupy a much smaller volume than the non-processed sludge. However, it should be remembered that the European Union does not promote storing as a method of management. As it is possible to set different forms and shapes of cement ashes coming from incineration of sewage sludge, it is economically viable to use them as a building or road paving material (Houillon and Jolliet, 2005). It is important then that such a material should meet all the required standards and criteria. For this purpose, the ash stabilization technology should be designed accordingly. By using suitable reactants, we should receive a material that meets the strength requirements, suitable for the intended use, while not being dangerous to the environment (Wu et al., 2011; Barbosa et al., 2011). Therefore, apart from strength tests, an analysis of extracts prepared on the basis of the relevant standards, should be performed. That will enable to classify the material as safe to use throughout the whole life cycle (Cusidó and Cremades, 2012) Based on results of analysis this is possible to conclude that, the material is dangerous for the environment. Material could be classified as toxic due to the leaching large amounts of heavy metals or other deleterious compounds. Conclusions draw on obtained results of the analysis can influence stabilization process to make ecological management of the ashes possible. It is clear, therefore, that analytics can be a tool supporting process of designing the management technology.

3.3.2. Vitrification

There are some other processes for thermal processing of sewage sludge in order to solidify them, for example vitrification. This process consists of vitrifying the material at very high temperatures (1000–1600 °C) with the addition of silica. Such materials are characterized by a very solid stabilization of contaminants such as heavy metals which in this form are completely insoluble in water. Because of the high processing temperature of the material, toxic organic compounds such as polycyclic aromatic hydrocarbons are most often oxidized to inorganic compounds and pose no threat to the environment (Bernardo and Dal Maschio, 2011). On the other hand, this process is very expensive because of the high energy demand. It is possible to recover some of the energy and the partial reimbursement of production costs through the sale of lightweight ceramic material which, being an environmentally safe product, often has good strength and insulating parameters. However, appropriate simulations should always be carried out to check whether the designed management method is economically and ecologically justified. Also appropriate analysis are needed to determine whether the product will cause environmental pollution. Especially after prolonged use since vitrification is characterized by greater retention of pollutants than cementing.

3.4. Raw materials recovery

Processed sewage sludge can be also used in different way. Lots of valuable compounds and rare elements can be recovered from processed sewage sludge.

3.4.1. Pyrolysis

An alternative for the previously described technologies of sewage sludge oxygen combustion is anaerobic pyrolysis. It is a process of sewage sludge combustion under conditions with limited access to or lack of air. Materials processed in that way can be further used in production of absorbents. They are received after adding appropriate reactants, e.g. full silica, to a heated raw material. A material processed in this way is characterized by a large development area (Spisona et al., 2011). It is a method of sewage sludge management including the generation of a specific raw material used in the industry. It is therefore possible to gain partial reimbursement of expenses incurred on raw material processing. Other product of the described process is pyrolysis liquids, also called bio-oil or pyrolysis oil, which can be applied as a fuel (Samolada and Zabaniotou, 2014). In both cases suitable analysis will be necessary, though, to prove that used product is safe both for the environment and for potential users.

3.4.2. Phosphorus recovery

There are different methods of sewage sludge managing in order to recover valuable materials. The most common of them is the recovery of phosphorus. Phosphorus is the eleventh most common element in the environment but its resources are not infinite. It is estimated that market prices of phosphorus will begin to grow from 2034 (Donatello et al., 2010) and current global reserves may be depleted within 50–100 years (Cordell et al., 2009) therefore more and more sewage treatment plants are incorporating the technology of phosphorus recovery or give the incinerated material, as it is the most common form of which phosphorus from sludge is being received, to a specialized facilities conducting such an operation. There are few methods of phosphorus recovery:

- The simplest way to use phosphorus without costly extraction and numerous preparations is to use dried and roasted sewage sludge as a fertilizing medium (Li et al., 2014). The biggest disadvantage is possible introduction of harmful heavy metals and all other toxic compounds adsorbed on the surface of ashes to environment.
- It is possible to design a burning process including chlorides of: sodium, potassium, magnesium and calcium at temperatures between 900 °C and 1100 °C allowing phosphorus to be transformed into a form which is more available for organisms (Donatello et al., 2010). However, there is a concern that contaminations such as heavy metals may be released into the environment. It is, therefore, crucial to make a prior analysis of sludge and possible removal of the above mentioned contaminations before further processing, as well as the analysis of ashes themselves. What is more, the costs connected with the production of necessary energy may be high.
- From ashes previously produced in a conventional way, phosphorus can be recovered by extraction of acidic solutions. This method of recovery is characterized by a lower need of energy than the process described earlier (Donatello et al., 2010). It is possible to recover even 66% to 99 % under laboratory conditions during 10-min extraction with 14% H_2SO_4 and a liquid/solid ratio (L/S) equal 2 (Donatello et al., 2010). During optimization of the process, the following parameters can be manipulated: type and concentration of mineral acid, time of reaction, L/S ratio and other additives. The type of acid used together with selected additives will determine the form in which the phosphorus will be received, e.g. in a form of struvite ($NH_4MgPO_4 \times 6H_2O$) (Xu et al., 2012) or similar to commercial Triple Superphosphate (Weigand et al., 2013).
- Similar extraction can be conducted under alkaline conditions and phosphorus can be recovered in the form of $FePO_4$ after iron electrolysis (Sano et al., 2012). This method does not require earlier incineration of sewage sludge, what reduces investment costs as well as those connected with heat energy generation. The effectiveness of this method is influenced by parameters such as extraction time and extraction temperature. Various types of lye can be an extraction medium. It should be noted, though, that organic contaminations will not be mineralized during incineration processes preceding techniques described earlier (Adam et al., 2009).
- Phosphorus recovery can be also carried out via electrodialytic separation. Main advantage of this process is simultaneous heavy metal removal from sewage sludge ash. Main disadvantage is long time of separation. Best results were achieved after 14 days of electrodialysis. After 7 days only 20% of total phosphorus was recovered in the anode end with almost 42% of the phosphorus remaining in the liquid phase (Guedes et al., 2014). Further studies should be carried out to improve the process.

Ashes after burning of sewage sludge often contain contaminations that can make extraction harder, or cause production of contaminated material, or even a material in a form not suitable for living organisms and thereby useless. The presence of heavy metals is the most common factor limiting usage of phosphorus compounds recovered from sewage sludge in agriculture. Such techniques as Ion exchange or thermochemical treatment prove to be useful for removing contaminations such as Al, Fe, Mg, Ca or Zn (Donatello et al., 2010; Xu et al., 2012; Adam et al., 2009).

3.4.3. Recovery of rare earth metals

Heavy metal contamination is a problem in almost all sewage sludge management systems (Mailler et al., 2014).

If so recovering such a material could be favorable management method. Valuable rare earth metals can be regained after sewage sludge incineration process. Recovering is conducted in furnaces (e.g. plasma ones) under oxidative or reduction conditions. Considering that such elements as Ag, Te, Tl, Bi, Sb, In, Ga, Sn, Ge, or Pb are not well spread in earth's crust but often present in sewage sludge this process may become very popular in the future, especially in cases when areas from which wastewaters are collected are highly industrialized. Many of those metals are used in the industry as catalysts and as additions to many products of special use. This type of development can gain special credit in highly developed countries where processing of rare metals is very high. The example of a country where this method may gain popularity is Japan where about 30% of the world's annual processing of rare earths metals takes place (Osaka and Jung, 2007).

In the future, because of slow depletion of non-renewable resources such as those, this method may turn out to be promoted and economically privileged as the prices of rare elements will grow faster over time. As a consequence, they may eventually become strategic raw materials, the same as black oil and other energy fuels. In addition, in other types of processing these elements are treated as contamination, which may make this process even more popular.

All individual processes, operations, and development methods described above are presented in Fig. 1. Their strengths and weaknesses are shown in Fig. 2.

4. Way of processing and methods of sewage sludge management in sewage treatment plant “Wschód” in Gdańsk

The “Wschód” sewage treatment plant in Gdańsk is a big treatment plant as for Poland, serving about 120 000 m^3/day of sewage from Gdańsk and its surrounding area. The modernization aimed at increasing the level of eliminating biogens from sewage and on implementation of technology of ecological and economically justifiable management of sewage sludge began in 2008. Processes conducted in the treatment plant are divided into two lines: a sewage treatment line and a sludge utilization line (Dział Technologii Wschód, SAUR Neptun Gdańsk, 2011).

At the beginning of the sludge utilization line, sludge is thickened with the use of belt thickeners and next disintegrated in order to easily release organic matter. In that way about 28 tons of thickened sludge is produced per day. It is sent to a Closed Fermentation Chamber (CFC) where the process of biogas recovery lasts for 20.5 days. Biogas is directed to a CHP (Combined Heat and Power) installation for combined power and heat energy production, and burned in turbines there. Sludge that comes out of CFC after the fermentation process is centrifuged and transported to an Installation of Sludge Thermal Conversion (ISTC) where it is dried

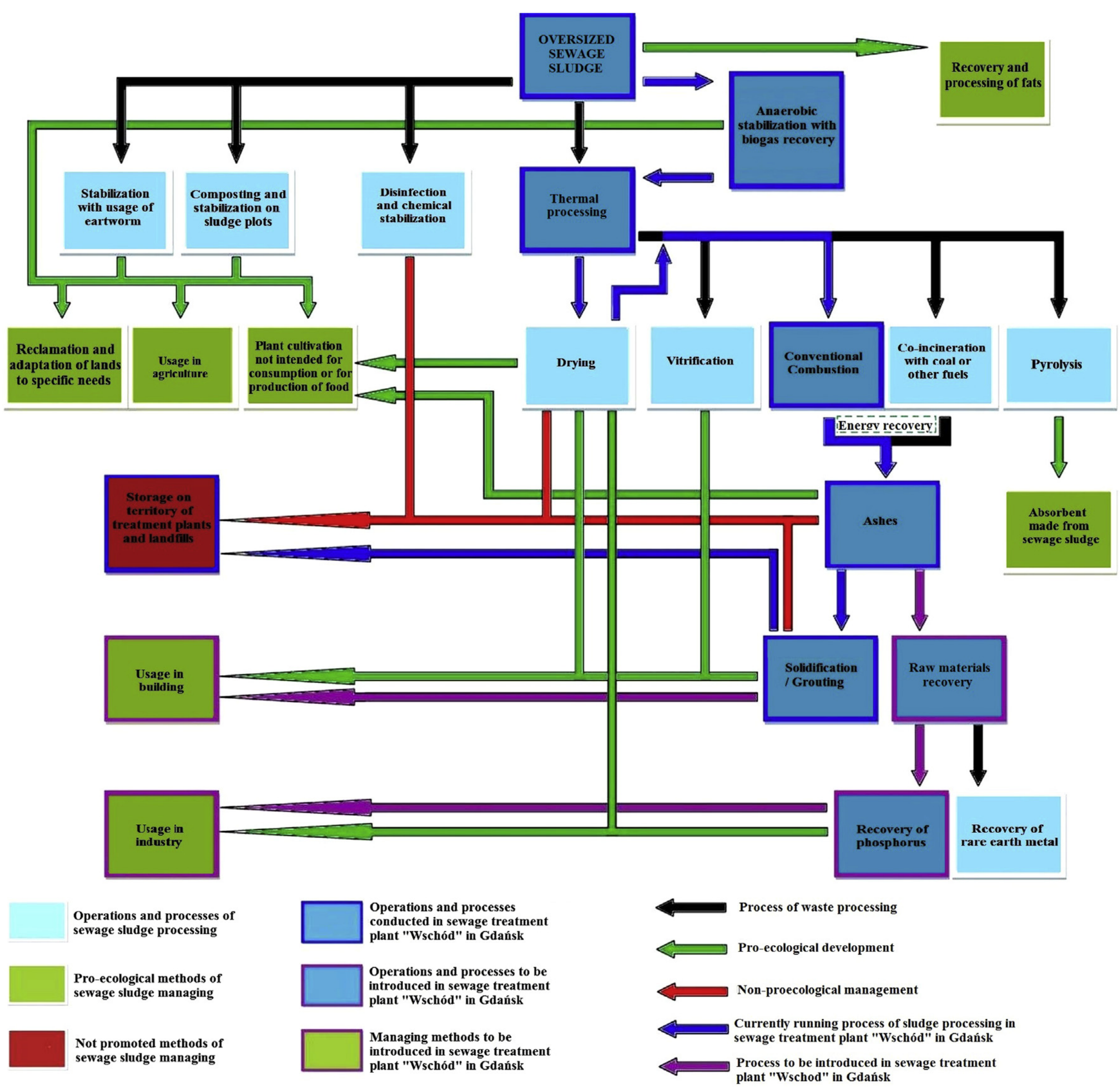

Fig. 1. Methods of sewage sludge management.

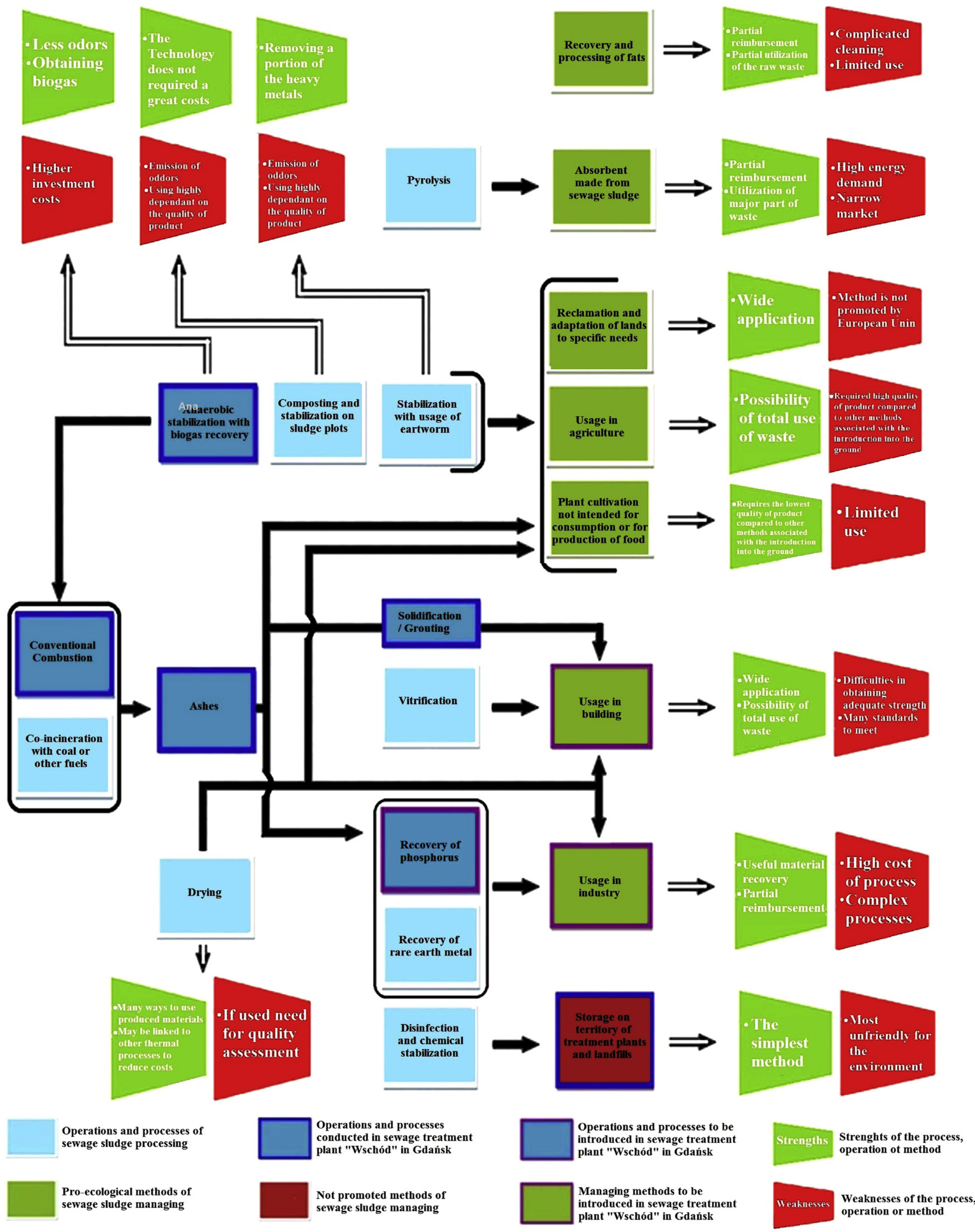

Fig. 2. Strengths and weaknesses of processes, operations and management methods used for sewage sludge.

and next incinerated in a fluidized furnace (Gdańska Infrastruktura Wodociągowo Kanalizacyjna, 2010; Dział Technologii Wschód, SAUR Neptun Gdańsk, 2011; Biuro Projektowo – Doradcze EKOSYSTEM Sp. z o. o., 2005).

Ashes with a high phosphorus content after burning are stopped by bag filters and stored within the ISTC. Ashes fraction together with combustion gases that passes the first set of bag filters are stopped further and mixed with lime to neutralize gases and begin

Table 2
Analytical techniques used to analyze sludge contamination and processed sewage sludge with the highest acceptable concentrations applicable in Poland and Europe.

Type of material processed	Chemical individual / parameter	Analytical technique	Limit of detection (LOD)	The maximum acceptable concentration / parameter limit values	
Excess sewage sludge	pH	Potentiometric analysis	Not applicable	Dependant on further management method	
	Mg, Al., Ca, Cr, Mn, Fe, Ni, Cu, Zn, As, Mo, Cd, Pb	APHA, 2005. Standard Methods for the Examination of Water and Wastewater, 20th ed. Washington, DC (Sano, et al., 2012)	Not known		
	5 days' biological oxygen demand (BOD_5)	Culometry According to EN 1899-1 and 1899-2 standards	Not applicable		
	Chemical oxygen demand (ChOD)	Sodium/potassium chromate (VI) titration (Lapa, et al., 2007)	Not applicable		
Oxy and non-oxy stabilized sludge to be used in agriculture and for reclamation works	pH	Potentiometric analysis	Not applicable		All standards concerning fertilizers and their quality and also quality standards of soil and land are presented in quoted Regulations. (European Parliament and Council 2003/2003; Ordinance of the Ministry 9 September 2002)
	EC_{50} – 30 min	Vitotoxkit toxicity test (Kapanen, et al., 2013)	Not applicable		
	EC_{50} – 30 s				
	17- b-estradiol eqv	Gas chromatography coupled with mass spectrometer (GC-MS) (Kapanen, et al., 2013)	14 ng/g		
	5-alfa-dihydrotestosteron		60 ng/g		
	Pb	Atomic absorption spectrometry (AAS) (Lapa, et al., 2007)	1.0 mg/kg dm	500 mg/kg[a*]	
	Cd		0.32 mg/kg dm	10 mg/kg[a*]	
	Hg		0.012 mg/kg dm	5 mg/kg[a*]	
	Ni		0.63 mg/kg dm	100 mg/kg[a*]	
	Zn		0.13 mg/kg dm	2500 mg/kg[a*]	
	Cu		0.41 mg/kg dm	800 mg/kg[a*]	
	Cr		0.50 mg/kg dm	500 mg/kg[a*]	
Granulates and pellets to be used in agriculture and for reclamation works	pH	Potentiometric analysis (Lapa, et al., 2007)	Not applicable		All standards concerning fertilizers and their quality and also quality standards of soil and land are presented in quoted Regulations. (European Parliament and Council 2003/2003; Ordinance of the Ministry 9 September 2002)
	Chemical oxygen demand (ChOD)	Sodium/potassium chromate (VI) titration (Lapa, et al., 2007)	97 mg O_2/kg dm		
	Phenolic compounds	Colorimetry (Lapa, et al., 2007)	0.50 mg/kg dm	0.1 mg/L[b]	
	Free cyamide	Flame photometry (Lapa, et al., 2007)	0.10 mg/kg dm	0.1 mg/L[b]	
	EC_{50} – 30 min	Daphtoxkit F magna toxicity test (Lapa, et al., 2007)	Not applicable	10 % v/v[b]	
	EC_{50} – 48 h				
	EC_{50} – 30 min	Microtox toxicity test (Lapa, et al., 2007)	Not applicable	10 % v/v[b]	
	EC_{50} – 48 h				
	As	Atomic absorption spectrometry (AAS) (Lapa, et al., 2007)	0.03 mg/kg dm	0.05 mg/L[b]	
	Cd		0.32 mg/kg dm	0.2 mg/L[b]	
	Cr		0.50 mg/kg dm	0.5 mg/L[b]	
	Cu		0.41 mg/kg dm	0.5 mg/L[b]	
	Hg		0.012 mg/kg dm	0.05 mg/L[b]	
	Ni		0.63 mg/kg dm	0.5 mg/L[b]	
	Pb		1.0 mg/kg dm		
	Zn		0.13 mg/kg dm		
	Fe		0.60 mg/kg dm		
	Al		3.4 mg/kg dm		

Type of material processed	Chemical individual / parameter	Analytical technique	Limit of detection (LOD)	The maximum acceptable concentration / parameter limit values	
Ashes to be used in agriculture and for reclamation works	pH	Potentiometric analysis (Lapa, et al., 2007)	Not applicable		All standards concerning fertilizers and their quality and also quality standards of soil and land are presented in quoted Regulations. (European Parliament and Council 2003/2003; Ordinance of the Ministry 9 September 2002)
	Chemical oxygen demand (ChOD)	Sodium/potassium chromate (VI) titration (Lapa, et al., 2007)	97 mg O_2/kg dm		
	Phenolic compounds	Colorimetry (Lapa, et al., 2007)	0.50 mg/kg dm	0.1 mg/L[b]	
	Free cyamide	Flame photometry (Lapa, et al., 2007)	0.10 mg/kg dm	0.1 mg/L[b]	
	EC_{50} – 30 min	Daphtoxkit F magna toxicity test (Lapa, et al., 2007)	Not applicable	10 % v/v[b]	
	EC_{50} – 48 h				
	EC_{50} – 30 min	Microtox toxicity test (Lapa, et al., 2007)	Not applicable	10 % v/v[b]	
	EC_{50} – 48 h				
	As	Atomic absorption spectrometry (AAS) (Lapa, et al., 2007)	0.03 mg/kg dm	0.05 mg/L[b]	
	Cd		0.32 mg/kg dm	0.2 mg/L[b]	
	Cr		0.50 mg/kg dm	0.5 mg/L[b]	
	Cu		0.41 mg/kg dm	0.5 mg/L[b]	
	Hg		0.012 mg/kg dm	0.05 mg/L[b]	
	Ni		0.63 mg/kg dm	0.5 mg/L[b]	
	Pb		1.0 mg/kg dm		
	Zn		0.13 mg/kg dm		
	Fe		0.60 mg/kg dm		
	Al		3.4 mg/kg dm		
	Naphthalene	Gas chromatography with flight time analyzer coupled with mass spectrometer (GC-TOF-MS) (Zou, et al., 2003)	1.43 µg/g		
	Acenaphthylene		1.24 µg/g		
	Acenaphthene		1.39 µg/g		
	Fluorene		1.13 µg/g		
	Phenantrene		1.36 µg/g		
	Anthracene		0.53 µg/g		
	Fluoranthene		0.35 µg/g		
	Pyrene		0.89 µg/g		
	Benzo(a)anthracene		0.77 µg/g		
	Chrysene		1.31 µg/g		
	Benzo(b)fluoranthene		0.71 µg/g		
	Benzo(k)fluoranthene		0.92 µg/g		
	Benzo(a)pyrene Indeno(1,2,3-cd)pyrene		0.89 µg/g		
			0.92 µg/g		
	Dibenzo(a,h)anthracene		0.69 µg/g		
	Bezno(ghi)perylene		1.11 µg/g		

Type of material processed	Chemical individual / parameter	Analytical technique	Limit of detection (LOD)	The maximum acceptable concentration / parameter limit values
Dried sludge intended to burning	Ignition temperature, Burning temperature, The amount of ashes after burning	Thermogravimetric analysis (TG) (Magdziarz & Wilk, 2013; Magdziarz & Werle, 2014)	Not applicable	Not found
Ashes and sludge; stabilized, dried, sanitized or cemented and solidified intended for storage	pH	Potentiometric analysis (Wu, et al., 2011)	Not applicable	> 6 [c]
	As	Atomic absorption spectrometry (AAS) (Barbosa, et al., 2011)	0.03 - 0.63 mg/kg	2 mg/kg of dry matter in leaching for liquid/solid phase = 10 l/kg (L/S= 10) [c]
	Ba		0.16 mg/kg	100 mg/kg of dry matter (L/S= 10) [c]
	Cd		0.32 - 6.3 mg/kg	1 mg/kg of dry matter (L/S= 10) [c]
	Cr		0.50 mg/kg	10 mg/kg of dry matter (L/S= 10) [c]
	Cu		0.41 mg/kg	50 mg/kg of dry matter (L/S= 10) [c]
	Hg		0.01 - 0.24 mg/kg	0.2 mg/kg of dry matter (L/S= 10) [c]
	Mo		Not known	10 mg/kg of dry matter (L/S= 10) [c]
	Ni		0.63 mg/kg	10 mg/kg of dry matter (L/S= 10) [c]
	Pb		1.0 - 19.7 mg/kg	10 mg/kg of dry matter (L/S= 10) [c]
	Sb		0.003 -0.06 mg/kg	0.7 mg/kg of dry matter (L/S= 10) [c]
	Se		0.01 - 0.18 mg/kg	0.5 mg/kg of dry matter (L/S= 10) [c]
	Zn		0.13 mg/kg	50 mg/kg of dry matter (L/S= 10) [c]
	Chlorides	Ion chromatography (Barbosa, et al., 2011)	Not known	15000 mg/kg of dry matter (L/S=10) [c]
	Fluorides	Ion chromatography (Barbosa, et al., 2011)	Not known	150 mg/kg of dry matter (L/S= 10) [c]
	Sulphates	Ion chromatography (Barbosa, et al., 2011)	Not known	20000 mg/kg of dry matter (L/S=10) [c]
	Dissoluble organic carbon (DOC)	Culometry	Not known	800 mg/kg of dry matter (L/S= 10)[c]
	Total organic carbon (TOC)	Culometry	Not known	5 % of dry matter [c]
	Naphthalene	Gas chromatography with flight time analyzer coupled with mass spectrometer (GC-TOF-MS) (Zou, et al., 2003)	1.43 µg/g	Not found
	Acenaphthylene		1.24 µg/g	
	Acenaphthene		1.39 µg/g	
	Fluorene		1.13 µg/g	
	Phenantrene		1.36 µg/g	
	Anthracene		0.53 µg/g	
	Fluoranthene		0.35 µg/g	
	Pyrene		0.89 µg/g	
	Benzo(a)anthracene		0.77 µg/g	
	Chrysene		1.31 µg/g	
	Benzo(b)fluoranthene		0.71 µg/g	
	Benzo(k)fluoranthene		0.92 µg/g	
	Benzo(a)pyrene		0.89 µg/g	
	Indeno(1,2,3-cd)pyrene		0.92 µg/g	
	Dibenzo(a,h)anthracene		0.69 µg/g	
	Bezno(ghi)perylene		1.11 µg/g	

Type of material processed	Chemical individual / parameter	Analytical technique	Limit of detection (LOD)	The maximum acceptable concentration / parameter limit values	
Cemented ashes and other thermally processed materials intended to be used in building	Phenolic compounds	Colorimetry (Barbosa, et al., 2011)	0.50 mg/kg	Regulations not specified in a single legal act and distinct depending on the purpose of construction materials	
	Sulphates	Ion chromatography (Barbosa, et al., 2011)	Not known		
	Fluorides	Ion chromatography (Barbosa, et al., 2011)	Not known		
	Chlorides	Ion chromatography (Barbosa, et al., 2011)	Not known		
	Cyanate	Flame photometry (Barbosa, et al., 2011)	Not known		
	Cr	Atomic absorption spectrometry (AAS) (Barbosa, et al., 2011)	0.13 mg/kg		
	Zn		0.50 mg/kg		
	As		0.13 mg/kg		
	Ni		0.03 - 0.63 mg/kg		
	Cu		0.63 mg/kg		
	Pb		1.0 - 19.7 mg/kg		
	Cd		0.32 - 6.3 mg/kg		
	Hg		0.01 - 0.24 mg/kg		
	Ba		0.16 mg/kg		
	Mo		Not known		
	Sb		0.003 -0.06 mg/kg		
	Se		0.01 - 0.18 mg/kg		
				A[d] mg/kg	B[e] mg/kg
	Cd	Atomic emission spectrometry coupled with inductively excited plasma (ICP-AES) (Wu, et al., 2011)	0.005 mg/L	1	1
	Cr			15	5
	Cu			100	-
	Zn			100	-
	Ni			5	-
	Pb			5	5
	As			5	5
	Se				
	EC_{50} – 30 min	Extracts toxicity test to *Vibrio fisheri* (Barbosa, et al., 2011)	Not applicable		
	EC_{20} – 72 h	Extracts toxicity test to *Pseudokirchneriella subcapitata* (Barbosa, et al., 2011)	Not applicable		
	EC_{50} – 48 h	Extracts toxicity test to *Daphnia magna* (Barbosa, et al., 2011)	Not applicable		
	Cd, Cr, Cu, Zn, Ni, Pb, As, Se, Mn	X-ray fluorescent spectrometry (XRF) (Wu, et al., 2011)	Not known		
	Defining the molecular structure of tested material	X-ray diffraction (XRD) (Wu, et al., 2011)	Not applicable		
	Naphthalene	Gas chromatography with flight time analyzer coupled with mass spectrometer (GC-TOF-MS) (Zou, et al., 2003)	1.43 µg/g		
	Acenaphthylene		1.24 µg/g		
	Acenaphthene		1.39 µg/g		
	Fluorene		1.13 µg/g		
	Phenantrene		1.36 µg/g		
	Anthracene		0.53 µg/g		
	Fluoranthene		0.35 µg/g		
	Pyrene		0.89 µg/g		
	Benzo(a) anthracene		0.77 µg/g		
	Chrysene		1.31 µg/g		
	Benzo(b) fluoranthene		0.71 µg/g		
	Benzo(k) fluoranthene		0.92 µg/g		
	Benzo(a) pyrene		0.89 µg/g		
	Indeno(1,2,3-cd) pyrene		0.92 µg/g		
	Dibenzo(a,h) anthracene		0.69 µg/g		
	Bezno(ghi) perylene		1.11 µg/g		

<table>
<tr><th>Type of material processed</th><th>Chemical individual / parameter</th><th>Analytical technique</th><th>Limit of detection (LOD)</th><th colspan="2">The maximum acceptable concentration / parameter limit values</th></tr>
<tr><td rowspan="16">Phosphorus raw materials recovered from processed sewage sludge</td><td>P</td><td>Photometry (Donatello, et al., 2010; Xu, et al., 2012)
Atomic emission spectrometry coupled with inductively excited plasma (ICP-AES) (Sano, et al., 2012)
^{31}P NMR spectroscopy (Li, et al., 2014)</td><td>Not known</td><td colspan="2" rowspan="6">All standards concerning fertilizers and their quality are presented in Regulation (EC) No. 2003/2003 of the European Parliament and Council dated on 13 October 2003 (European Parliament and Council 2003/2003; Ordinance of the Ministry 9 September 2002)</td></tr>
<tr><td>Defining molecular structure of tested material</td><td>Scanning microscopy (SEM) (Tantawy, et al., 2013)</td><td>Not applicable</td></tr>
<tr><td>Defining molecular structure of tested material</td><td>Fourier transform infrared spectroscopy (FTIR) (Tantawy, et al., 2013)</td><td>Not applicable</td></tr>
<tr><td>Defining molecular structure of tested material</td><td>X-ray diffraction (XRD) (Donatello, et al., 2010; Xu, et al., 2012; Adam, et al., 2009; Tantawy, et al., 2013)</td><td>Not applicable</td></tr>
<tr><td>Si, Al, Fe, Ca, Mg, Ti, S, Na, K, Mn, P</td><td>X-ray fluorescent spectometry (XRF) (Donatello, et al., 2010; Xu, et al., 2012; Adam, et al., 2009; Tantawy, et al., 2013)</td><td>Not known</td></tr>
<tr><td>Cd, Cu, Hg, Zn, Ni, Cr, Pb</td><td>Atomic emission spectrometry coupled with inductively excited plasma (ICP-AES) (Xu, et al., 2012)</td><td>Not known</td></tr>
<tr><td>As</td><td rowspan="10">Optical emission spectrometry coupled with inductively excited plasma (ICP-OES) (Adam, et al., 2009)</td><td>Not known</td><td>40 mg/kg [f]</td><td>-</td></tr>
<tr><td>Cd</td><td>0.1 mg/kg</td><td>4 mg/kg [f]</td><td>15 mg/kg [g]</td></tr>
<tr><td>Cu</td><td>Not known</td><td>-</td><td>667 mg/kg [g]</td></tr>
<tr><td>Cr</td><td>Not known</td><td>70 mg/kg [f]</td><td>778 mg/kg [g]</td></tr>
<tr><td>Hg</td><td>0.1 mg/kg</td><td>1 mg/kg [f]</td><td>1 mg/kg [g]</td></tr>
<tr><td>Mo</td><td>Not known</td><td>-</td><td>-</td></tr>
<tr><td>Ni</td><td>Not known</td><td>80 mg/kg [f]</td><td>100 mg/kg [g]</td></tr>
<tr><td>Pb</td><td>0.1 mg/kg</td><td>150 mg/kg [f]</td><td>100 mg/kg [g]</td></tr>
<tr><td>Sn</td><td>Not known</td><td>-</td><td>-</td></tr>
<tr><td>Zn</td><td>Not known</td><td>1000 mg/kg [f]</td><td>3333 mg/kg [g]</td></tr>
<tr><td>Ashes from which raw materials other than phosphorus can be recovered</td><td>Ag, Bi, Co, Cr, Ga, Ge, In, Mn, Mo, Ni, Pd, Pt, Sb, Sn, Ta, Te, Tl, V, W, Zr, Al., Ca, Cd, Cl, Cu, Fe, K, Na, Mg, Pb, Si, Zn</td><td>Atomic emission spectrometry coupled with inductively excited plasma (ICP-AES) (Osaka & Jung, 2007)
Mass spectrometry coupled with inductively excited plasma (ICP-MS) (Osaka & Jung, 2007)</td><td>Not known</td><td colspan="2">Not found</td></tr>
</table>

a*- Ordinance of the Minister for the Environment dated on 1 August 2002 on the municipal sewage sludge [26] - Poland,
b- CEMWE – French regulations,
c- Council Directive dated 19 December 2002 on the establishment of criteria and procedures for acceptance to store waste of a given type, [28]
d- GB 5085.3-2007 Identification standard for dangerous waste – identification of extracts toxicity,
e- US EPA directives for toxicity characteristics for procedures concerning washing of the contaminations, maximal contamination concentration,
f- acceptable values without marking responsibility,
g- limit values for German regulation about fertilizing,
* Legal act repealed.

solidification. In this way, the ashes held are fully solidified with proper reactants. It is possible to cast the desired shapes from produced cemented material. Because the process of modernization has not been finished yet the material is cast to big bags to be stored within the installation and driven to a dumping site (Gdańska Infrastruktura Wodociągowo Kanalizacyjna, 2010). Activities focused on determination of chemical and toxicological characteristics of ashes received in the process as well as ashes solidified, are performed in order to incorporate ecologically safe and economically justified methods of sludge management. The path of sludge processing prepared by the company and aimed at building and/or recovery of raw materials from remaining ashes is presented in Fig. 1. Biogas recovery, incineration of sludge and alkaline extraction from ash for phosphorus recovery could be an appropriate method in this case (Nakakubo et al., 2012).

5. Analytical methods and techniques used in determination of selected individuals and sewage sludge parameters at different stages of its processing

Because of the aforementioned modernization of the „Wschód" sewage treatment plant in Gdańsk, the ashes and the solidified ashes will undergo a number of tests. In order to design the best methods of sludge management, chemical characteristic of each raw material on each stage of processing should be made. Analytical techniques that could be used to analyze raw materials and products at each stage of the sewage sludge processing process are depicted in Table 2.

Legislation and regulations presented in Table 2 concerning some of European Union countries come into being in all member countries on the basis of European Union directives such as e.g. the Council Directive dated on 19 December 2002 on the establishment of criteria and procedures for acceptance to store waste of a given type. The aforementioned Directive is adopted in EU countries such as Poland (Council Directive, 19 December 2002). In every country the highest acceptable concentrations can be lower than those given in relevant directives. Local regulations should therefore be monitored in order to control the fulfillment of legal criteria concerning relevant methods of waste management (Kelessidis and Stasinakis, 2012; Samolada and Zabaniotou, 2014).

During the use of processed sludge for agricultural and reclamation purposes it is important to control the concentration of contamination in soils on which the sludge mentioned are used. Here the criteria included in legal acts such as the Ordinance of the Minister for the Environment dated 9 September 2002 on soil quality standards and land quality standards must be fulfilled (Ordinance of the Ministry, 9 September 2002). In some countries, certain legal acts, such as the Polish Ordinance of the Minister for the Environment dated 1 August 2002 on the municipal sewage sludge (Ordinance of the Ministry, 1 August 2002) provide contamination rates that cannot be exceeded in case of using sewage sludge in agriculture and other methods of managing connected with releasing this type of sludge into soil, were repealed. Currently, there are no equivalents of such acts and due to that sometimes there is a situation in which there are no unequivocally specified regulations that should be met by sludge being released into the environment.

Equally important is the control of other standards not mentioned in the table above. These are standards issued by the European Union concerning specified types of construction materials that are being adapted by the member countries. If sewage sludge is processed in the construction industry it is also necessary to fulfill the requirements included in local legal acts. In Poland, the requirements the Ordinance of the Minister of Health and Social Welfare dated 12 March 1996 on the maximum permissible concentration and intensity of factors harmful for health emitted from building materials, devices and items of equipment in rooms intended for people's stay must be met. If potentially dangerous processed waste is used in this way, it is often necessary to perform tests and analysis on a semi-technical or technical scale. Simultaneously, standards should be fulfilled concerning washing of the contaminations into soil of such managed, stabilized materials.

In phosphorus raw materials are recovered from sewage sludge, the product obtained which is to be classified as fertilizer must fulfill many requirements specified in Regulation (EC) No. 2003/2003 of the European Parliament and Council dated 13 October 2003. Widely described requirements in this case make it possible to limit the marketing of dangerous products which, in consequence, may force manufacturers to use advanced technologies in the production of fertilizers devoid of compounds dangerous to the environment and human health. Simultaneously, it increases investment and operating costs eliminating the possibility of such sludge management in some cases.

When raw materials other than phosphorus ones are to be recovered from sewage sludge, the lack of defined law standards concerning manufactured products becomes a problem. Here process profitability will be the limiting aspect. As the technology progresses and the availability of raw materials decreases such management methods will become more and more popular and profitable, especially in highly developed countries.

6. Conclusions

Large amounts of harmful chemical compounds that may occur in processed sewage sludge lie outside the control according to currently established legal regulations. When sewage sludge management method does not involve high temperature treatment, main problem are organic contaminants. Determination of this type of pollutants generally is quite complicated because of the complex matrix. In this case, it may be necessary to use analytical techniques like gas or liquid chromatography and numerous preparation techniques. The quantity and diversity of organic pollutants can be enormous. All this increases the time of preparation, analysis and of course cost of whole process of management. Moreover it affects time and cost of further control of managed media. Therefore dealing with sewage sludge which is processed with high temperature is simpler in some respects. Virtually all organic compounds are destroyed. For this reason sewage sludge ashes do not contain organic impurities. Notwithstanding, due to the fact general part of mater is mineralized, ashes may contain other contaminants like heavy metals or ions. But yet heavy metal analysis at level included in European Union legislation, can be less complicated and cheaper. Removal, extraction or immobilization of heavy metals present is processed sewage sludge or sewage sludge ash can be vital during process of management. To decrease environmental hazard, the development of a safe method concerning management of processed sewage sludge is crucial. Poorly designed method can cause situation in which substances may negatively influence the ecosystem and, as a consequence, human health, may be released to the environment. Sewage sludge management process should be developed separately for each treatment plant. Only then it is possible that management methods will be ecologically and economically justified. Comprehensive chemical characteristics together with toxicity characteristics are essential for the development of methods concerning sewage sludge management.

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