THE ASPECTS OF SLUDGE THERMAL UTILIZATION

A. Flaga

Institute of Heat Engineering and Air Protection, Cracow University of Technology,
ul. Warszawska 24, 31-155 Kraków, Poland
(E-mail: agnieszkaflaga@poczta.onet.pl)

ABSTRACT
The article focused on the problem of sludge thermal utilization. Different aspects of this problem are presented here. Starting from introducing sludge treatment and utilization options, through explanations connected with energetic usefulness of sludge treated as a fuel and with the amount of energy in sludge that could be effectively used, ending at last on presenting sludge thermal utilization options and their advantages or disadvantages.

KEYWORDS
Energy properties of sludge, sewage sludge, sludge drying, sludge incineration, sludge treatment, sludge thermal utilization

INTRODUCTION

Sewage sludge comes from wastewater treatment processes and comprises lumpy, flaky and colloidal solids dispersed in water. Together with industry development and growing number of population, increase in the amount of produced sewage sludge can be observed. At present there is an urgent need to take the proper steps to deal with the problem of excessive amount of sludge.

When dealing with sewage sludge, we should take into consideration the principle of sustainable development. Its main assumption in the context of sewage sludge management is to recirculate mass or energy. In the first case it would mean ***environmental use***, that is: using sludge for agriculture, recultivation, product recovery etc.; in the second case ***industrial use***, that is termochemical treatment with obtaining and reuse energy from the sewage sludge.

The physical and chemical characteristics of sewage sludge are changing. Within the last few years the application of sewage sludge to agricultural land (which is connected with mass recirculation and has been the most common method of disposal so far) had become a cause for concern as a threat to human health and the environment (Pollington D., 1996). At the same time methods of industrial use of sewage sludge (sometimes called energetic ones) have become more popular. They are justified by the fact that there is a significant amount of energy in the carbonaceous component of sewage sludge, which can be effectively used.

Growing load of contaminants in sludge (heavy metals especially) as well as the fact that sludge is posing sanitary threats caused, that methods based on incineration or co-incineration are perceived as the optimal solution of the sludge problem. There is also growing an awareness, that widely applied, so far, sludge landfilling is not the best solution of the problem and that the new, more advanced methods of utilization are looked for. Therefore, at present some projects of industrial use of sludge are being put into practice. The main idea of those projects is to dry dewatered sewage sludge so it could further be incinerated or co-incinerated, with minimum energy added.

SLUDGE TREATMENT AND UTILIZATION OPTIONS

The possibility and the final effect of sludge utilization depends strongly on the properties (energetic or fertilising) of sludge and the previous way of its preparation, which determine the specific usage. Fig. 1 presents a wide range of sludge treatment and utilization options.

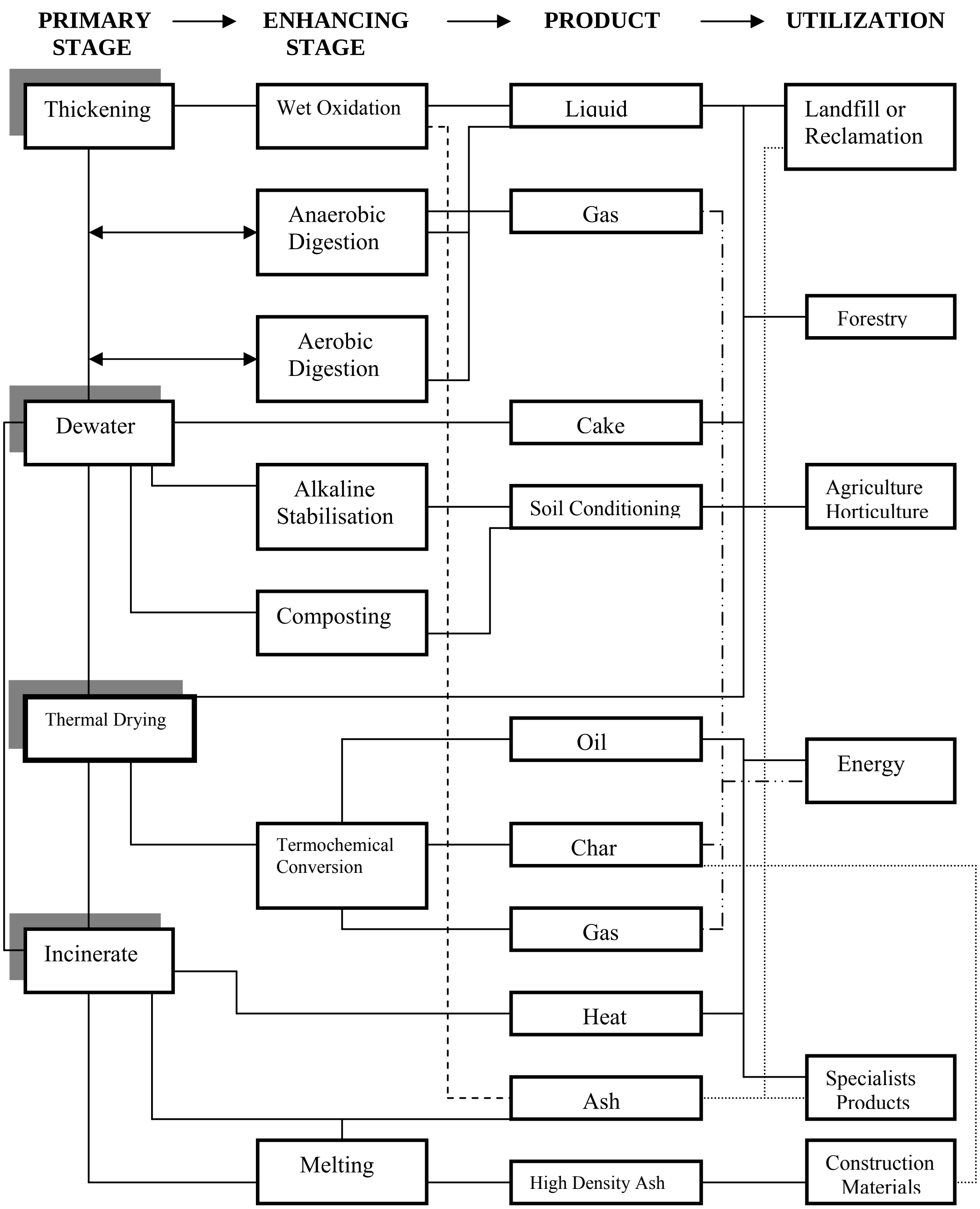

Figure 1. Sludge – treatment and utilization options.(Furness D.T., Hoggett L.A. and Judd S.J., 2000).

In the following part of the article stress will be laid on the methods of industrial/energetic use of sludge, as the ones in agreement with the new trend of sludge management and utilization. The methods of co-incineration and incineration of sludge or energetic products coming from the termo-chemical treatment of sludge, will be called one common name: the thermal utilization of sludge.

REMOVING WATER FROM THE SEWAGE SLUDGE

Since sewage sludge is highly hydrated (consist in 98-99% of water) processes like thickening (condensation), dewatering and drying are necessary to prepare sludge for energetical use. In its original form sludge is not energetically attractive. Fig. 2 presents different stages of removing water from the sludge.

Water in sludge may be of the following types:

- water between pores (non – bonded);
- free capillary water;
- bound water
  - intercellular (adsorbed)
  - intracellular (absorbed)

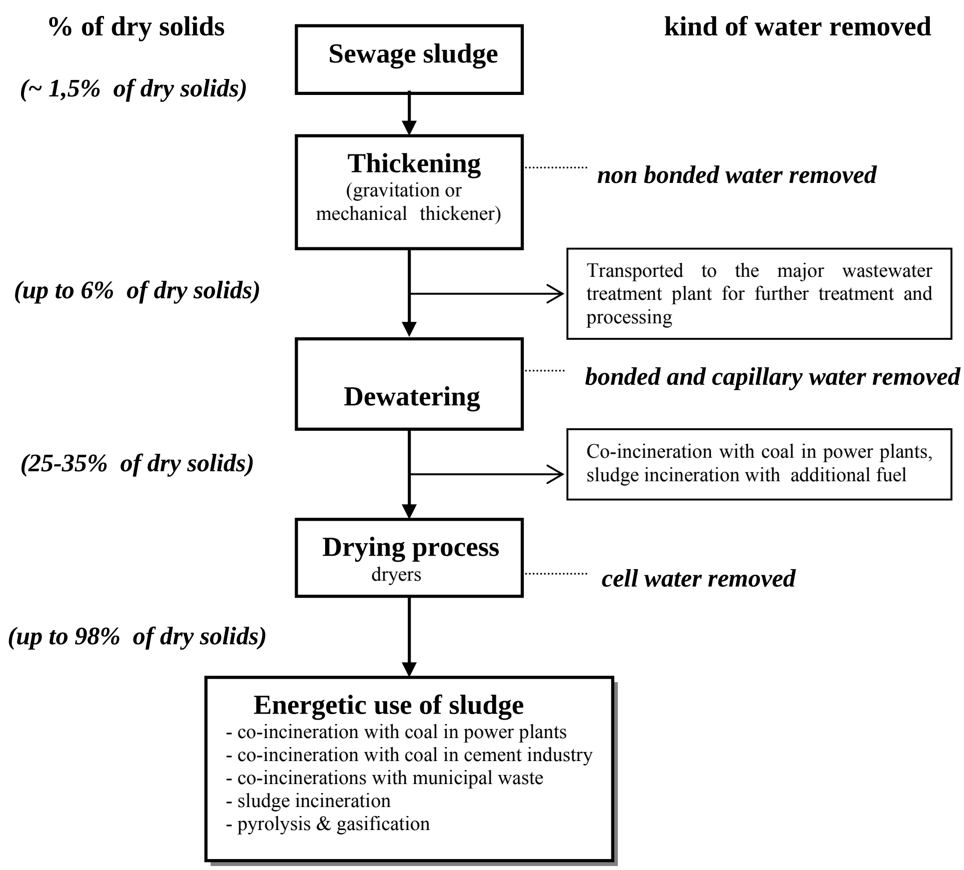

Figure 2. Sludge dewatering process.

Non-bonded water may be removed from sludge by thickening. Free water is readily removed from sludge by gravity settling or dewatering with or without chemicals. The bound water, in intercellular form, is also removable (in part) but requires the addition of polymers. The intercellular water is retained in the sludge by chemical bonding, which may be broken by the addition of polyelectrolytes which cause a change in the electric charges. The intracellular bound water is only possible to remove if the sludge particle walls can be broken by either heating, freezing or electroinduced forces.

It should be underlined that the amount of energy used to mechanical dewatering of sludge is much lower than the quantity used during sludge drying. Authors (Kowalik P., 1998) estimate that approximately 17-34 kWh/ m3 of water taken from sludge is needed during mechanical treatment, while during drying in the temperature of 300 ^{o}C 850 kWh/m^3 will be required. This means that drying is 25 to 30 times more energy consuming process than mechanical dewatering and leaving sludge on specific fields to dry. Unfortunately, methods of mechanical dewatering in most cases are not able to remove water from sludge to the level lower than ~ 75% of the origin water quantity in sludge. When taking under consideration a wide range of thermal utilization methods (fig. 3), sludge drying should be treated as an integral and necessary process; only ways of diminishing amount of conventional fuel used to produce energy for drying should be looked for.

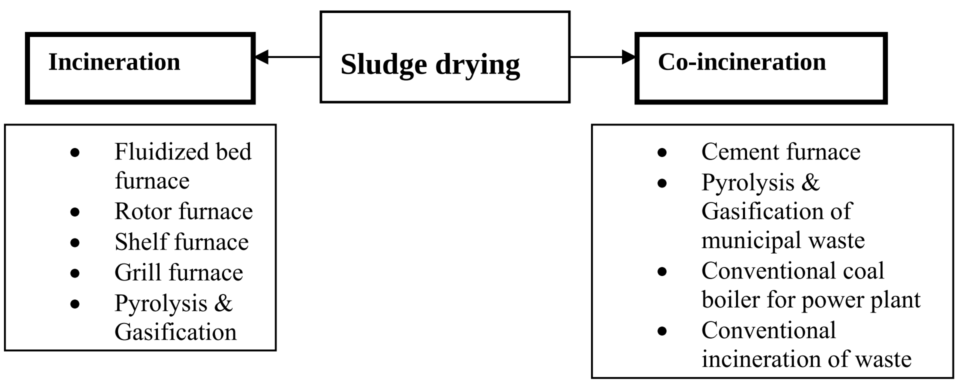

Figure 3. The methods of sludge thermal utilization.

ENERGY PROPERTIES OF SLUDGE

Sewage sludge used as a fuel can be characterized on the main energy parameters:

- **Low calorific value** from wet sludge solids;
- **High calorific value** from water-free sludge (dry solids);

Each of the above parameters has a different value for the same sludge and therefore sludge moisture or combustible fraction has to be additionally determined in sludge dry solids. The most precise and reliable parameter is a sludge high calorific value and the real low calorific value can be calculated according to the following formulas (Grabowski Z., Oleszkiewicz J.A., 1998):

Wd = Wg * (1-w) – r * (w + 9H) [MJ/kg of wet sludge]
Wd = W g,s.m.bp * (1-w-p) – r * (w + 9H) [MJ/kg of wet sludge]

Wd – low calorific value from wet sludge
Wg – high calorific value of sludge [MJ/kg of water-free sludge]
W g,s.m.bp – high calorific value of ash- and water-free sludge

R – water evaporation enthalpy at the ambient temperature
H – fraction of combustible hydrogen in wet sludge (by weight)
If there is no sufficient information on elementary hydrogen fraction in the combustible mass of the sludge, empiric formulas may be used, which assume typical values of this element for different types of sludge (according to Żygadło M., 2001):
For raw sludge
Wd = 14,235 – 1,683 * w   [MJ/kg of wet sludge]
For digested sludge
Wd = 10,467 – 1,306 * w   [MJ/kg of wet sludge]

The sludge high calorific value is not an equivalent of the quantity of heat that could be practically used. To evaluate energetic usefulness of the sludge technical and elementary analysis are needed. To estimate the sludge potential for autothermic combustion (combustion without any supplementary fuel) the Tanner's triangle could be used. This triangle has been dveloped on the basis of communal waste combustion research. Fig. 4 presents the Tanner's triangle with co-ordinates corresponding with the mass shares of water (moisture), combustible and mineral fraction of the sludge. The darkened area marks the limits of waste autothermic combustion. The limiting values for communal waste autothermic combustion, concluded from the triangle are:

- ***Water content*** (wilgotność) – ***50%***
- ***Combustibles*** (części palne) – ***25%***
- ***Mineral fraction*** (części niepalne) – ***60%***

All in all, the total value of the shares must amount to 100%.

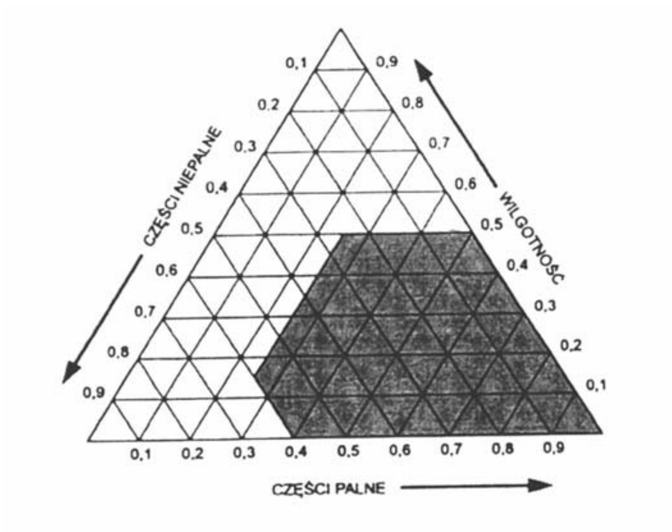

Figure 4. Tanner's triangle

Taking into consideration practical research which confirm the estimation made on the basis of the Tanner's triangle, sludge used as an energy source incinerates autothermaly (without an auxiliary fuel) once properly dewatered. The sludge cake of 20-30% dry solids can be incinerated if only an auxiliary fuel is added; with 50% of dry solids or higher sludge incinerate autothermaly. (Grabowski Z., Oleszkiewicz J.A., 1998).

It should be underlined that by dewatering process maximum of ~30% dry solids in sludge can be achieved. Higher values (including 50% of DS needed to autothermic combustion) can be reached by sludge drying; therefore the sludge drying process is always necessary before any thermal process which sludge undergo. Since the fraction of mineral ballast and organic material can vary in sewage sludge, the moisture value W = 35% was assumed as the safe limiting value for an autothermic incineration process.

According to Kowalik (Kowalik P., 1998) the high calorific value of sewage sludge usually ranges from 10 to 20 MJ/kg of DS (dry solids). Maximum water content in sludge directed to incineration is 60%; it means that there should be minimum 40% of dry solids. In most cases the high calorific value of organic matter in sludge dry solids is counted as 22 MJ/kg of organic dry mass. Presuming that 1/3 (33,3 %) of sludge dry mass is mineral (does not undergo incineration process), the high calorific value of dried sludge is approximately 14 MJ/kg of DS. In the case when the dry solids consist in 50% of mineral fraction (and the rest is organic) the high calorific value of dried sludge is about 11 MJ/kg of DS. The high calorific value of digested and dried sludge is usually lower then raw sludge by about 2 MJ/kg of DS. (Kowalik P., 1998).

According to Grabowski (Grabowski Z., Oleszkiewicz J.A., 1998) the high calorific value of raw sludge ranges from 16 to 20 MJ/kg of DS and for digested sludge between 10-15 MJ/kg of DS. The raw sludge consist of organics (combustible fraction) in 75-85% of DS; after stabilization (digestion) of sludge this value lowers to 45-60% of DS. It means that the share of mineral fraction is approximately 40-55% of DS.

Chosen fuel properties of sewage sludge according to German research presents table 1.

Table 1. Chosen fuel properties of sewage sludge according to German research. (Poradnik Gospodarowania Odpadami 2003):

Properties	Sludge type				
	Raw sludge		Digested sludge		
	from mechanical treatment	biological	Poorly digested	Well digested	Very well digested
Dry solids [%]	5-10	4-8	4-12	4-12	4-12
Organics [% of DS]	60-75	55-80	50-60	45-55	30-45
High calorific value [MJ/kg DS]	16 - 20	15 - 21	12,5 - 16	10,5 - 15	6,3 - 10,5

Dadej (Dadej W., 2000) says that the organic matter contents in DS of digested sludge is approximately 52,6-58,4 % what guarantees energy surplus during incineration.

Thanks to a typical content of such combustible elements as carbon, hydrogen and sulphur in the sludge, a combustible fraction of the sludge is similar to the values observed for lignite.

After Kowalik (Kowalik P., 2000), the high calorific value of completely dried and digested sewage sludge is similar to the slimed peat, about 12-14 MJ/kg of DS.

Schubering (Schubering A., 1992) gives Austrian values according to which the high calorific value of sewage sludge that contains 50% of organic matter in DS and is dewatered to 50% of water content is about 4 MJ/kg. When sludge contains 75% of organic matter and is dewatered to 50% it’s low calorific value is 6,5 MJ/kg. And when there is 50% of organic matter in sludge DS and sludge is dewatered to the level of 85% of water content it’s low calorific value diminishes to 0 MJ/kg.

The nett surplus energy value

Presented low calorific values can be misleading, especially for sludge with high water content. It should be reminded that wet sludge will not incinerate autothermally; the limiting value for water content is 50%. The drying process, thanks to which useless water is evaporated from the sludge, is necessary. The rough energy ballance performed for wet sludge incineration shows that:

> If there is 70% of organic substance in sludge dry solids and the slugde is dried to 45% of DS (there is 65% of water in sludge) 5,6 MJ of thermal energy per kg of incinerated sludge may be obtained. However, before incineration, 2,8 MJ of energy per kg of the sludge must be provided to dry the sludge to the condition which enables incineration.
>
> Summing up, 2,8 MJ/kg must be delivered for water evaporation, so the ***nett surplus energy value*** is: 5,6 - 2,8 = 2,8 MJ/kg of incinerated dry sludge. (Kowalik P., 1998)

The excess energy is partially lost due to heat losses at the drying and incineration installations as well as to a stack loss (flue gas enthalpy and drying air enthalpy at the drier outlet).

Sludge in terms of a fuel

There is a method of fuel properties describing. In this method the high calorific value, ash content and sulfur content are counted and presented as best describing properties of the specific fuel. For example, the pit-coal characteristic is: 25/22/08. It means that the high calorific value of pit-coal is 25MJ/kg, fuel contains 22% of ash and 0,8% of sulphur. According to this method, raw sludge can be described as 14/40/1,2 (14 MJ/kg of DS, 40% of ash and 1,2% of sulphur in sludge dry mass) and digested sludge as 12/40/1,5. From comparison with pit-coal it appears, that 1 ton of pit-coal is energetically equal with 2 tonnes of dried sludge.

Moreover, from given values 3-5 MJ/kg should be subtracted as the amount of energy needed to water vaporization from wet sewage sludge. (Kowalik P., 1998).

TECHNOLOGIES FOR SLUDGE THERMAL UTILIZATION

The main aspects which determine the choice from technologies for sludge thermal utilization (fig. 3) are:

- Fuel properties of sludge which define its ability to the autothermic incineration;
- Previously applied processes of sludge dewatering or complete drying. (Sludge drying process, carried out as an independent thermal process and realized in the wide range of water evaporation, definitely broadens the circle of possible ways of sludge utilization);
- Economically justified transport possibilities of the mechanically dewatered sludge to the place of its utilization; (Pająk T., 2003)

Sludge incineration technologies are technically quite well mastered. Pyrolysis and gasification alone as well as their combination belong to the solutions of a small application scale and a high investment risk degree; detailed energetic analysis are necessary here, but these processes have a potential. Sludge incineration is justified for bigger agglomerations and groups of water treatment factories producing over 10.000 t of DS per one year. (Grabowski Z., Oleszkiewicz J.A., 1998)

Sludge co-incineration with communal waste is especially justified in the area where the facilities for thermal utilization of solid waste already exist.

Sewage sludge can also be treated as an alternative, substitute or supplementary fuel and co-incinerated in the rotor furnace in cement industry. The most often required conditions are:

- to dry the sludge over 90% of dry solids before it is incinerated;
- the high enough calorific value (many country cement factories require min. 12 MJ/kg of DS); what in the case of previously digested sludge could be hard to achieve.

Cement industry often demands also subscribing long-term agreements with defined conditions of sludge utilization cost and sludge quantity. It is due to ensuring that there will be enough of this kind of a fuel to continue the process of cement production, which is superior. The main characteristic of the process of sludge co-incineration in the cement furnace is an immobilization of a significant amount of contaminants in the final product. Thermally dried sludge combusted in the cement furnaces are not only a source of energy, but a mineral filler of the cement as well. The sludge is added together with a fuel to the furnce in which cement is produced.

For approximatelly 5 sec. in the temperature of 1800-2000 ^{o}C organic compounds are completely destroyed. Depending on the quantity and the quality of sludge additional eliminations of NO_x and SO_2 may be necessary. If calorific value of the sludge is high (e.g. raw sludge), the profit made on its incineration is enough to cover an additional cost of flue gas treatment in already existing cleaning system. (Korczak – Niedzielska M., Gromiec M.J., 1998)

It should be, however, taken into consideration that the emission freedom in that kind of process could be in the future limited by the newest 2000/76/EC directive. The moment it is implemented to the country law, the factories will have to apply additional installations for flue gases treatment. This duty could diminish the interest in co-incineration of this kind of supplementary fuel in the cement industry (Pająk T., 2003).

A different way of the sludge usage is its co-incineration with coal in the power plants. This technology enables co-incineration of dried as well as dewatered (25-35% DS) sludge. While considering co-incineration of only dewatered sludge right proportions of moisture in coal and sludge should be secured. The sludge is dried thanks to the waste heat of the flue gases usage. The level of 25-35% of dry solids in sludge is easily achievable by the centrifuge or press.

In this technology sludge mixed with coal or separately is directed to a coal mill, grinded and homogenized there and after this treatment transported to the boiler burning chamber together with coal dust. The technology has been well worked out in several German power plants. An observation of the effects obtained there allows optimistically consider an application of this technology in the country conditions.

Usually, sludge dry mass share shouldn't be higher than 5% of the directed to the burning chamber coal dust mass. It guarantees invariability of the ash composition and possibility of using ashes in the construction industry. When the boilers in a power plant have a high thermal efficiency (the demand for coal is high), the amount of co-incinerated sludge could be quite significant with reference to a year. It should be also underlined that there are already existing flue gas cleaning systems and units for incineration in the power plants; only sludge dosage system is missing and must be installed when considering sludge co-incineration.

It is also important that sludge co-incineration with coal in power plants is cheaper than:

- co-incineration with municipal waste
- sludge incineration (Steier K., 2003)

On the basis of performed (in the full technical scale) tests it has been stated that the 3% addition of sludge (with 85% of DS) to the incinerated coal is of no significance for the emission. In the gaseous products of combustion only an increase in HCl and HF concentration has been observed. Dust and heavy metals were on the same level. Heavy metals, however, were found in ashes. It's been also stated that the incineration of sludge which consist of dry solids in less than 85% causes odours spreading.

CONCLUSIONS

Communal sewage sludge is lately dynamicly coming out of the shadow of communal waste and is claiming its necessary place in the strategy of waste handling and management. The best solutions of the "sludge problem", good sewage sludge management plans are looked for.

This article is only a kind of suggestion to the assumptions of the sludge management plan. Detailed models for calculation of costs, emissions, energy demand, the quantity and a kind of a fuel are needed to continue the conciderations.

1. As an answer to the "sludge problem", the new trend of energetic/industrial sludge utilization is being developed. The sludge utilisation is understood here as an incineration or co-incineration of the thermally dried sewage sludge. It is perceived as the only long term solution for still growing sludge quantity.

2. The process of sludge drying is consuming much energy. Wet sludge however, is not attractive as a fuel, a source of energy; so that in case of sludge thermal utilization drying is necessary. The best ways of minimizing supplementary fuel (used instead of the dried sludge) for drying are looked for.

3. When debating on choosing one of several options of sludge thermal utilization, the existing nearby elements of waste management system or places where a fuel request is high should be taken into consideration. To the already existing objects and facilities which could be helpful in sludge utilization belong:

- facilities for sludge thickening, dewatering or drying in wastewater treatment plants;
- municipal waste incineration plants;
- coal-fueled power plants;
- cement factories;

4. The decision about the specific sludge thermal utilization way should depend also on the volume of produced sludge stream. If the sludge stream is small the most suggested proposals are:

- to process it on site to the proper state and after this transport it to the places, where further actions (e.g. incineration, drying, co-incineration) will be applied. In this case it is possible to concentrate the main process and a significant sludge volume in one place.
- to transport the sludge directly after thickening to the major wastewater treatment plant for further processes. This solution is suggested only when there is no place for sludge processing to the proper state (~ 30% of DS) on site or when the distance between the place of sludge production and the main wastewater treatment plant isn't long. It should be underlined, that after thickening sludge in ~ 95 % consist of water.

If the sludge stream produced in one wastewater treatment plant is significant, processing on site proved correct. Sewage sludge can be dewatered up to 35% of DS and incinerated with a supplementary fuel. Another possibility is after sludge dewatering transport it to the coal-fueled power plant. When drying is possible, sludge could be dried to the level of ~ 90% of DS and transported as a fuel to cement factories or power plants or to the municipal solid waste incineration plants or used on site for example to dry another portion of the sludge. The choice is dependant mostly on economic, environmental and technical possibilities of the wastewater treatment plant, on the sludge character and opportunities of the sludge market.

5. Not all from the available processes for sludge thermal utilization are well known. Some of them (pyrolysis, gasification) need further studies, but are perceived as "the ones with the potential". There are also problems of the emissions during different ways of sludge incinneration and their legal restrictions.

6. The concept of sustainable development demands to analyse the solution of the sludge problem from economic, technical/environmental and social points of view. In the article only the technology (technical part) of sludge thermal utilization with an emphasis on its application has been presented. What must be practically done with the sludge before it is ready for the specific technology and what are advantages or disadvantages of each solution. It should be reminded that every technology has its costs, in some way has an influence on the environment and there is also the social aspect of it. Due to the concept of sustainable development all aspects of each solution for the "sludge problem" should be taken into consideration in details to create a good plan of sludge management and utilization. To combine all the aspects and choose the best solution for the "sludge problem" multi-criteria analysis are needed. It should be the next step in solving the "sludge problem".

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