MINIMIZATION OF SEWAGE SLUDGE PRODUCTION – EUROPEAN TRENDS AND SELECTED TECHNOLOGIES

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ABSTRACT
Contemporary environmental policy of the European Union has resulted in the desire of maximization of the use of sewage, mainly to minimize their final disposal. Final agricultural disposal of sludge has been caused mainly by stringent EU directives. Conventional storage of sludge are economically feasible on condition that comprehensive national strategy is issued. Both technical and legal aspects led to increasing importance of minimization quantity of sludges outgoing treatment plants. This strategy has been recently supported by significant economic reasons for plants' operators as in typical municipal wastewater treatment plant (WWTP) sludge treatment and handling costs are estimated as high as up to 60% of total operational costs. Implementation of specific technologies resulting in significant reduction of the amount of residual substances introduced into the environment occurred to be of crucial importance for modern sustainable plants. Numerous improvements in sludge processing facilities were proposed in last decade however a sludge disintegration seems to be most feasible at present. The paper describes selected technologies of sludge minimization with special emphasis on proven disintegration technologies.

In general terms - a disintegration breaks down solids, first of all the microbial cells, leading to release of intracellular fluid, which thus become more accessible for further biological treatment processes, wastewater and sludge. The result is intensified decomposition of organic substances contained in the sediment and accelerate the transformation into biogas, finally resulting in decrease of the amount of sludge to be transferred out of the WWTP.

This paper presents a description of the biochemical changes occurring in the biomass in wastewater and sludge lines complemented the characteristics of new manufacturing processes used to minimize the amount of sewage sludge. Some processes have been analyzed for their advantages and drawbacks detected or predicted (for the less popular solutions) when applied in practice.

INTRODUCTION

Retrofitting of municipal wastewater treatment plants to fulfill contemporary legal and technical requirements has to incorporate improvements in both wastewater and sludge treatment trains(Kurbiel *et al.*, 1996).. Despite sludge stabilization a main task of sustainable sludge processing technology is to produce an additional source of easybiodegradable carbon compounds to increase efficiency and intensification of nutrient removal from wastewater (Rybicki, 2013). However a conventional requirement i.e. reduction of dry mass together with an increase in biogas production in anaerobic stabilization is still valid in routine operation. The EU directives regarding wastewater and sludge processing provide grounds for the development of legal acts for all

European countries. Following the directives member countries have been obligated to undertake the following actions (Cimochowicz-Rybicka, 2013):

a) limit possibilities of sewage sludge deposition;
b) process more municipal sludge before its introduction to the environment, including thermal processing;
c) utilize more municipal sewage sludge in biogas stations and as an energy source;
d) increase the amount of municipal sewage sludge that is thermally processed;
e) utilize nutrients present in sludge;

The analysis of the official statistical data (EUROSTAT, 2012), with regards to the amount of sludge generated by municipal sewage treatment plants in Europe, underlines the diversity of approach to these issues by individual countries, even though a common policy is formally applied. Table 1 contains a summary of data on the total sludge weight, the mass of sediment per capita and basic methods of sludge disposal, being completed from official information from 10 selected EU countries (and Switzerland) producing the highest dry mass of municipal sludge.

Table 1. Sludge produced at municipal sewage treatment plants and the ways of its management in the European countries (Cimochowicz-Rybicka, 2013):

Country	Total	Sludge dry mass per capita	Basic method of disposal		
			Agriculture +Composting	Incineration	Other
	thou.ton/ year	kg/cap*year	percent of total mass		
Germany	2049	24,99	53%	47%	0%
United Kingdom	1771	28,63	70%	16%	9%
France	1087	17,37	73%	19%	0%
Spain	1065	23,12	65%	4%	16%
Italy	1056	17,51	44%	3%	11%
Poland	563	14,76	26%	2%	58%
Netherlands	353	21,37	0%	95%	0%
Hungary	260	25,95	60%	1%	10%
Austria	254	30,28	38%	36%	17%
Czech Republic	220	20,94	78%	1%	8%
Switzerland	210	27,14	10%	90%	0%

The average unit sludge production in municipal wastewater treatment plants (WWTP) was 23 kg/cap*year, with the highest value observed in Austria (30,28 kg/cap*year). The lowest reported unit value was found for Poland (14,76 kg/cap*year). It can be explained by a low percentage of population connected to WWTPs. The table 1 shows that prevailing final sludge handling methods are: agricultural applications and composting or thermal incineration. It should be noted that the largest sludge ‘producer’ i.e. Germany and largest unit sludge ‘producer’ (Austria) apply agriculture/composting and incineration methods in similar proportions (almost half-and-half). In other countries, the predominance of one of these two methods may be observed:

- agricultural methods dominate in the United Kingdom, France, Spain, the Czech Republic and Hungary
- in the Netherlands and Switzerland at least 90% of sludge is incinerated.
- Italy is the only country where landfilling remains the leading method of disposal
- Poland declares that over 50% of the sludge is subjected to the "other methods of disposal".

Deeper studies on Polish policy in sludge processing showed that total annual mass of sewage sludge, generated at the Polish WWTP increased significantly in years 2000 – 2008. However one can be found that this trend has decreased slightly in recent years. It may be credited to broad investments in construction of new treatment plants that took place since 1990s until the end of last decade. The funds were spend on new constructions as well as for operational optimization. An improvement of plants' operation resulted in a decrease of amount of sewage sludge stored at the WWTP. The analysis of official data on sludge management at Polish municipal wastewater treatment plants, has showed that a visible growth of a number and capacity of WWTPs has been supported by improvements in sludge management. Another good example of improvement of sludge handling is a formal and economical requirement for an increase of a renewable energy share in the total country energy balance. At present, production of renewable energy from biomass and waste incineration in Poland equals 8.5% of the annual production of primary energy, while the average value for 27 member countries of the European Union is 12.5%.

Table 2. Trends in sludge production and utilization at the Polish municipal wastewater treatment plants (Cimochowicz-Rybicka, 2013).

	Year	2000	2005	2008	2009	2010
Total sludge	Thou. ton/year	359,8	486,1	567,3	563,1	526,7
Waste disposal methods						
Agriculture	Thou. ton/year		66	112	123,1	109,3
Land reclamation	Thou. ton/year		120,6	105,8	77,8	54,3
Composting	Thou. ton/year	25,5	27,4	27,5	23,5	30,9
Incineration	Thou. ton/year	5,9	6,2	6	8,9	19,8
Landfilled	Thou. ton/year	151,6	150,7	91,6	81,6	58,9
Other	Thou. ton/year	176,8	115,2	224,4	248,2	253,5

Implementation of specific technologies resulted in a significant reduction of the amount of residual substances that are released to the environment and remain in its circulation. Such an approach seems to be proper way of operation of modern sustainable plants. Besides sludge stabilization, the main task of contemporary sludge processing technology is to produce an additional source of easy biodegradable carbon compounds to intensify nutrient removal (Boehler&Sigrist 2006, Ødegaard 2004, Nickel&Neis 2007, Zielewicz 2007). The key mechanisms of sludge reduction, incorporated in wastewater treatment or sludge disposal units, can be described as followed (Foladori et al., 2010):

1. cell lysis and cryptic growth,
2. uncoupled metabolism,
3. endogenous metabolism,
4. microbial predation,
5. hydrothermal oxidation.

The reduction of solids' dry mass accompanied with an increase of methane rich gas (a 'biogas') production via an anaerobic digestion remains still valid in a routine operations (Wei et al., 2003, Winter 2002, Valo et al., 2004, Zhang et al., 2008, Cimochowicz-Rybicka 2013, Rybicki 2013).

SELECTED METHODS AND STRATEGIES OF SLUDGE MINIMZATION

As the hydrolysis performance is a limiting factor for both aerobic and anaerobic decomposition on bacteria cells (digestion), an overcome of this limit is a mail goal for all attempts to minimize sludge amount. It can be reached through 'acceleration' of initial part of hydrolysis achieved by one of following mechanisms:

- cell lysis;
- endogenous metabolism;
- microbial predation;
- hydrothermal oxidation of cell walls.

By now most of practical attempts to apply these mechanism are focused mainly on cell lysis improvement, this group of processes contains: enzymatic hydrolysis, chemical and thermo chemical hydrolysis, oxidation with strong oxidants (mainly ozone), chemical treatment, mechanical treatment, ultrasound disintegration and thermal treatment. Application of endogenous metabolism (aerobic and/or anaerobic digestion) is based on improvement of widely applied processes (aerobic and/or anaerobic digestion) by changing operation mode (subsequent anaerobic/aerobic condition or using higher temperature of sludge exposed to digestion (thermophilic processes). Remaining mechanism are at premises of their use , these are: microbial predation and hydrothermal oxidation. Proper choice of sludge minimization should be based on consideration of specific advantages and disadvantages of each of technical options. Table 3 summarizes advantages of most common pre-treatment technologies based on cell lysis.

Table 3. Selected technical advantages of most common sludge pre-treatment technologies based on cell lysis

Advantage→ Technology↓	Easiness of application	Short contact time	Dewaterability improvement	Increased biogas production	Low odor	Low investment costs
Enzymatic hydrolysis	✚		✚			✚
Chemical and thermo chemical hydrolysis	✚		✚	✚		
Oxidation with strong oxidants				✚		
Mechanical treatment	✚	✚	✚			
Ultrasound disintegration	✚	✚		✚	✚	
Thermal treatment	✚		✚	✚		

It can be stated that no method is easy in operation, and still there is limited knowledge concerning routine operation, so simultaneously with prospective advantages also possible drawbacks should be taken into consideration prior a decision about full-scale application of specific technology. Most operational problems are associated with increasing energy consumption, complex operational procedures and deterioration of pre-treatment equipment. Some of methods create specific disadvantages, most common ones (for the same minimization technologies as analyzed in Table 3) are presented in table 4. Besides problems listed in this table some other drawbacks may occur e.g. odor formation problems while thermal -related technologies are applied.

Table 4. Selected technical disadvantages of most common sludge pre-treatment technologies based on cell lysis

Disadvantage→ Technology↓	Limited application	Additional volume needed	Dewaterability worsening	Erosion and/or destruction of equipment	Higher investment costs	Higher operational costs
Enzymatic hydrolysis	✓					✓
Chemical and thermo chemical hydrolysis		✓		✓		✓
Oxidation with strong oxidants					✓	✓
Mechanical treatment				✓		✓
Ultrasound disintegration			✓	✓		✓
Thermal treatment		✓		✓		✓

EXAMPLES OFSLUDGE MINIMIZATION TECHNOLOGIES

Ultrasound disintegration is known as one of best recognized technologies from the group based on cell lysis, as it seems to be an ecologically reasonable and economically feasible solution, leading to a decrease of dry mass of processed sludge and intensifies generation of a methane-rich gas, simultaneously (Müller 2000, Bień&Szparkowska 2004, Rybicki 2004, Pilli et al. 2010, Cimochowicz-Rybicka&Rybicki 2010). Being a relatively new area of sewage treatment, this process stil has not got unified standards/procedures which would allow for a clear assessment of the process efficiency (Zielewicz 2007, Cimochowicz-Rybicka et al., 2009). Figure 1 shows potential places of sludge disintegration unit location in the WWTP's layout (Ried et. al, 2002, Żeglin-Kurbiel et al., 2003) At present, most of sludge minimization units are located on wasted activated sludge pipeline prior to anaerobic digestion.

Application of predator microbes is still under development, however it seems to be a prospective technology on condition that specific operational problems are solved in coming future. General concept of this technology is based on additional reactor with predation worms (*Tubificidae* or *Lumbriculidae*) where excess sludge is transformed into worms' feaces.

Figure 2 shows a diagram of a predation reactor in sludge handling unit (Foladori et al.,2010). Significant advantages this method are following: low operational const as well as low energy consumption with significant improvement of dewaterability. This method however has some disadvantages such as: large space required for worms' growth and increased discharge of N and P load to a wastewater treatment train via worms' excreta. General principle of predation by worms is still unknown, so it is not possible to control this process in day-by-day operation, which requires further investigations.

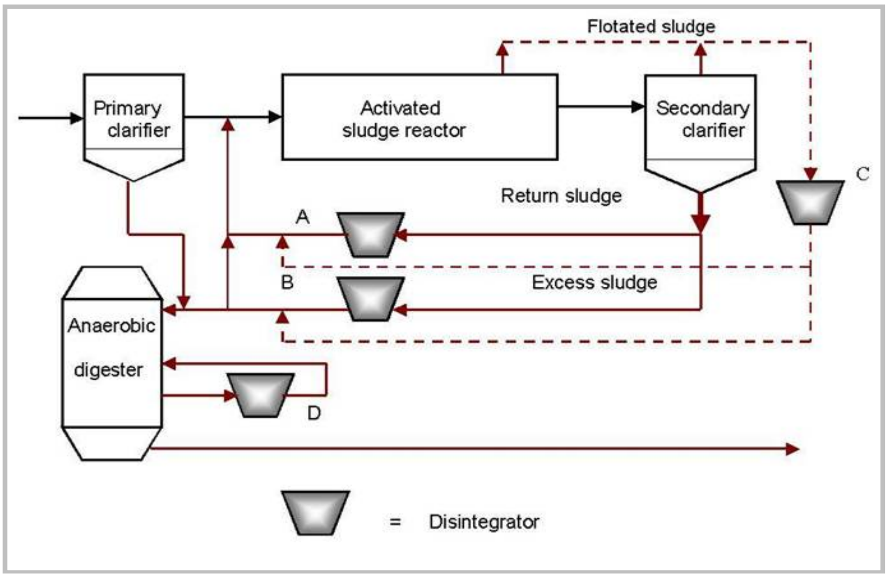

Figure 1. Location of sludge disintegration units in a plants' layout (Ried et. al., 2002, Żeglin-Kurbiel et al.,2003)

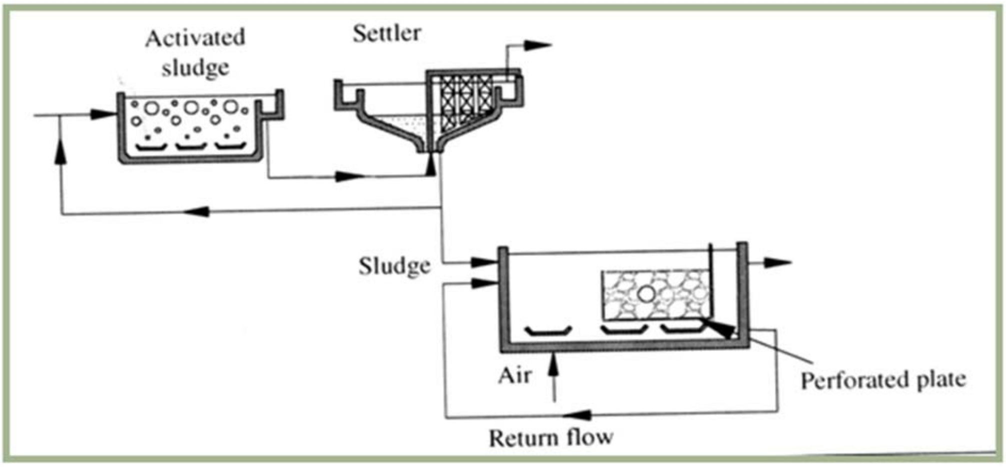

Figure 2. Diagram of a predation reactor in sludge handling unit (from Foladori et al.,2010).

Supercritical water oxidation and wet air oxidation methods of sludge pretreatment to minimize its mass and volume are counted among 'hydrothermal methods', and they are still under development with some promising results from first commercial applications (ZIMPRO® or ATHOS®). Wet air oxidation is presented on Figure 3.

This process is being performed at temperatures between 150 and 320 ^{o}C and at pressure between 1 and 22 MPa. In such condition almost 80% of a total COD load is oxidized with remaining COD load converted into soluble - mostly degradable form (sugars, amino acids and fatty acids) - which further can be circulated to a wastewater treatment train. Organic nitrogen compounds is changed into ammonia so it require remove e.g. by stripping. Advantages of this process, besides full-scale application, are: high solids' reduction (up to 70% by mass), low impact exhaust gases and it is exothermic process. Disadvantages are following: high investment and operational costs, problems of corrosion of equipment.

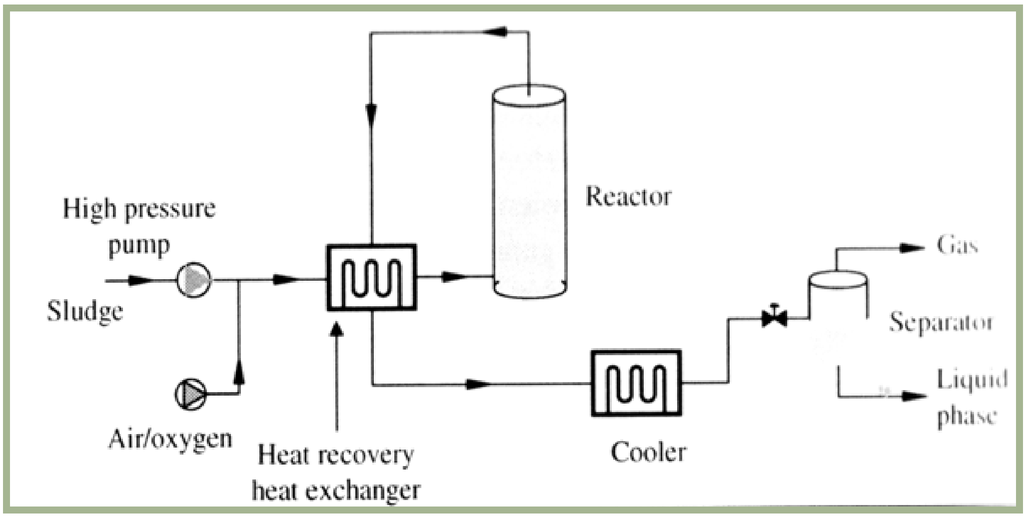

Figure 3. Diagram of a predation reactor in wet air oxidation (from Foladori et al.,2010)

Sludge minimization technologies may adversely impact overall efficiency of wastewater treatment train (Rybicki 2013). In case of wet air oxidation discharge of strong liquid fraction to the wastewater treatment train leads to increased costs of aeration. Application of supercritical water oxidation, auto thermal thermophilic aerobic digestion, strong oxidation or predator-reactor may lead to increased nutrient (N and P) load discharge to wastewater treatment train.

CONCLUSIONS

1. Sludge minimization technologies are necessary to minimize an 'ecological footprint' of contemporary wastewater treatment plants. At present most of them aare focused on destruction of microorganisms cells' on various ways. The reduction of solids' dry mass accompanied with an increase of methane rich gas (a 'biogas') production via an anaerobic digestion remains still valid in a routine operations
2. The key mechanisms of sludge reduction, incorporated in wastewater treatment or sludge disposal units are following:
   - cell lysis and cryptic growth,
   - uncoupled metabolism,
   - endogenous metabolism,
   - microbial predation,
   - hydrothermal oxidation.

   Each of these method has specific drawbacks related mainly to complexity of equipment and significant increase of operational costs. Only few of methods recognized in this paper was successfully proven to be reliable in routine operation.
3. Choice of sludge minimization method must be based on careful recognition of pros and vices of each of them with respect to long term economical feasibility of operation.

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