TRENDS IN DEVELOPMENT OF WASTEWATER SLUDGE TECHNOLOGY

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Abstract
The paper presents the development trends in solving sludge management problems in wastewater treatment plants with the respects to sustainable environment development. It is anticipated that predominate utilisation of wastewater sludge will be in natural environment. The general requirements enabling implementation of sustainable development principles in sludge management have been determinated. The optimal technologies and development trends concerning unit processes applied in sludge management systems are described. They are aiming to minimise quantity of sludge and to improve their quality to fulfil the criteria of sustainable development.

Keywords
wastewater sludge, sludge treatment processes, sustainable development, trends in sludge management

IMPROVEMENT OF THE SLUDGE COMPOSITION THROUGH LIMITATION OF HARMFULL AND TOXIC SUBSTANCES IN WASTEWATER

There has been a substantial progress and diversity observed in the approach to the problems dealing with the development of sludge treatment processes in the wastewater treatment plants. However, there are still only three basic ultimate disposal methods for processed sludge: land application, landfill and incineration.
Four basic rules govern the sludge management policy:

- Limitation ”at the source” of the amount of the harmful and toxic substances incoming to the plant and effecting the sludge content
- Efficient sludge processing using technically, ecologically and economically feasible methods to reduce their quantity and improve their utilization properties
- Energy and product recovery performed using the advanced sludge processing methods
- Safe and reliable sludge utilization preferably as an agricultural supplement

Efficent execution of the first two rules becomes a necessary condition for proceeding with the third and fourth ones, which are a crucial element of the sustainable development concept. Mastering of the technological and technical methods necessary to comply with those rules is in the focus of both research and technical phases.

It is expected that in year 2005 about 45% of sludges produced at the wastewater treatment plants in the EU will be utilized in agriculture, while 38% will be used for energy recovery and only 17% of the sludge will be stored in the landfills (Ostojski, 1999). Such policy remains in the agreement with the policy of the European Union Council, which prioritizes sludge recycling as the best sludge handling method. However, to proceed with such policy requires maintaining the high sludge quality standards. Introduction of sludge quality standards in the industry (ISO 9000) can significantly help in fulfilling this goal (Bernacka, 2000).

Practical application of this rule requires an appropriate wastewater system management in the municipalities. A noticeable reduction of the amount of heavy metals discharged to the municipal sewers have been observed in recent years resulting in a substantial decrease of the metal content in the sludge.

In the 80's (Bastian, 1998) an effective programs were developed in the US to improve sludge quality by reduction of their heavy metal content. Comparing of sludge characteristics at 5 large wastewater treatment plants showed that the reduction of the heavy metals in the sludge over the period of 1983-89 varied as follows: Zn - from 26% to 97%, Pb - from 90% to 98%, Cr - from 42% to 99%, Ni - from 50% to 100%, Cd - from 42% to 91%, Cu - from 27% to 99%. The surveys on the sludge quality, conducted at 50 largest wastewater treatment plants in the US by the US EPA in 1988 and 1992, indicated that in mostly cases the sludge quality had improved.

Such tendency resulted in a broader interest in further sludge utilization. Additional legal regulations concerning sludge quality, introduced in the US in 1993 and 1995, allowed for the better and more stringent "at the source" control of the industrial wastewater including their mandatory pretreatment.

Apart from heavy metals also some chemical organic compounds are considered as toxic and hazardous substances (Bernacka, 2000). They comprise: polychlorinated biphenyls (PCB), poly aromatic hydrocarbons (PAH), chloro derivative organics expressed as a combined factor (AOX), polychlorinated di-benzodioxines (PCDD) and polychlorinated dibenzofurans (PCDF). All the above contaminants accumulate in soil and persist in the environment for a very long time, some of them are considered to be cancerogenic. While the heavy metal content in the wastewater sludge is strictly regulated in the EU Directive, the concentration of the organic toxic substances in the sludge has been left to the consideration of the particular members of the European Union. Therefore, the range and values of standards for those parameters vary significantly in different countries. In Sweden the recommended standards for the organic compounds in the municipal sludges include nonylophenol, toluen, total PAH, total PCB.

In Poland the concentrations of those compounds are not regulated. The Polish Institute of Environmental Protection conducted a 2-years preliminary study on the amount of toxic organic compounds in the municipal sludges at Polish wastewater treatment plants. The study showed that the concentration of those substances in the Polish sludge is rather low. In majority of cases it was much lower than the German and Swedish criteria for the sludge utilized in the agriculture. According to Bernacka (2000), occurrence of those compounds in such low concentrations justifies their absence in the Polish regulations.

However, in those cases when the wastewater treatment plant receives a specific effluent e.g. from the boiler house or the chemical plant, the agricultural utilization of sludge needs to be preceded with a careful analysis of its content, especially in terms of the toxic organic compounds. It may also concern the sludge from plants located in the catchments with a combined sewer system.

In the summary it may be concluded that one of the crucial elements of the future trends in sludge handling is a constant effort to improve sludge quality by development and implementation of special programs designed to assure a source control.

DEVELOPMENT OF TECHNICALLY, ECOLOGICALLY AND ECONOMICALLY FEASIBLE SLUDGE TREATMENT PROCESSES TO MINIMIZE ITS QUANTITY AND TO IMPROVE ITS QUALITY.

Advanced wastewater treatment plants, apart from providing a sufficient wastewater treatment process, are also obligated to assure an adequate level of sludge handling (volume reduction, stabilization, hygenization). Moreover, the plants with biological nitrogen and phosphorus removal require different approach to sludge handling processes than the traditional biological wastewater treatment plants. The main differences include separate thickening of primary and secondary sludge, generation of volatile fatty acids (VFA) from primary sludge, mechanical thickening of secondary sludge, possible pretreatment of sludge supernatants.

Sludge from advanced WWTP and its characteristics.

The amount of primary sludge coming to the plant depends on the local conditions (type of the sewerage system) but mainly on the characteristics of the industrial wastewater discharged to the plant. Therefore the plant operator has a very limited influence on amount of primary sludge; the only way it may be limited is pretreatment of industrial wastewater at source. The amount of secondary sludge produced at the plant is highly dependent on the type of technological processes used at the plant. Higher excess sludge yield is accompanied with a higher fraction of easily biodegradable COD in raw wastewater. If looking at the biological treatment process used, the lower sludge yield is observed for biological process with a longer sludge age and for biological process with alternating anaerobic and aerobic conditions (growth rate of heterorophic bacteria is lower then autotrophic bacteria).

Taking into consideration the above tendencies the amount of biological sludge produced at the wastewater treatment plant varies broadly ranging from 0,5 to 1,2 kg VSS produced/ g BOD removed. (Oleszkiewicz et al, 2000).

Additional aspect that needs to be considered while looking into reduction of the sludge volume at the plant, is elimination of the chemical precipitation process and specially preliminary precipitation. As the Polish experience shown, the preliminary precipitation increased the amount of produced sludge even by 30%,if compared with the amount of primary sludge coming to the plant.
Polish experience from advanced wastewater treatment plant operation showed that a total sludge yield for primary and secondary sludge was 0.8 – 1.1 kg dry solids/ kg BOD removed.

Oleszkiewicz (2000) performed a mass balance for a typical advanced wastewater treatment plant with biological nitrogen and phosphorus removal and generation of VFA from primary sludge. The plant characteristics: capacity Q = 50 000 m^3 /d, sludge age 12 days, separate anaerobic digestion of sludge. The plant produced the following amount of sludge:
suspended solids in the influent – 11 750 kg/d; 50-70% of the solids are captured in the primary clarifier and undergo further processing

- excess biological sludge produced at the plant – 3 261 kg/d (equivalent to 0,8 kg dry solids/kg BOD removed or 0,36 kg dry solids/kg COD removed).
- sludge that escapes from the secondary clarifier and is discharged with the final effluent equals 1 000 kg/d (14% of the total mass of sludge)
- sludge after anaerobic digestion – 4433 kg dry solids/d (sludge volume – 17 m^3/d at 25% solids content)

Advanced sludge treatment in the anaerobic digestion process produces sludge with the organic content of 50 – 55 % dry solids, nitrogen content 2.5 - 3.5 % dry solids with the abundance of mineral forms of nitrogen available for plants and phosphorus content of 0.5 – 2 % dry solids.

The above mass balance helps to capture (visualize) the scale of the sludge problem at the wastewater treatment plant and highlights the urgent need of the sludge processing and dewatering to minimize their volume and optimize their quality.

Trends in sludge thickening

Sludge thickening process, which substantially decreases the sludge volume, is the major element of the sludge processing sequence. The process, if efficiently performed, can lead to a 60-70% reduction of primary sludge volume and 90-95% reduction of the biological sludge volume (the last value includes thickening in the secondary clarifiers hopper).

Introduction of the advanced wastewater treatment methods with biological removal of nitrogen and phosphorus was followed by a different approach to the sludge thickening process. Primary and secondary sludge have to be thickened separately by different thickening methods.

Combined thickening of primary sludge and generation of VFA. The best way of primary sludge thickening is using gravity thickeners. These units with the appropriate parameters and additional technical equipment can operate as the preliminary fermenters for VFA generation. Therefore, the major developments in the sludge thickening process should focus on such technical design of the thickener, so as it was possible to intensify the generation of VFA and their utilization in the biological treatment process. On the other hand the sludge thickeners should maintain their major function of sludge volume reduction before further sludge processing. Traditional construction of gravity thickeners allows only for a partial generation of VFA. Intensification of this process can be achieved by the extension of the thickening time (SRT = 3-5-h) and providing additional sludge mixing by sludge recycle from the bottom of the thickener to the inlet channel. Future increase of VFA generation efficiency can be achieved by using a separate completely mixed tank for a preliminary acidic digestion (fermenter) and then gravity thickeners. A proper control of the process (redox and pH probes) helps to optimize the acidic digestion phase. Also other features responsible for odor control (purification of gases produced during the process) are being slowly implemented and need further improvement.

Application of mechanical processes for primary sludge thickening has a great advantage of much smaller area requirements but generation of VFA during the thickening process can not be accomplished; in order to proceed with VFA generation an additional fermenter ahead of the mechanical thickener is required. Moreover, mechanical thickening of sludge requires addition of polyelectrolytes. Their presence in sludge increases the operational costs of the process and also may upset the nitrification process (inaccurate doses of polyelectrolyte) in the biological stage.

Excess activated sludge thickening. The excess sludge has to be thickened very quickly to avoid an unwanted release of any accumulated phosphorus from the biomass. Therefore, mechanical thickeners instead of the gravity ones are recommended for excess sludge thickening. Mechanical thickeners include: rotary drums, centrifuges and belt presses; all these units required addition of polyelectrolytes to enhance the thickening process. The ideal solution seems to be thickening by flotation with dissolved air. This way the thickening process can be speeded up and aerobic conditions prevent unwanted release of any accumulated phosphates from biomass. Additional advantage of the process is the fact that it does not require any polyelectrolytes and the sludge supernatant can be safely returned to the nitrification process in the biological reactor. An air to solids mass ratio of at least 0.03 must be provided to achieve 4 - 5% solids. It is less then for the regular mechanical thickeners, which can deliver sludge of 6-7% of dry solids. Although the operation costs of the flotation process are rather low, the investment costs are usually higher (Oleszkiewicz, 2000).

The above solutions concern sludge thickening process ahead of stabilization. Better economics of these processes can also be reached by so-called ” in - process thickening”. Such concept, which goes back to the old Torpey’s concept, has recently been introduced at the wastewater treatment plant in Seattle, and Phoenix. Thickening centrifuges were installed in the sludge recycle line from the anaerobic digesters (Figure 1). Higher efficiency of the thickening process resulted in the better sludge digestion.

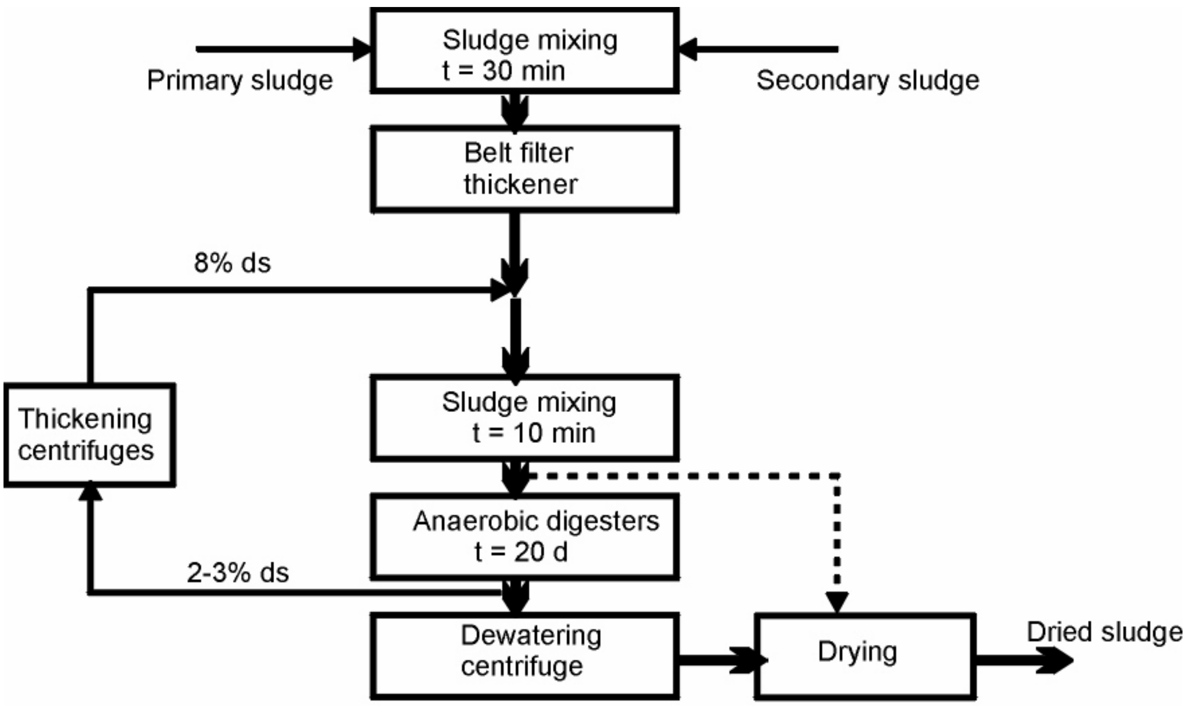

Fig 1. Sludge processing station with sludge thickening ahead and during the process

Another innovative solution in sludge thickening is a combined lysis/thickening process in the BSC 4-2 centrifuge (Baker Huges). During this process a disintegration of the excess activated sludge cells takes place (Zabranska et. al., 2000). Lysis/thickening, if conducted ahead of the anaerobic digestion process, can enhance the biogas production by 11.5 - 31.3 % through a better degradation of an organic fraction of the digested activated sludge.

Trends in anaerobic and aerobic sludge digestion

Anaerobic digestion in separate digesters is used at wastewater treatment plans with sewage flows exceeding 20 000 m^3/d. Now a days, open -air anaerobic digesters are seldom used and the most popular solution becomes anaerobic digestion in mesophilic mode (i.e. at 36-37°C). The process is conducted in closed completely mixed anaerobic digesters heated with energy recovered from biogas.

The biogas produced during the digestion process is burned in boilers to produce the heat necessary for heating digesters or can be used for electricity generation.

One of the modifications of the anaerobic digestion process (Kempa, 2000) is operation of this stages process in a step-mode. Digestion proceeds in separate tanks, operating in series line, were subsequent stages of a microbial process of organic matter transformation take place. In Poland, two - stage anaerobic digestion installations have so far been constructed at the newly built advanced wastewater treatment plants but some were converted to one-stage digestion. Ghosh (1991) demonstrated that two-phase digester consisting of acidogenic and methanogenic fermentation phases, showed volatile solids reductions in excess of 70% at a fermentation period of only 12 days. There is still no full-scale installation with a four-stage digestion process though it seems that this concept will soon be verified in practice in a newly planned sludge processing line at the Zielona Gora WWTP.

Anaerobic digestion, as the process conducted at mezophilic conditions, does not kill pathogens in a sufficient way. Therefore after mesophilic digestion the sludge is further chemically stabilized with quick lime.

A recent tendency to apply methods, which combine more then one-unit process, led to popularization of the thermophillic digestion (48-57°C). This process allows for simultaneous stabilization and hygienization of sludge. Such trend resulted in upgrading of the some conventional anaerobic digesters so as they could operate in thermophilic (~55^{o} C) conditions. Anaerobic digestion can also be operating as a two-stage process with a thermophilic and mesophilic (36^{o} C) phase in serie; such digestion assures a good inactivation of pathogens.

A number of other methods aimed to reduce the digestion time (SRT) and increase volatile solids destruction rate have been researched recently. They include: sodium hydroxide hydrolysis of excess activated sludge followed by a combined digestion with primary sludge (SRT reduced down to 10 days), pulse power electric arc technology or ultrasonic technology (Bien et. al. 1997). All the processes have been introduced ahead of the digestion process. Application of the last two technologies improved volatile solids decomposition in the sludge and resulted in a higher methane production. The improvement is due to a destruction of flocs and disruption of cell walls and better availability of organics for the anaerobic digestion process (Müller, 2000).

Frequency of ultrasonic vibration is usually set at 20 kHz or 35 kHz, and ultrasonic energy above 1 W/cm^3. Excess activated sludge having density of 3,1% ss after 25 sec. of sonification produce large increase of COD in supernatant. It increased from 200 mg/l before to 16000 mg/l after sonification. Anaerobic destination performance of sonificated sludge increases in specific methane yield of over 60% at a 15-day SRT comparing to conventional digestion operation.

Various methods o mechanical disintegration of excess activated sludge prior to its anaerobic digestion were investigated at the Technical University of Braunschweig (Müller, 2000). Best results are achieved by using the stirred ball mills with small grinding beads, than by the high-pressure homogenizers at the pressure of 500*10^5 Pa and by the ultrasonic homogenizers at a frequency of 20 kHz. Author derived the conclusion that disintegration of secondary sludge may be particularly useful of those plants, which have problems with sludge handling.

Takashima et. al. (1996) combined membrane – enhanced digester with alkaline heat post – treatment and achieved almost complete organic solids decomposition. This process involves reacting the sludges with 0,1 M NaOH at 175^0 C for 1 hour. Methane production increased by 14%, but membrane permeate COD increased significantly.

As a pretreatment techniques Hobson et. al. (1992) proposed that heating sludge before digestion to above 150^0 C for 30 min. will cause the disruption of activated sludge cell walls and convertion of organics into a form more readily digestable.

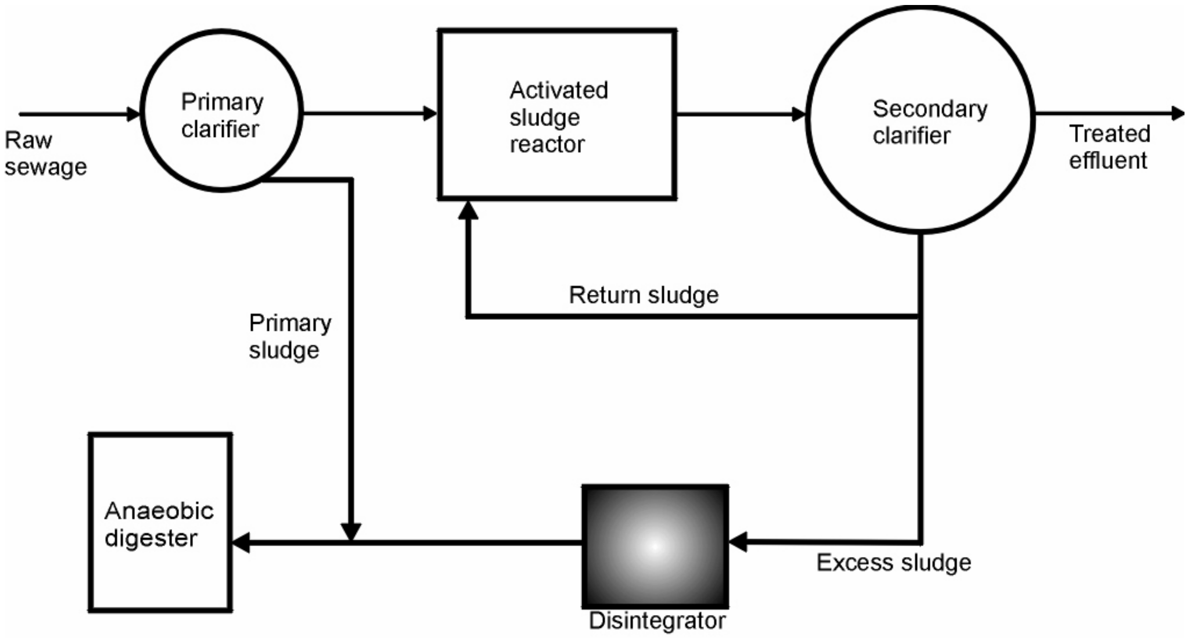

Fig 2. Scheme of wastewater treatment plant with mechanical desintegrator applies for excess activated sludge.

Anaerobic digestion of the sludge from the WWTP with enhanced removal of nutrients may create a problem of phosphate release to supernatant. It may approach to 60%. As counter action the aeration of supernatant is applied for CO_2 stripping following by dosing of lime (Kempton et. al. 1999)

*Aerobic stabilization***.** Aerobic digestion was introduced in the sludge stabilization technology much later then anaerobic one and it has been very extensively used for both small and large wastewater treatment plants, including a stabilization process carried out simultaneously with biological wastewater treatment (e.g. Nowy Sacz). The process does not always provide sufficient sludge stabilization in terms of pathogenic organisms reduction. Also final sludge dewatering is less effective. Aerobic stabilization conducted in an ambient temperature (10-20^0 C) usually is completed after 20-40 days being also an energy consuming option. However, since the process is easy to operate aerobic stabilization still recommended but rather for smaller wastewater treatment plants. Simultaneous aerobic stabilization should be introduced to the plants of less then 2000 m^3/d while for the larger ones economically sound is use of a separate aerobic stabilization. For large plants (Q>20 000 RLM, according to the ATV design guidelines) aerobic stabilization is not recommended.

A new development in the aerobic stabilization concept is a thermophillic process. First implemented in Germany in 1977, autothermal thermophilic aerobic digestion (ATAD) is conducted in closed tanks where the feed sludge is concentrated to 4% dry solids (optimum 5-7%) mixed and aerated. During oxidation of organic fraction of sludge bacteria generate heat and at the same time stabilize the sludge. In the optimal process conditions, the process temperature rises spontaneously to 50-70 ^{0} C and over 40% reduction of organic biomass is observed. At the same time, an excessive inactivation of the pathogens takes place. The process can be conducted as a single stage process or as a more efficient two-stage process. The reactors are arranged in a series with the temperature in the first being 35-50 ^{0} C and in the second 50-70 ^{0} C. Typical process parameters include SRT - 5-6 days, air requirements 4 m^3/m^3 *h.

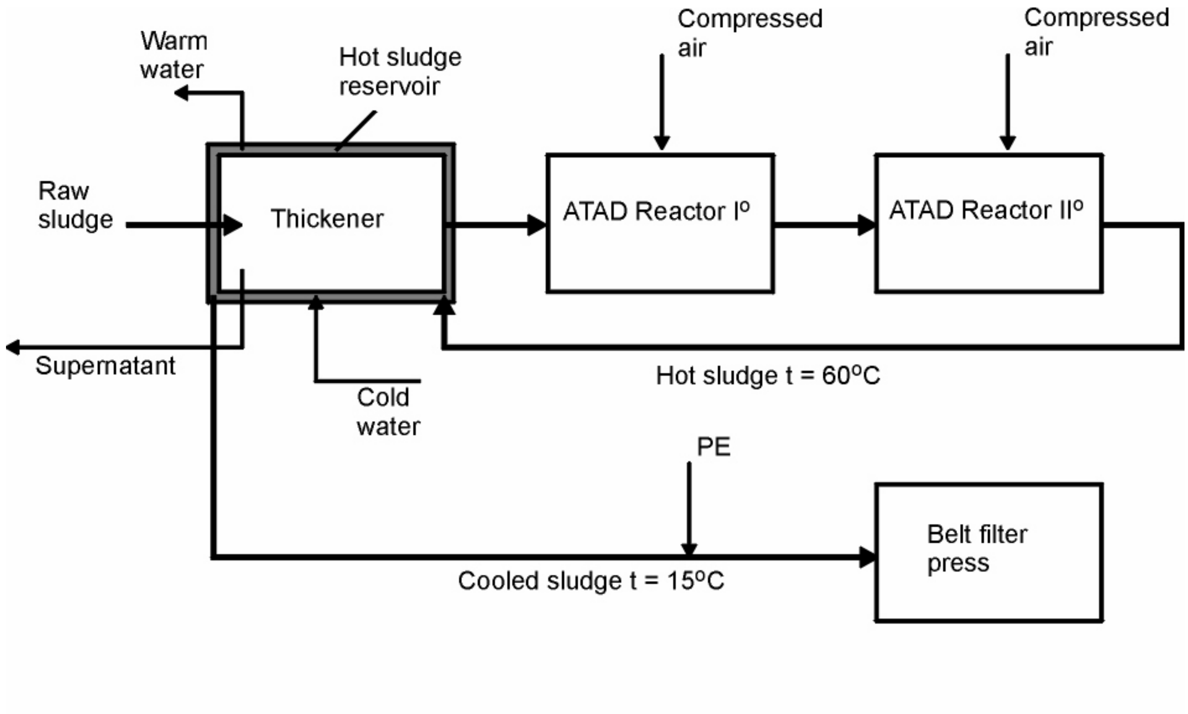

Fig 3. Autothermal thermophilic aerobic digestion proces (ATAD) performed in two-stage reactors.

The most recent approach to the ATAD design includes addition of the third stage, mostly in case when primary and highly loaded with organic waste sludge are stabilized or for sludges of the industrial origin.

Another option of the above process is a primary authothermal thermophilic aerobic digestion (PATAD) used as a preliminary step ahead of the anaerobic mesophilic digestion. As the first step ATAD reactor is used with a retention time 12-24 hours; raw sludge is heated in the heat exchangers up to 60-65^{0}C. The process is run at reduced air requirements, to inhibit the mineralization of VFA for better sludge hygienization and maximize gas production in the anaerobic stage. The PATAD reactor assures a full inactivation of pathogens. The subsequent anaerobic digestion process results in a higher biogas production and full sludge stabilization. Power requirements for PATAD reactors are approximately 100 W/m^3, air supply - 1 m^3/ m^3*h. This method does not require chemical stabilization of sludge.

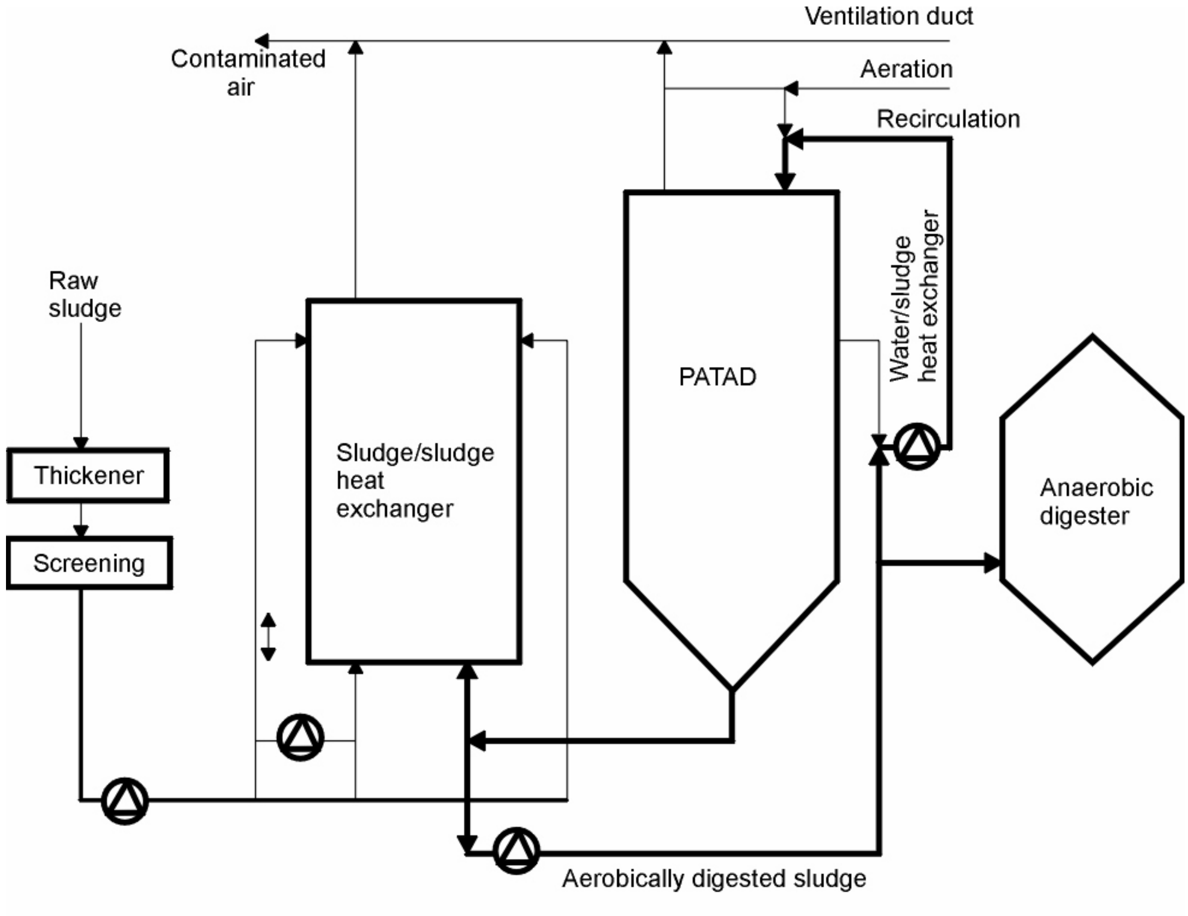

Fig 4. Two-stage sludge stabilization applying primary autothermal thermophilic aerobic digestion (PATAD) ahead of mesophilic anaerobic digestion

Trends in final sludge dewatering process.

Mechanical dewatering equipment guarantee efficient and fast sludge dewatering however the dewatering installations have rather high operating and investment costs. There are many technical options for final sludge dewatering. A new generation of the dewatering equipment has recently appeared on the market, which combine thickening and dewatering of sludge in one unit. To make a right choice, it is necessary to have a good understanding of not only the required final solids content that should be reached at the lowest possible unit costs, but also transportation to a desired final disposal site. If there is a long distance transportation for disposal site frame press dewatering to 40% solids content may be feasible (Kempa, 1997). The choice is also greatly influenced by the size of the wastewater treatment plant.

The electro-osmotic belt filter (voltage 15-25 volts) developed by Smollen and Kaffar allowed achieving more cost – effective dewatering of non-digested waste activated sludge resulting in cake solids above 20%.

The cost analysis performed in Poland (Fukas - Plonka, 2000) showed that for small and medium plants (up to 10 000 PE) the costs of sludge processing reached 50% of the total costs. Cost-benefit analysis showed that for plants with PE< 7 000 (equivalent to Q = 1000 m^3/d) a mobile sludge dewatering installation is the best option. While designing the plant where sludge is dewatered in the mobile installation it is important to make sure that the minimum volume of the sludge storage tank is equal of a daily installation output. This way a mobile unit can visit the plant no more than once in 3 weeks (aerobic digestion) or once a month (anaerobic digestion).

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