BALTIC COASTAL ZONE
Journal of Ecology and Protection of the Coastline

Vol. 16 pp. 5-18 2012

ISBN 1643-0115

Original research paper

Received: **08.08.2011**
Accepted: **08.08.2011**

ANALYSIS OF TEMPERATURE CHANGE AND DRY MATTER CONTENT IN THE PROCESS OF SLUDGE NEUTRALIZATION

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Abstract

The study presents an analysis of temperature change and dry matter content in sludge resulting from autothermal thermophilic stabilization process (ATAD), referring to selected sewage-treatment plants. The first in Poland ATAD installation manufactured by FUCHS, GAS und WASSERTECHNIK Mayen-Deutschland and functioning at SZCZECIN-SKOLWIN S.A. paper-mill and in Bystry has been presented, also, the study describes the first use of the installation at municipal sewage-treatment plant in Giżycko. Sewage disposal affects the Baltic basin. The study of the mentioned sewage-treatment plants was conducted in the years 2004-2009. The temperature of processed sludge and the dry matter content in collected samples were continuously measured at both plants. The collected data is subjected to an analysis which enables us to assess the effectiveness of the process when used to generate full value fertilizer. There is conclusion stemming from the study and own experience of the described installation exploitation.

Key terms: autothermal aerobic stabilization of sludge, sludge neutralization, sludge sanitation, natural use of sludge

INTRODUCTION

Each waste water treatment plant generates various waste materials, whose amount depends on a plant's size and realized technological processes. The necessity to engage highly effective methods of sewage treatment may cause formation of excessive preliminary sludge, after precipitation and external delivery of organic carbon sources, required for realization of technological processes connected with removal of nitrogen compounds (denitrification). In 2009 Poland the amount of generated industrial and municipal sewage-treatment plants reached 908.1 thousand tons of sludge dry matter, out of which 563.1 thousand tons were deposited in municipal plants. The total amount of sludge at wwtps is 6772.6 thousand tons, including 453.8 thousand tons at municipal plats (Rocznik Statystyczny...). These figures depict the state of sludge economy of waste-water disposal.

Generated sludge needs to be rendered harmless for legal, esthetic, and practical reasons. Economically and ecologically speaking, sludge should be processed and returned to the natural environment. In the case of small and medium sewage treatment plants, it is recommended that sludge be agriculturally utilized which is the cheapest method of ultimate sludge disposal. However, only a small fraction of it is utilized in agriculture, that is 166.1 thousand tons of dry matter, which makes something little more than 18% of the entire amount; 164.7 thousand tons are used for land reclamation (Rocznik Statystyczny...). There are many methods of transforming sludge into useful biomass. One of them, still little known in Poland, is the process of autothermal aerobic thermophilic sludge stabilization, employed in the here described plants. The purpose of the article is to show the changes which occur in sludge in the course of this process. Two, simple enough to be applied in any sewage treatment plant, technological parameters have been used; they are significant though, to evaluate sludge neutralization after it has been stabilized and sanitized.

CHARACTERISTIC OF THE PROCESS AND TECHNICAL SOLUTION

Aerobic thermophilic stabilization of sludge is becoming more frequently employed in Western European and North American countries. In Germany the system is called ATS (*die **A**erob-**T**hermophile **S**chlammbehandlung*), in the USA and Canada it know as ATAD (***A**utothermal **T**hermophilic **A**erobic **D**igestion*), in Poland it is named ATSO (***A**utotermiczna **T**ermofilna **S**tabilizacja **O**sadów*).

The technology of aerobic stabilization in thermophilic conditions was developed by Hubert L. Fuchs in the 1970s (Borowski et al. 2001). Then, first installation was set up in Vilsbiburg, Germany; it is still functioning. Outside Europe such installations are active in the USA, Canada, and Japan.

Microorganisms, which facilitate decomposition process in sludge, play a crucial role in the process of thermophilic aerobic stabilization. This is a two-stage process. Hydrolysis of complex organic compounds (proteins, carbohydrates, fats) and lysis of decaying microorganic cells are the first stage. Hydrolysis and lysis take place due to intracellular enzymes produced by thermophilic bacteria. At the second stage the dissolved in water products of hydrolysis are oxygenated by thermophilic microorganisms to low-energy compounds. These reactions are accompanied by heat emission, and the final substances are CO_2, H_2O, and NH_3 (Kovács et al. 2007, Wersocki and Hupka 2006). If substrates of proper density are fed, amount of oxygen is sufficient, tanks are thermally insulated, sludge spontaneously warms up to the temperature of 55÷80°C (Wersocki and Hupka 2006, Layden et al. 2007a).

Unfortunately, there are side-effects of the thermophilic aerobic stabilization process: sludge foaming and smell burden. Foaming appears as the population of thermophilic bacteria grows. Decaying microorganic cells release intracellular matter, which lowers the surface tension facilitating foam formation. Foam is a sign of well progressing process. Foam also works as an insulator and ensures better utilization of oxygen from the air. Within the foam biological activity is at its peak. For exploitation reasons foam formation should be controlled, especially the thickness and density of the foam layer.

The air fed to the chambers of thermophilic aerobic stabilization contains compounds, which are olfactory hardly bearable. These are ammonia and the products of decay and incomplete oxidation of organic substances. Ammonia results from ammonification of proteins and is the chief cause of olfactory inconvenience. Beside ammonia, there are reduced compounds of sulfur (e.g. hydrogen sulfite, mercaptanes, dimethyl sulfite), aldehydes, ketons, volatile fatty acids, thioalcoholes, and others. Generation of odor compounds is facilitated by oxygen shortage caused by high temperature of the process and low redox potential (Shanchayan et al. 2006).

Despite these inconveniences the process effects fully stabilized and sanitized sludge, which may be successfully used for nature purposes. The presented here technology is of multiple uses. The ATAD installation proved useful in municipal as well as industrial sewage-treatment plants.

The process of thermophilic aerobic stabilization continues in tanks connected in series. Two or more tanks are used, their shape is usually cylindrical, they are made of steel, concrete, or plastic. To minimize heat loss reactors are thermally insulated and closed. A typical ATAD installation reactor is shown on Figure 1.

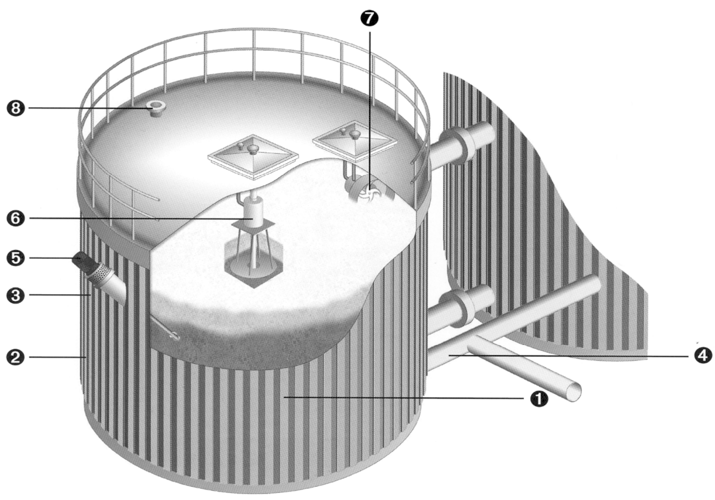

Fig. 1. Cross-section of a typical ATAD reactor
1 – reactor, 2 – insulation, 3 – coating, 4 – pipeline, 5 – spiral aerator, 6 – circulatory aerator, 7 – foam controller, 8 – gas exhaust

With tanks connected in series, the temperatures generated at first stage of installation are in the lower range of thermophilic distribution, the highest temperatures and maximal disinfection are yielded at the last stage. Daily dump of neutralized sludge takes place at the last stage. When next dump is finished, raw sludge is fed to the first stage, whilst partially processed sludge is moved to the next reactor. The shift of sludge from the first reactor to the next causes a little temperature fall. After sludge is fed to reactors, they remain isolated for 23 hours, when thermophilic decay takes place. To limit temperature rise in the last reactor a heat exchanger may be built in. The process requires continuous air supply, which is ensured by aerators. The aerators make the content of chamber be effectively blended.

Regulation of the amount of generated foam is an important element. To totally liquidate the produced foam is not the target of the process, since its presence is of much benefit, but the use of froth beakers controls its thickness and density. The motions of these rotatory devices cuts froth/foam, which in turn is carried off to the surface of sludge in a reactor and mixed with its contents.

Even the best designed installation for thermophilic aerobic stabilization requires a system for cleaning the air generated in reactors and carrying it away into the atmosphere. Usually water scrubbers are applied to remove ammonia, and biofilters or recently chambers, in which a process of photo-catalytic oxidation of odorous substances takes place (Bartkowska et al. 2007).

DESCRIPTION OF THE STUDIED FACILITIES

Papermill SZCZECIN-SKOLWIN S.A. is located in the North part of Szczecin, in the Skolwin quarter, directly by the Odra riverbank. The wwtp was built in 2001. It is situated on a 9,279 m^2 plot along a sewage canal which runs from Skolwin housing estate through the plant to the Odra River, affecting thereby the Baltic coastal zone.

The maximal projected flow capacity of the plant equals 12,000 m^3/day, which includes paper mill sewage 10,000 m^3 and municipal sewage 2,000 m^3. It is a mechanical-biological sewage treatment plant, working as a classical flow plant with an aerated active sludge chamber.

Sludge generated in the plant is fed into a collecting tank before the ATAD reactors. Storage of sludge is necessary because the system is powered portion-wise once every second day. Proper stabilization and sanitizing takes place in two tanks which work in a two-stage manner. Neutralized sludge is dehydrated in a KUFFERATH press. After dehydration by 50% of dry matter, sludge is incinerated in the nearby thermal-electric power station.

The reactors are closed steel tanks, protected by anticorrosive coatings, thermally insulated, fitted with controlling equipment and aerating as well as froth breaking devices. The odors from the tanks are carried off into the atmosphere though a biofilter (Bartkowska et al. 2005).

The sewage-treatment plant in Giżycko is situated in Bystry between the Niegocin and Grajewko lakes. The plant was modernized in 2003. Raw sewage is fed in via gravitational and pumping sewage system delivered by waste removal rolling stock to a drainage point. The receiver of treated sewage is the Niegocin Lake. Excessive sludge which sediments on the bottom of secondary settling tanks is pumped into gravitational thickener. After preliminary thickening, sludge undergoes autothermal aerobic stabilization, then, it is dehydrated in centrifuge. Processes sludge is used as manure in agriculture delivered directly onto farming fields.

The projected capacity of the plant is 14,000 m^3/day. It collects typical municipal sewage. Preliminary mechanical treatment is performed in grate building. The next stage of mechanical treatment is desander/sand trap, where the flow slows down and the mineral suspension undergoes precipitation and sedimentation.

When mechanical treatment is completed, sewage flows to a system of biological chambers, which are the place of biological treatment. The 5-stage BARDENPHO variant makes it possible to reduce significantly the amount of total nitrogen and phosphor. Treated sewage is channeled to the Niegocin Lake by means of bottom outlet. Excessive sludge is removed from the sewage in two places alternatively: in re-circulation system after the secondary settling tanks, or in the last aerated chamber of biological reactor. Then, it is directed to the gravity thickener where it is fed into drum thickener. Sludge thickened to 5% dry matter is stored in a tank for thickened sludge. So prepared sludge is cyclic-wise directed to ATAD reactors. Proper stabilization and sanitation take place in four tanks, which function as two parallel, two-stage lines.

The reactors are executed as closed steel tanks, covered by anticorrosive coatings, thermally insulated, fitted with control equipment, and devices for aerating and breaking froth.

Stabilized and cleaned sludge is dehydrated in decanting centrifuges. After dehydration down to 25-28% of dry matter, sludge is transported to temporary storage places such as sediment/sludge lagoons, or is directly destined for agricultural usage.

The gases carried off the ATAD reactors are directed to two biofilters installation (Bartkowska 2005).

RESULTS AND DISCUSSION

The sludge temperature, an important technologic parameter of process, is measured continuously in the presented ATAD installations. Rise in temperature denotes correctly progressing reactions of biochemical decay of organic compounds contained in sludge. Every tank has a temperature sensor.

Another important parameter is the content of dry matter, especially its organic fraction. Dry matter content was studied in sludge samples collected between identical time intervals from thickened sludge tank (before ATAD process), and in the final product before its dehydration. The samples of stabilized sludge were collected before re-feed, so as not to be contaminated by fresh sludge. The analyses were made, according to current research method, in a gravimetric manner after drying at 105°C, in accordance with PN-EN 12880:2004 standard. The studied parameters were recorded. On this basis a data base was prepared characterizing the real conditions of the ATAD installation. To ease summation, make generalizations and draw conclusions, the collected statistic data were analyzed by means of descriptive analysis method in the first place.

The selected values of distribution measures, computed for analyzed sludge temperature, are shown in Table 1.

Fluctuation of temperature occurs in each installation tank, both at the first and second stage in both plants. An example of such fluctuation of temperature of sludge in

Table 1

Selected values of distribution measures

Distribution measures	Temperatures recorded in ATAD installation in Skolwin		Temperatures recorded in ATAD installation in Bystry			
	stage I	stage II	first technological line		second technological line	
			stage I	stage II	stage I	stage II
Mean value	38.5	50.9	24.3	53.3	25.6	51.7
Minimal value	31.0	45.0	18.7	45.0	21.2	47.2
Maximal value	51.0	58.0	31.5	57.7	35.3	56.4
Percentile 10%	32.0	46.0	20.1	47.4	22.7	49.7
Percentile 90%	48.0	56.0	27.6	56.9	31.5	54.3
Variance	31.4	17.1	8.5	13.4	10.7	3.9
Standard deviation	5.6	4.1	2.9	3.7	3.3	1.9

ATAD installation in Skolwin is shown on Figure 2. The ATAD installation in this sewage treatment plant consists of two reactors connected in series. Temperature at the first installation stage is represented by line T1, at the second stage by line T2.

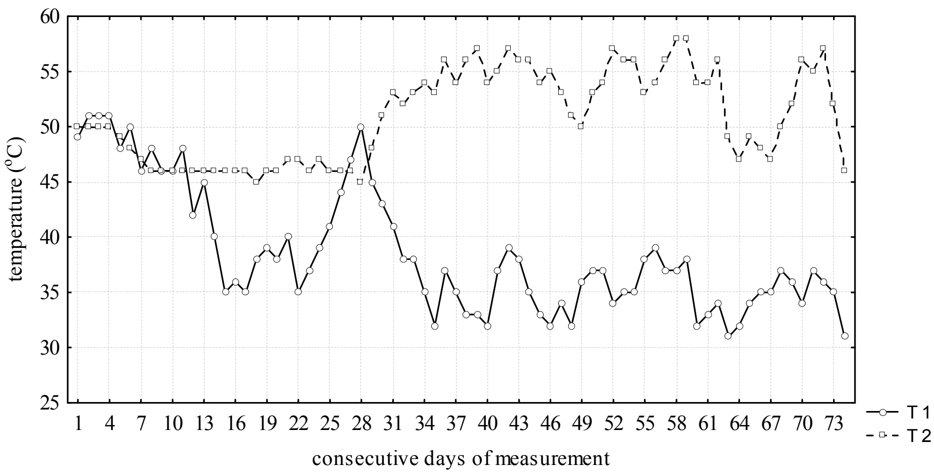

Fig. 2. Fluctuation of sludge temperature in ATAD installation in Skolwin (T1 – first installation stage, T2 – second installation stage)

During the study. the mean sludge temperature was 38.54°C at stage I and 50.89°C at second stage. The temperature fluctuated between 31.00°C and 51.00°C. and between 45.00°C and 58.00°C. Only 10% of measurements sank below 32.00°C in the first tank and below 46.00°C in the second tank. The differentiation of population is much greater at the first installation stage, which has variance of 31.37, than at the second stage (variance 17.13). It is also confirmed by the value of standard deviation and denotes that the values are clustered around the mean in the case of the second tank.

The ATAD installation in Bystry consists of four reactors, which constitute two parallel two-stage technological lines. Examples of temperature measurements in this plant are shown on Figure 3, where the temperatures of the first installation stage are represented by lines T1 and T3, while the second stage by lines T2 and T4.

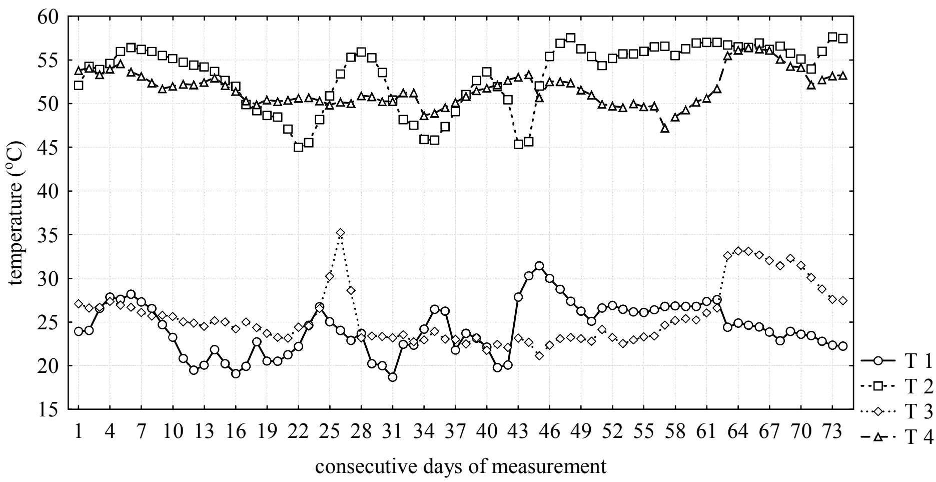

Fig. 3. Fluctuation of temperature in ATAD installation in Bystry (T1 – Ist installation stage of first technological line, T2 – IInd installation stage of technological line, T3 – Ist installation stage of second technological line, T4 – IInd installation stage of second technological line)

During the study the mean sludge temperature at the first ATAD installation stage was 24.31°C in the first technological line, and 25.60°C in the second. Higher temperatures were reached at the second installation stage: their mean values were 53.31°C in the first technological line and 51.74°C in the second line. Fluctuation of sludge temperature ranged between 18.70°C and 31.45°C at the first stage, and between 21.15°C and 35.25°C at the second stage.

Higher temperatures of sludge obviously were recorded at the second stage and ranged between 45.00°C to 57.65°C for one line. and between 47.20°C and 56.40°C for the other. As for the stage I reactors, 10% of results were below 20.10°C in the first line and below 22.70°C in the second line. In the stage II reactors 10% of observations were below 47.35°C in one of them and below 49.65°C in the other. The differentiation of results is lesser than recorded in Skolwin.

Analyzing the fluctuation of sludge temperature in both plants. we should notice that their ranges are different most at the first stage of ATAD installation. Figure 4 represents the distribution of the discussed statistic feature in the form of box graph for the tanks belonging to the I installation stage.

The temperature range of sludge obtained at the stage I of ATAD installation fits the spectrum of thermophilic temperatures, in the beginning range of values. While in

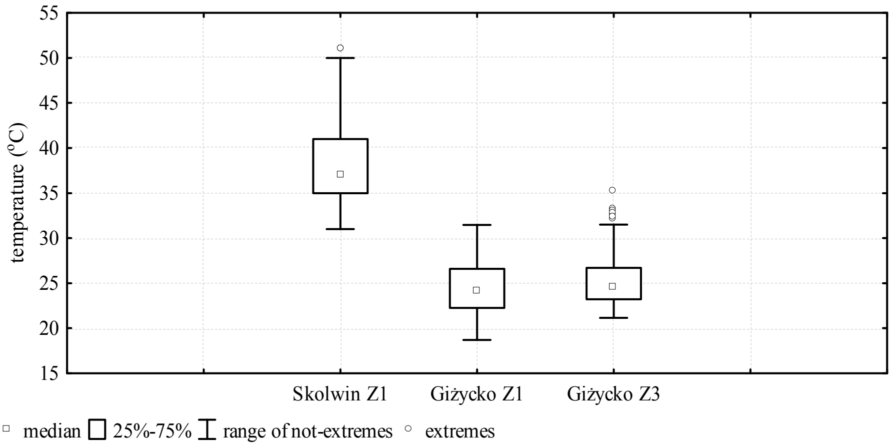

Fig. 4. Comparison of temperature distribution of sludge obtained in tanks of stage I ATAD installation

Bystry plant the temperatures belong to the higher values of mesophilic range. The literature rarely describes temperatures obtained in the I stage of installation. Only the studies carried out in municipal sewage treatment plant in Ireland recorded temperatures at the stage I of ATAD installation at the level 40÷55°C (Leyden 2007), nearing those obtained in Skolwin.
The distribution of sludge temperatures at stage II of installation for both plants is shown on Figure 5.

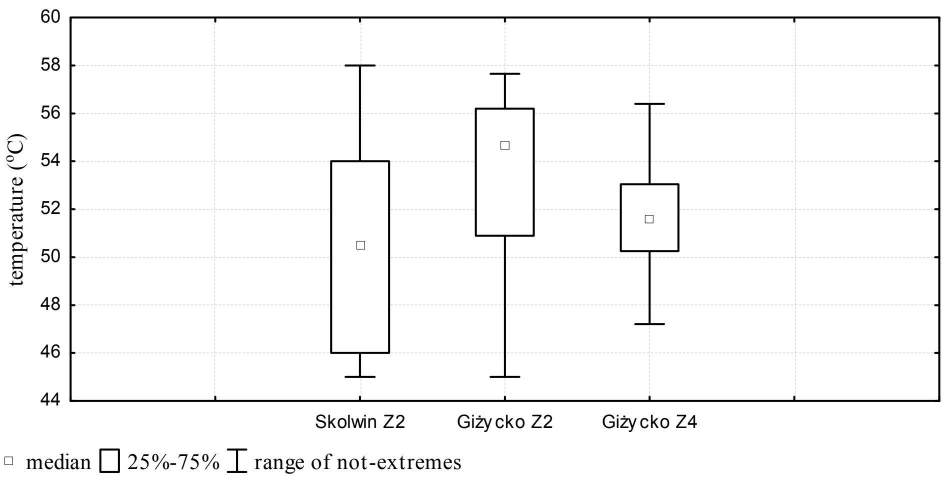

Fig. 5. Comparison of temperature distribution of sludge obtained in tanks of stage II ATAD installation

At the second stage installation in both plants the sludge temperature range is similar. The recorded values are less differentiated, no extreme values were observed. Their range overlaps with the one quoted in subject literature, reaching values exceeding 55°C (Borowski et al. 2001, Kovács et al. 2007, Layden 2007, Layden et al. 2007a, Layden et al. 2007b).

The results of descriptive statistics for the content of dry matter in sludge are shown in Table 2. They refer to both plants within the range of thickened sludge prepared for ATAD process as well as for stabilized sanitized sludge resulting from the process.

The analysis shows that in both plants the character of thickened sludge is very similar. After the ATSO process in Skolwin the obtained sludge had lower content of dry

Table 2

Selected values of distribution measures

Distribution measures	Content of dry matter in sludge			
	in Skolwin		in Bystry	
	before ATSO	after ATSO	before ATSO	after ATSO
Mean value	4.38	3.61	4.37	3.60
Minimal value	3.49	2.74	3.40	2.67
Maximal value	5.78	4.46	5.90	4.98
Percentile 10%	3.89	2.99	3.80	3.02
Percentile 90%	4.94	4.22	5.00	4.15
Variance	0.24	0.19	0.26	0.22
Standard deviation	0.49	0.44	0.51	0.47

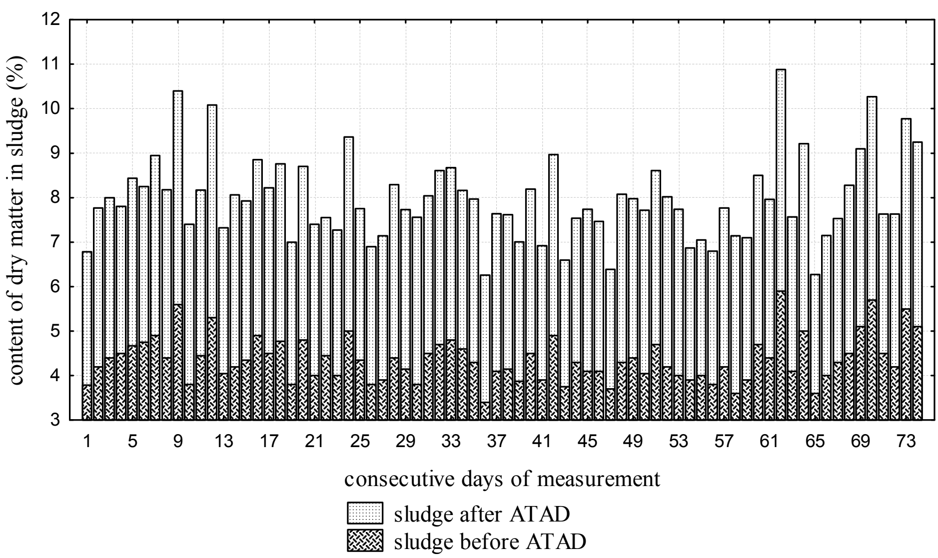

Fig. 6. Content of dry matter in thickened sludge and after the ATAD process in Skolwin

matter, which means it had been reduced. The reduction of dry matter content in the sewage-treatment plant in Skolwin is shown on Figure 6.
The realized in Skolwin ATAD process causes reduction of dry matter content by a few to 40%.
The content of dry matter in thickened sludge and after the process in Bystre is shown on Figure 7.

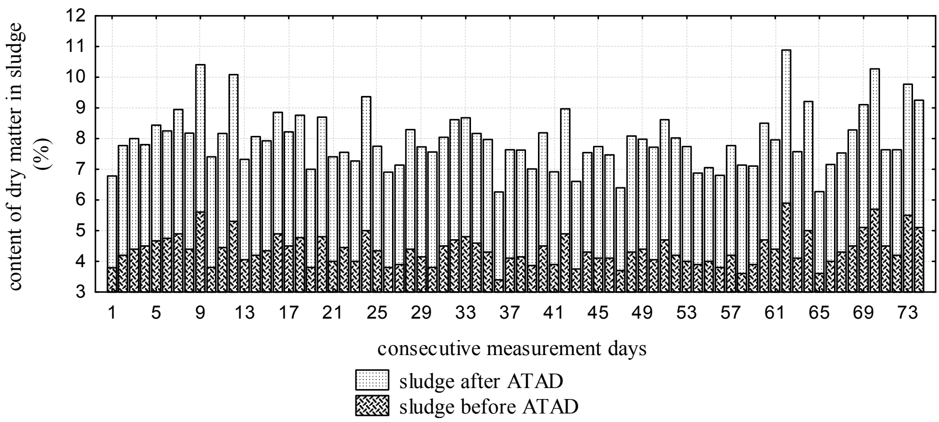

Fig. 7. Content of dry matter in thickened sludge and after the ATAD process in Bystry

The realized in Skolwin ATAD process causes reduction of dry matter content by a few to about 31 per cent.
During the study influence of ambient temperature on the ATAD process was not observed. Fluctuation of temperature, which certainly causes cooling of the treated sewage and thickened sludge, does not affect the effectiveness of installation. Sig-

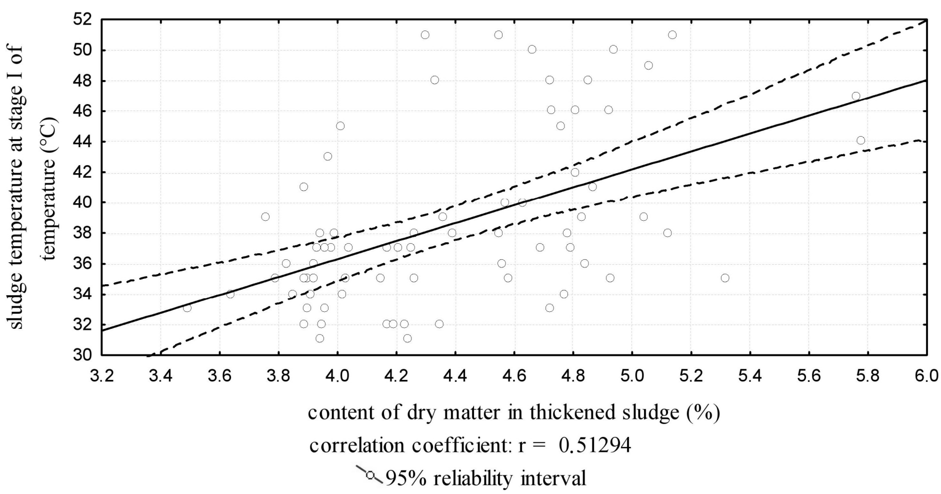

Fig. 8. Correlation between sludge temperature at stage I of ATAD installation and the dry matter content in thickened sludge

nificant correlation (correlation coefficient above 0.5) was noticed between the coefficient of dry matter in thickened sludge and the temperature rise at stage I of installation. Graph of this correlation is shown on Figure 8.

The basic factor responsible for sludge sanitation is temperature. According to American studies the time necessary to destroy totally eggs of parasites is 2 hours at 55°C. or two days at 45°C (Borowski et al. 2001, Wersocki. Hupka 2006). Lowering of temperature effects reduced bactericidal effectiveness, which means longer minimal time necessary for effective destruction of pathogens (Augustin et al. 2007, Piterina et al. 2010). During the observation of working ATAD installations it has been confirmed, that the temperature of thickened sludge when processed rose, on average, by 35.89°C in Skolwin and by 37.52°C in Bystry. The temperature rise of sludge ranged from 30.00°C to 43.00°C in Skolwin, and from 32.20°C to 42.65°C in Bystry. In the case of the Skolwin plant higher temperature rises were observed after stage I of installation, by 23.54°C on average, and by 14.52°C after stage II. In the other plant the situation was different, after stage I the temperature rose on average by 10.50°C and by 29.00°C after stage II. It may have been caused by the load of organic substance in sludge which was different in these plants. The total temperature rise in both facilities was similar; more intense biochemical processes effected higher temperature rise at the 1st and 2nd stage.

The content of dry matter in sludge decides the intensiveness of exothermic processes going on in reactors. The process of autothermal thermophilic stabilization requires preliminary thickening of sludge to 4% of dry matter, due to which greater unitary content of organic substances is won, which should be no lesser than 40.0 g/l, expressed by COD value. The degree of sludge stabilization depends on the decrease of dry matter content, especially its organic fraction. In Ireland and the USA the required reduction of dry organic matter equals 38% (Layden. 2007). Many authors claim however, that a reduction of dry matter by 30% in the process of aerobic stabilization suffices for full stabilization of sludge (Borowski et al. 2001). Unfortunately, we do not have in Poland a uniform criterion how to evaluate the degree of sludge stabilization. The reduction of dry matter content in the studied sludge ranges between a few to about 40%. The findings of other authors indicate that the reduction of dry organic matter content in the process of aerobic stabilization is similar (Borowski et al. 2001, Layden 2007).

CONCLUSION

The process of autothermal thermophilic stabilization ensures simultaneously full stabilization of sludge and a high degree of elimination of pathogenic factors, which means their sanitation. It is characterized by a very stable course of biochemical reactions and necessitates short time of sludge storing (6 to 5 days), as well as little area, which decreases the cost of investment. This technology is of wide-ranging usage. The ATAD installation has already proved to be effective when it comes to treat municipal and industrial sewage, mostly in reference to food industry. The study demonstrated that it is also effective in other industrial branches. The technology may also be used for modernization of existing sludge lines as a preliminary system, e.g. before conventional fermentation chambers. It is used then to lessen the organic load of fermentation chambers, to lessen load and simultaneously disinfect sludge before fermentation chamber, and exclusively to disinfect sludge before fermentation chamber.

In the course of carried out studies on the exploitation of ATAD installation in both plants typical of the process problems were not observed. Spontaneous heating of sludge induced by fed air, which causes sludge foaming, is not burdensome due to employed foam-breakers which ensure its desired thickness. The odors generated by biochemical changes are also successfully eliminated by biofilters.

The study results obtained during the analyzed period in both sewage treatment plants, and rich experience stemming from observation allow us to draw the following conclusions:

1. The process of autothermal thermophilic stabilization of sludge ensures temperatures which enable sanitation of sludge. Full air-tight sealing of reactors makes it impossible to the sludge processed be secondarily contaminated. Proper function is also performed by thermal insulation of tanks, and the function ensures proper process conditions whatever the external temperature is.
2. Spontaneous generation of high temperatures gives the opportunity to recover and manage the excess of heat energy. Possibility of placing a heat exchanger in reactors of stage II installation should be considered.
3. In sludge processed through ATAD the content of dry matter is reduced. Not always does it meet the conventional criterion of stabilization, but sludge is characterized by groundy odor and does not decay: this lets it be stabilized. Moreover, the Ministry of Agriculture and Country Development issued in 2008 a decision about turnover of organic manure called “BIOGIZ” produced by PWiK Sp. z o.o. in Giżycko in Bystry plant.
4. The ATAD process is a good way how to adapt sludge for fertilization. It does not necessitate, like for example composting, use of additional enriching materials. The demand of area for construction of installation is little. Air-tight sealing of tanks and use of devices for purification of generated gases make the process not burdensome to the environment.
5. Beside the known uses of the ATAD process in municipal sewage treatment plants and in food industry, the process may be employed in paper industry.

Natural exploitation of sludge still seems rational way of it utilization, contributing to improvement of organic matter balance in soil. Nevertheless, the quality of sludge channeled to ground and possibly influencing shallow and deep waters, ought to be monitored. In the case of the two plants it refers to the Baltic Sea basin, directly even to the coastal area. The plant in Bystry is a good example of exploitation of sludge. Produced there organic fertilizer, systematically tested, enjoys rising interest among individual farmers.

Studies of the uses of ATAD process should continue. Other such installations are already functioning, others are being realized. The range of research should be widened however, determining the content of dry organic matter. It is essential also to study the content of fertilizing substances in generated sludge and the content of heavy metals. Since these parameters influence the quality of shallow waters and their excessive amount may ultimately jeopardize the natural environment within the Baltic basin.

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ANALIZA ZMIAN TEMPERATURY ORAZ ZAWARTOŚCI SUCHEJ MASY W PRZEBIEGU PROCESU UNIESZKODLIWIANIA OSADÓW ŚCIEKOWYCH

Streszczenie

W opracowaniu przedstawiono analizę zmian temperatury osadów ściekowych oraz zawartości suchej masy w wyniku procesu autotermicznej termofilnej stabilizacji (ATSO) na przykładzie wybranych oczyszczalni ścieków. Zaprezentowano pierwszą w Polsce instalację

ATSO firmy FUCHS, GAS und WASSERTECHNIK Mayen-Niemcy pracującą w oczyszczalni ścieków w Fabryce Papieru SZCZECIN-SKOLWIN S.A. oraz w Bystrym, gdzie również po raz pierwszy wykorzystano ją w oczyszczalni ścieków komunalnych z Giżycka. Odprowadzane ścieki oddziaływają na zlewnię Bałtyku. Badania w wymienionych oczyszczalniach prowadzone były w latach 2004-2009. W obu obiektach dokonywano w sposób ciągły pomiaru temperatury przetwarzanych osadów oraz określano zawartość suchej masy w pobranych próbach. Uzyskane wyniki poddano analizie, która pozwala na zdefiniowanie na ich podstawie skuteczności omawianego procesu w pozyskiwaniu produktu stanowiącego pełnowartościowy nawóz. Przedstawiono również wnioski wynikające z przebiegu badań i własnych doświadczeń w zakresie eksploatacji opisanych instalacji.