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Research Article

CHANGES IN HYDROGEN ION EXPONENT OF SEWAGE SLUDGE IN THE PROCESS OF AUTOTHERMAL THERMOPHILIC AEROBIC DIGESTION

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ABSTRACT
This paper presents a study on the evaluation of digested sewage sludge during the process of Autothermal Thermophilic Aerobic Digestion (ATAD), taking place as a three-tank process at a municipal waste water treatment plant in Luban, Poland. ATAD installation was manufactured by FUCHS Enprotec GmbH Mayen-Deutschland. Over the period from June 2006 to February 2010 sewage sludge digested by tha ATAD-Process was examined. The hydrogen ion exponent was measured in every tank. The results obtained indicated changes in the composition of the digesting sludge at successive stages of the process. Over the study period the ATAD-installation was in both a two- and a three-stage process. pH of sludge under study during the process of the thermophilic stabilisation changes and its value grows significantly, with the installation working in a two-stage arrangement from 6,63 to 7,99, and when the installation was operated as a three-stage system from 6,60 to 8,14. The results collected were subject to the statistical analysis. The paper presents conclusions drawn from the study and own experience.

Keywords: activated sludge, hydrogen ion exponent, sewage sludge, sludge processing, thermophilic aerobic digestion.

INTRODUCTION

The least-expensive method of disposal or reuse of sewage sludge is to return it to the natural environment [Woźniak et al. 2004]. However, the sludge can be naturally utilised only when stabilised and without metals [Skowron et al. 2011]. Appropriate processing of sewage sludge is required by legal regulations. Initial and excessive precipitate generated at every waste water treatment plant, after chemical precipitation and addition of organic carbon from external source with this carbon required for some processes, e.g. to remove nitrogen compounds (denitrification), require engineering the installation process to meet expectations, depending on their quantity and quality. This qualifies the ATAD process as useful.

CHARACTERISTICS OF THE PROCESS

The ATAD process allows to stabilise sewage sludge and to achieve pathogenic reduction in one installation. As a result, sewage sludge turns into Class A Biosolids and is required to meet fewer restrictions placed on its use [Augustin et al. 2007].

Biological stabilization of sludge is based on the reduction of organic substances contained in sewage sludge. In the ATAD-process the contents of these substances is reduced by microorganisms. Aerobic transformation is an exothermic process, i.e. a lot of heat is released. The final products of this process are simple substances like H_20 and CO_2 [Bartkowska 2005]. From a chemical point of view this chemical reaction can have a form of simplified equations basing on a hypothetical matter of an organic cell $C_5H_7NO_2$, representing an active sludge [Wersocki, Hupka 2006, Zupančič, Roš 2008]:

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3 + \text{energy} \quad (1)$$

$$C_5H_7NO_2 + 7O_2 \rightarrow 5CO_2 + 3H_2O + H^+ + \text{energy} \quad (2)$$

Good retention of heat released during the decomposition produces high working temperature (>50 °C), followed by high degree of organic material decomposition as well as destruction of pathogens. This process requires sludge pre-thickening to more than 4% D.S., and therefore, higher elementary organic matter content can be achieved, which cannot be less than 40.0 g/l expressed by the COD value [Bartkowska et al. 2005a, b].

If a proper oxygen amount is supplied at a temperature from 55 ^{0}C, the process develops automatically. For most plants this process is limited to 55–60 ^{0}C, with possible recovery of heat. High temperature along with smaller dimensions of a reactor (the design dwell time is several days) allow a substantial reduction of the contents of organic substances down to 38–50% of dry mass by volume [Layden 2007] and a safe sludge; i.e. safe in terms of the contents of pathogenic factors [Nosrati 2007].

The ATAD installation consists of reactors working in series. The system is batch-supplied once a day after which reactors are isolated and closed in order to minimise the heat loss. The process is effective thanks to aeration, which causes the foam to generate fast. The foam acting as insulation ensures a better utilisation of oxygen and an increase in the biologic activity. The use of foam disintegrators allows to control the formation, the thickness and to some extent the density of the foam layer [Bartkowska, Dzienis 2007].

In the first stage of the installation the temperature keeps within the lower thermophilic distribution: (40–50 °C). The disinfection maximum is reached in the last stage with the temperature between 50 and 60 °C. The daily dump of neutralised sewage sludge takes place from the last stage. With the successive dump completed the raw sludge is fed to the first stage while partly transformed sediment is moved to the next reactor. As the sludge is moved from the first reactor to the next one, a small temperature drop occurs. After being fed the reactors remain isolated for 23 hours and the thermophilic decomposition occurs [Bartkowska 2005, Bartkowska, Dzienis 2007]. To limit the temperature growth in the last reactor a heat exchanger is installed.

The ATAD installation under study comprises of three reactors in a form of closed steel tanks protected by anti-corrosion coats, thermally insulated, equipped with control instrumentation, aeration and foam disintegrating equipment and equipment for photo catalytic oxidation of odours (PCO), which are generated during the process. The installation was designed in order to process the formation of initial sludge and excessive sludge to the amount of 58 m^3/day, thickened to about 5% of dry mass and containing some 75% of organic substances. The diameter of every single tank is 8.57 m. Every tank is filled up to the height of 3.0 m. The working capacity of single tank is therefore 173.0 m^3, with the dwelling time of sludge inside it if some 9 days.

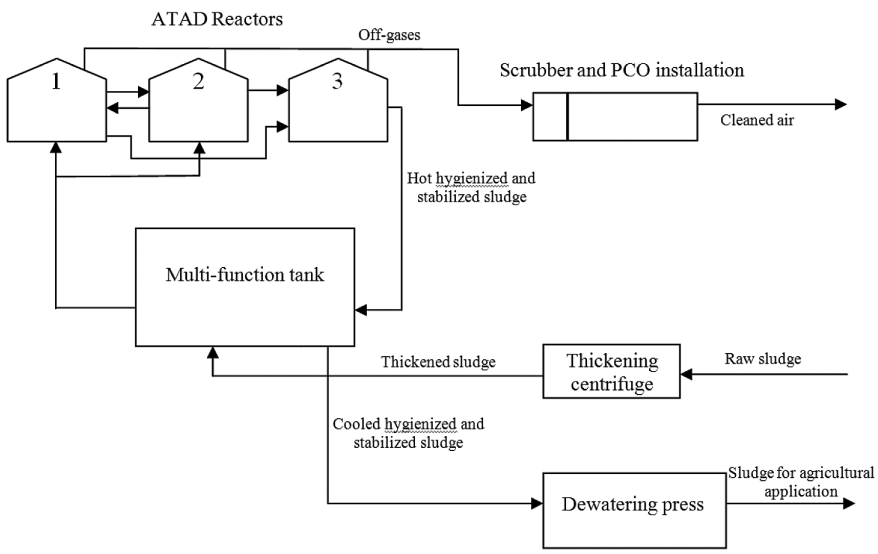

Figure 1. Simple diagram of sludge complex in Lubań wastewater treatment plant

With these three reactors the installation can be run in two or three working stages. In a two-stage system reactors No. 1 and 2 run simultaneously as the first stage and No. 3 as the second stage. In a three-stage arrangement all reactors work in series as successive stages. The reaction time is 23 hours and the emptying and charging time is 1 hour for both systems. The scheme of sedimentation node of the plant is shown in Figure 1.

METHODOLOGY, RESEARCH RESULTS AND DISCUSSION

The research was conducted at an existing object from June 2006 to February 2010. The goal of this study was to evaluate the appropriateness of selected process parameters for the estimate of the process of the Autothermal Thermophilic Aerobic Digestion for sewage sludge stabilisation, with a special focus on an easy method of measuring pH. The pH was examined in the raw, thickened sludge and in successive reactors of the installation. The research was carried out during operation of both a two-stage system and a three-stage system.

The pH was measured by a potentiometer method using an ion-selective electrode according to the PN-90/C-04540.01 standard.

All gathered results were subject to statistical analysis. The summary of the data set in order to draw basic conclusions and generalisation was conducted by a method of the descriptive stats. Table 1 presents the results of the statistical analysis.

Regarding the ATAD process as the oxidation of organic matter from dead microorganisms by thermophilic bacteria we can observe changes occurring there, which are visible in the analysis of the processed sludge pH. The pH of sludge under study during the process of thermophilic stabilisation changes and its value grows significantly.

With the installation working in a two-stage arrangement pH of sludge, thickened prior to the ATAD process, and was on the average of 6.63 pH and after the first stage of the installation it rose to 7.67 pH after it left tank No. 1 and to 7,62 after it left tank No. 2 The pH for stabilised and disinfected sludge upon leaving tank No. 3 was at average value of 7.99. The value of the tested parameter in thickened sludge was ranging from the minimum of 6.41 pH to the maximum of 7.05 pH. After the first stage of the installation pH increased from 6.98 to 8.60 (tank No. 1) and from 6.89 to 8,52 (tank No. 2). The pH of digesting sludge was characterised by the values within the range of 7.14 to 8.76 . The lowest diversification in the pH results was characteristic for the thickened sludge, for which the value of the standard deviation was 0.14 and the variance was 0.02. After the first process stage the differences in results were higher. For sludge from tank No. 1 the standard deviation was 0.45 and the variance was 0.20. Results for sludge from tank No. 2 show the standard deviation of 0.43 and the variance

Table 1. Values of selected distribution units

Distribution units	Sediment thickener		Reactor No. 1		Reactor No. 2		Reactor No. 3	
	Sludge pH during operation of the installation in a 2 or 3-stage arrangement		Sludge pH during operation of the installation in a 2 or 3-stage arrangement		Sludge pH during operation of the installation in a 2 or 3-stage arrangement		Sludge pH during operation of the installation in a 2 or 3-stage arrangement	
	2-stage	3-stage	2-stage	3-stage	2-stage	3-stage	2-stage	3-stage
Minimum value	6.41	6.23	6.98	7.07	6.89	7.48	7.14	7.72
Maximum value	7.05	7.08	8.60	7.93	8.52	8.34	8.76	8.91
Arithmetic mean	6.63	6.60	7.67	7.50	7.62	7.84	7.99	8.14
Median	6.62	6.57	7.58	7.49	7.63	7.81	7.92	8.09
Mode	6.62	multiple	7.68	multiple	7.53	multiple	7.71	multiple
Standard deviation	0.14	0.22	0.45	0.20	0.43	0.20	0.37	0.27
Variance	0.02	0.05	0.20	0.04	0.19	0.04	0.14	0.07
Range	0.64	0.85	1.62	0.86	1.63	0.86	1.62	1.19
Skewness coefficient	0.78	0.11	0.42	0.02	-0.01	0.85	0.18	0.92
Curtosis	0.95	-0.87	-0.77	-0.05	-0.78	0.56	-0.16	0.53
Percentile 10%	6.46	6.32	7.05	7.23	6.99	7.62	7.62	7.90
Percentile 90%	6.79	6.88	8.37	7.76	8.18	8.17	8.54	8.52

of 0.19. The pH of sludge after the ATAD process shows the standard deviation of 0.37 and the variance of 0.14. The range of pH values of the sludge processed by the ATAD process are shown in Figure 2. The diagram demonstrates that during the ATAD due to occurring biochemical processes pH increases gradually.

For thickened sludge the expected value of pH below and above the same number of observations is 6.62. The median value for sludge after the first ATAD stage in tank No. 1 was 7.58 pH and respectively 7.63 in tank No. 2 and for sludge after the entire process it was 7.92 pH. The most often occurring value of the sediment pH at individual sets determines the mode, which for thickened sludge amounts is 6.62 for sludge from tank No 1 is 7.68 and from tank No. 2 amounts to 7.53. The most often measured value in stabilised sediments was 7.71 pH. The results of the sediment pH are distributions of a right hand symmetry. The largest concentration around the average value is characteristic for the thickened sludge. With a 90 % probability we can also state that the pH value for the thickened sludge will be 6.79 or less. After the first stage of the installation 90% of results show values below 8.37 pH in tank No. 1 and similarly 8.18 pH in tank No. 2, where in the stabilised sludge these values will be lower than 8.54 pH.

Over the period under study the growth of the pH for sludge due to the autothermal thermophilic stabilisation was on the average 1,36, however, for 10% of the results it was 1.90 to 2.23 and in case of 90% of observations the growth was above 0.98. A significant increase was observed after the first stage reactors. After tank No. 1 the pH increased on the average by 1.04 units and after tank No. 2 by 0.99 units. After tank No. 1 the pH increased on the average by 1.04 unit and after tank No. 2 by 0.99 unit.

After reactor No. 3 the pH value grew by 0.32 units on average against reactor 1 and by 0.37, comparing to reactor 2.

When the installation was operated as a three-stage system the characteristic average value of pH for the thickened sludge was 6.60 pH, but ranging between the low of 6.23 and the high of 7.08 pH. After the first stage of the ATAD the pH rose with its mean value being 7.50 and ranging from 7.07 to 7.93. Higher values were recorded in sludge after the second stage of the installation being on the average 7.84 pH and ranging between 7.48 and 8.34 pH. For the stabilised sludge with the process completed the pH value ranged between 7.72 and 8.91, with the calculated average value being 8.14. The largest differentiation of the pH results was found out for the stabilised sludge. The ranges of the pH in sewage sludge under study are shown in Figure 3.

The presented diagram confirms a constant growth of pH for the observed sludge after successive stages of the installation. The median as a consistent and asymptotically unbiased estimator of an expected value shows a growing tendency of the analysed feature, the value of which was successively: for the thickened sludge 6.57 pH after the first installation stage and 7.82 pH after the second stage and 8.09 pH in the stabilised sludge. The results of the sludge pH are distributions of a right hand symmetry. The curve of size of the analysed feature is in case of the thickened sludge more flat than with a normal distribution, however, as the process advances after successive stage it slims. For the analysed results, 90%

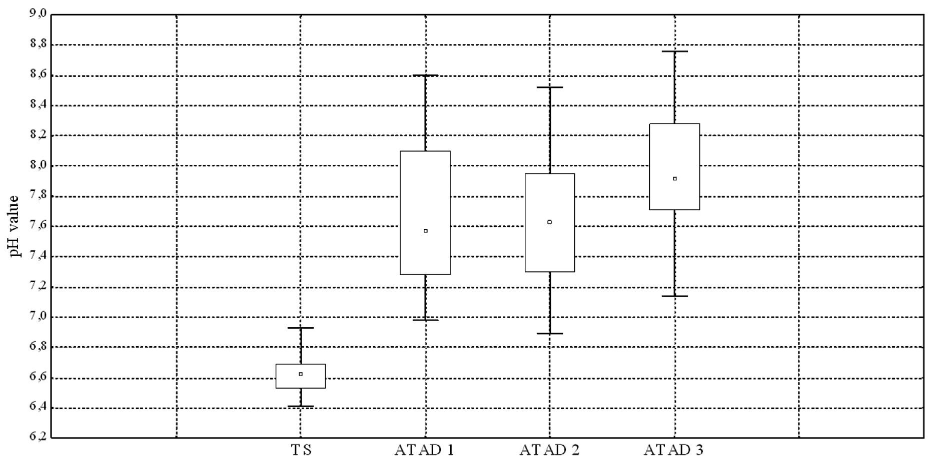

Figure 2. The ranges of the pH value for sludge measured during operation of a two-stage installation

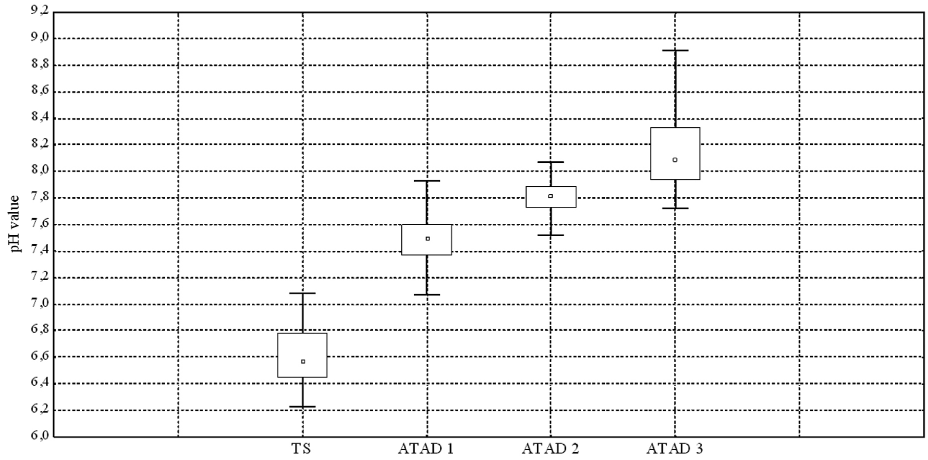

Figure 3. The ranges of pH value for sludge under study during operation of a three-stage installation

of these showed for the thickened sludge values lower than 6.68 pH, after the first stage under 7.76 pH and after the second stage under 8.17 pH. For sludge after the ATAD process 90% of determinations were below the pH value of 8.52.

During the study a growth of the pH value due to the deposits stabilisation was observed – on average by 1.54, however, for 90% of all the analysed results it was above 1.10. The greatest increase in the sludge pH occurred after the first ATAD stage – by 0.90 unit on average. After the second installation stage this value was 0.34 pH on average and after the third stage by 0.30 pH.

Taking into account the chemistry of the Autothermal Thermophilic Aerobic Digestion of sewage sludge certain growth of pH seems to be understandable. The generation of ammonia in the process with it being carried away along with generated gases, however, still present in the liquid and creating a weak base as well as retarding the nitrification process – causing pH decrease – as caused by thermophilic temperatures, may explain this phenomenon. Changes of pH in sludge caused by the Autothermal Thermophilic Aerobic Digestion for their stabilisation according to available bibliography point to ranges similar to those received. A most common growth of pH starts from 6.3 for the raw sludge and goes up to 9.1 for the stabilised sludge [Nosrati 2007, Piterina et al. 2010]. Also narrower ranges of changes are quoted from 7.0 pH for sludge prior to ATAD up to 8.2 pH after the process [Movahedian et al. 2005, Zhelev et al 2008]. Absolute sediment pH growth values due to the ATAD amount usually to 1–2 pH units [Kelly 2007, Zupančič, Roš 2008].

CONCLUSIONS

The Autothermal Thermophilic Aerobic Digestion is a process, which ensures a full sanitation of the sewage sludge and its effective stabilisation [Bartkowska et al. 2005a]. A full automatic control of the process ensures receiving sludge devoid of bacterial contaminations and as being a precious fertiliser a one which can be successfully returned to the natural circulation. The process is characteristic due to its very stable run of biochemical reactions with a short design dwelling time of sludge, therefore, the installation requires only a small area, thus resulting in low investment costs.

The research of the initial operation period of the ATAD-plant carried out at the subject plant confirms that the ATAD-process can be an effective way to stabilise and sanitize sewage sludge. Determination of the sediment pH allows a quick, easy and clear confirmation of the correctness of occurring biochemical processes. Results recorded over the period under discussion and rich experience from observations justify the following conclusions:

- The examination of the sediment pH allow an evaluation of the operation of an installation for the autothermal stabilisation, it confirms the direction of biochemical processes, this direction is additionally confirmed by the results of other parameters, therefore, it can serve as one of process indicators.
- Definitely larger increases in the pH value are observed at the first stage ATAD, where one can deem most of the biochemical processes. So one may consider a greater cubage of the

first installation stage, which will improve the energy balance of the process. The sludge in the first stage reactor will heat up quicker reaching a higher temperature. An increased capacity will also allow supplying more air according to the demand.

- A greater relative increase in the pH value was observed during a three-stage operation of the ATAD-installation. Therefore, we can suppose that in this operation cycle, processes occur more intensively.
- Results gathered during the research are, however, not clear to the extent they might point to a selection of a three-stage system. We must remember that a two-stage operation guarantees greater reliability.
- The presented technology enables to prepare sewage sludge to return it back to the natural cycle.

The differences observed during the research are, however, not so distinct to indicate a more advantageous manner to realise the process. This can be due to a short time of observations or can result from a different composition of sludge supplied to reactors in both cases. Another problem is that the operation regime of a centrifuge for initial compacting of sludge is difficult to maintain. Practical reasons favour a two-stage stabilisation, which with three tanks operating ensures a continuous operation of the installation, even with one tank failed.

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