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Sewage sludge stabilization indicators in aerobic digestion – a review

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Abstract: *Sewage sludge stabilization indicators in aerobic digestion – a review.* Raw sludge is a waste product that originates in the process of wastewater treatment. The sludge characterizes itself by significant ability to putrefaction, emission of odors and low ability to dewater. In addition, pathogenic bacteria, viruses and parasites exist in the sludges. This is the reason why they must be stabilized and disposed in order to eliminate or reduce unwanted or harmful features. There are several ways of sludge treatment with use of biological, chemical, and thermal methods. Biological methods, however, are most commonly used. Among these methods anaerobic fermentation or aerobic stabilization are usually in use. Aerobic digestion is basically used for small amounts of sludges, thus in small and medium-sized wastewater treatment plants. The process involves the removal of organic matter present in the sludge under aerobic conditions by microorganisms. There are various types of aerobic stability, differing with the temperature of the process or tanks in which the process is carried out. The paper presents sewage sludge stabilization indicators, which can be divided into physicochemical and biological activity parameters. These indicators are reduction of volatile suspended solids, total organic carbon, chemical oxygen demand, specific oxygen uptake rate and dehydrogenase activity. The paper shows the comparison of the results obtained by many foreign and Polish authors. The review of sewage sludge stabilization indicators also consists of the influences of some of other factors on volatile suspended solids.

Key words: aerobic digestion, sewage sludge stabilization indicators.

INTRODUCTION

The sludge is a waste product originates from wastewater treatment process. The primary and secondary sludge and sludge arises after chemical treatment are known. Primary sludge, as a result of sedimentation process of suspension both organic and mineral character, is generated in a primary sedimentation tank. Secondary sludge originates in sedimentation tanks after biological treatment of wastewater in activated sludge or trickling filter process. Sludge after chemical treatment arises as a result of chemical precipitation of phosphorus from primary or secondary sludge (Roman 1986; Stier and Fischer 1998; Bień and Wystalska 2005; Bień 2007; Podedworna and Umiejewska 2008).

Raw sewage sludge is hazardous waste. By dint of its content of easily degradable organic matter sludge is characterized by significant capacity of putrefaction, what involves the release of odors. This sludge characterizes itself by low ability to dewater, in consequence it consists the high degree of hydration. Generated sludge occupies high volume. Moreover, pathogenic germs, viruses and parasites live in sludge. For this mentioned reasons, the sludge has to be stabilized in order to eliminate or decrease unwanted or harmful features (Graczyk 1984; Podedworna and Umiejewska 2008). Next, sludge has to be disposed e.g. destined for agricultural use as soil and plants fertilizers, for land reclamation, combusted and then used for land reclamation or stored in landfills (Roman 1986; Siuta 2003).

There are several ways of sludge treatment. These are biological, chemical and thermal ones. Biological methods include aerobic and anaerobic digestion and composting. For the chemical methods lime stabilization is being used. Also thermal – the most radical methods, pyrolysis, burning or complete incineration are in use. Due to the efficiency and costs the most important and common is the biological stabilization performed under anaerobic conditions (fermentation) and aerobic (oxidative stabilization) (Bartoszewski 1994; Sadecka 2002; Podedworna and Umiejewska 2008; Podedworna and Heidrich 2010; Środa et al. 2012).

In terms of investment costs, aerobic sludge stabilization requires far less costs than anaerobic, and is mainly used for small amounts of sludge and, therefore, small and medium-sized wastewater treatment plants (Bartoszewski 1994; Sadecka 2002; Halicka and Heidrich 2008; Okutman 2010). Halicka and Heidrich (2008) say that, from an economic point of view, the fermentation is preferable for treatment with a population equivalent of more than 100,000 people, while the aerobic sludge stabilization is beneficial in towns with a population of between 10,000 and 30,000 people. These numbers showed by Halicka and Heidrich seem to be too high. Aerobic digestion involves the use of the decomposition process of organic matter contained in sewage sludge, involving microorganisms under aerobic conditions. The organic matter in sewage sludge is a substrate for microbial metabolic chain. In the first phase, easily degradable organic matter is oxidized on the strength of enzymes produced by the microorganisms living in activated sludge, resulting in rapid multiplication of microorganisms. These microorganisms use organic matter for biomass increasing and synthesis of the substance. The first phase is being continued until the sludge contains easily degradable organic matter. In the second phase, after the exhaustion of the external source of organic matter, cellular material is oxidized, and microorganisms obtain energy from self-oxidation of these cellular substances. In the third phase, the further intracellular oxidation is being continued. Phase two and three are called aerobic stability (Heidrich and Witkowski 2005; Podedworna and Umiejewska 2008).

Aerobic digestion may be carried out in various ways. For very small wastewater treatment plant, serving the village far below the 10,000 people equivalent, most commonly simultaneous aerobic digestion is being used due to the fact that the stabilization of sludge takes place in the nitrification tanks. The second way is the classic aerobic digestion of sludge applied to larger plants. The process takes place in isolated, open tanks. Another way is discontinuous stabilization with denitrification and densification, called combined anaerobic – aerobic digestion. It depends on the oxygen cycle phases during which the sludge is aerated and circulated and anaerobic phases, which excludes the mixing and aeration. During this phase sludge denitrification process take place. The sludge is then subjected to mechanical densification. Popular method, recently, is the stabilization in thermophilic conditions. The basis of the process is the concentration of sludge, after delivered of oxygen, spontaneous heating sludge follows to a temperature of 55–80°C. The process is carried out in separate, closed tanks with aeration (Steinle 1993; Podedworna and Umiejewska 2008).

SEWAGE SLUDGE STABILIZATION INDICATORS

Several criteria are being used to evaluate the sludge degradation. They vary in labor and speed of results obtaining. These criteria can be divided into physicochemical parameters and biological activity.

Physicochemical parameters

Volatile suspended solids (VSS) removal

Sludge mineralization occurs during the process of digestion, in which a reduction of volatile suspended solids take place. The loss of organic matter at the level of 38–40% is assumed as the stabilization limit (Podedworna and Umiejewska 2008). A number of studies were carried out, where one of the basic parameters for level of sludge degradation was dry weight and loss on burning. The authors based on these parameters recommended the minimum time required to sludge degradation. The investigation carried out by Okutman (2010) shows that for sludge from municipal wastewater treatment plants operating with activated sludge and bio-phosphorus tanks for advanced wastewater treatment, biggest removal of dry matter and volatile suspended solids was observed during aerobic digestion at 20°C after 18 days. The removal of dry matter was 26%, and removal of volatile suspended solids was 31%, and has not changed significantly over the following days of the experiment. The VSS/SS ratio, defined as the ratio of the concentration of volatile suspended solids to dry solids, was evaluated as well. Before digestion VSS/SS ratio was 0.59 and after 35 days of the experiment, 0.54. From 22nd day there was no significant change of the indicator. Also Cokgor et al. (2012) investigated the sludge coming from the municipal wastewater treatment plant operating with activated sludge with biological phosphorus removal. The stabilization was carried out at 20°C. In case of aerobic digestion dry weight removal was observed at 8.5% after 14 days and 22% after 30 days of the experiment. Volatile suspended solids removal was respectively 10% after days and 28% after 30 days. Okutman, Cokgor et al. also give the value of the VSS/SS ratio. Before digestion it was 0.52, 0.51 after 14 days of investigation and 0.48 after 30 days.

Bernard and Gray (2000) investigated the sludges from three wastewater treatment plants. Aerobic digestion process was conducted at an ambient temperature of 16.5–20°C. Loss of dry weight after 35 days of this study was in the range of 41.6–53.5%. However, volatile suspended solids removal at the same time was in the range of 53.1–63.9%. The authors indicate the minimum required stabilization time as 14 days. After this time, the loss of volatile suspended solids was in the range of 22–48%.

Table 1 summarizes the results obtained by the authors discussed above. Given values are: the temperature of individual experience, procentage reduction of volatile suspended solids after 14 or 18 days (in parentheses next to the value given the exact number of days) and after the end of stabilization process. Quite significant differences in the loss of volatile suspended solids obtained in the experiments of various authors may be noticed.

The removal of the concentration of volatile suspended solids also affected other factors. As Podedworna and Umiejewska (2008) stated, the rate of decomposition of volatile suspended solids is strongly dependent on the temperature process, and increases with the increase in temperature.

Borowski (2000) in his study shows that for the process temperature of 55°C sludge is stabilized after 8 days. The loss of volatile suspended solids after this time was 39.3%.

In a study by Ros and Zupancic (2002) of the aerobic digestion at 20, 37, 40, 45, 50 and 55°C, maximum loss of volatile suspended solids have been observed for the temperature of 50°C. Loss of 62.3% was achieved within 17 days. At the same time the increasing in loss of volatile suspended solids with the increase in temperature was noticed.

In another study conducted by Zupancic and Ros (2008), it was proved that the disintegration of volatile suspended solids is affected not only by the temperature but also by the gas used to aerate. The researchers came to the conclusion that both attempt of oxygen and air are two temperature ranges in which the stabilization process takes place in a satisfactory manner. The first range for both oxygen and air is in the mesophilic range and the best result was obtained at 38°C, the superior is system with oxygen. Loss of volatile suspended solids at a level of 60% was observed after 21 days of study, and the same loss of volatile suspended solids for the air was observed after 39 days. The second temperature range is different for the two methods of aeration. System with air is more effective for the temperature range of 50–58°C, where the loss of volatile suspended solids at a level of 60% was observed after 17 days for the temperature of 55.9°C. For the oxygen system, the second range of temperature was between 25–30°C, the loss of volatile suspended solids at a level of 60% was achieved after 31

TABLE 1. The comparison efficiency reduction volatile suspended solids after various authors

Indicator	Okutman	Cokgor	Bernard i Gray
Temperature (°C)	20	20	16.5–20
Reduction (%) of volatile suspended solids (after 14 or 18 days)	31 (18 d.)	10 (14 d.)	22–48 (14 d.)
Reduction (%) of volatile suspended solids (after stabilization process)	> 31 (did not change significantly)	28	53.1–63.9

days. The researchers also found that the system of aeration with oxygen does not work for thermophilic aerobic digestion. Above 50°C sludge stops to degrade due to high concentrations of dissolved oxygen. In nature such high concentration of dissolved oxygen at a temperature above 50°C is not observed and the bacteria probably is not able to survive and multiply in these conditions.

Total organic carbon (TOC)

Study by Cokgor et al. (2012) of the aerobic digestion of sludge originating from the wastewater treatment plant showed that the concentration of TOC at the beginning of the experiment was 2200 mg/ /L and was reduced to 995 mg/L. The authors affirmed that TOC content of the stabilized sludge is an important parameter when sludge is landfilling. In this study scientists reached remarkable removal of TOC after 30 days, but it didn't comply with the limitation for landfilling for their country.

Okutman (2010) investigated aerobically digested sludge coming from municipal treatment plant. The major reduction of TOC was observed after 22 days of digestion and achieved removal of 38%. The experiment lasted over month and achieved removal of 42% of TOC after that period. The author affirmed that most of removed TOC was consumed by microorganisms.

Chemical oxygen demand (COD) decrease

Chemical oxygen demand decline can be used to measure stability degree of sludge (Graczyk 1984).

Sanchez et al. (2006) observed that the initial value of COD, aerobically digested sludge coming from primary sedimentation tank, was 77.39 mg/L and fell to 37.31 mg/L by the end of the experiment. But form day 70, the value of COD was constant. The authors affirmed that it was because the system was stable and the remaining non-degraded COD was resistant to biodegradation.

COD was used by Zupancic and Ros (2008) as one of the main parameters of sludge degradation measurement. In this study the authors investigated aerobic digestion of waste activated sludge coming form municipal wastewater treatment plant. Pure oxygen and air was used to aeration in variety of temperatures. The scientist concluded that there were two ranges of temperatures for both oxygen and air aeration when successful degradation was observed. The first range for both oxygen and air was in the mesophilic range and the best result was obtained at 38°C. The superior is system with oxygen which reached 55% of COD degradation in 18 days and 60% in 23 days. The air-aerated system reached 55% in 18 days as well, but after that time degradation of COD was poor. The second temperature range was different for the two methods of aeration. The system with air was more effective for the temperature range of 50–58°C, where 60% of COD degradation was observed after 23 days for the temperature of 55.9°C. For the oxygen system, the second range was between 25–30°C, where 60% of COD degradation was observed after 27 days. The degradation of COD corresponds with VSS removal in this study.

Biological activity

The specific oxygen uptake rate (SOUR) and oxygen uptake rate (OUR)

The specific oxygen uptake rate (respiratory rate) it is the milligram of oxygen consumed by microorganisms per gram of volatile suspended solids (VSS) per hour. This rate shows the degree of stability of sludge and is combined with removal of biological substrate and growth or decay of microorganisms.

Sanchez et al. (2006) investigated aerobically digested sludge coming from the primary sedimentation tanks. Specific oxygen uptake rate (SOUR) had an initial value of 3.08 mg O_2/g TS/h at the beginning of the experiment and increased to a maximum value of 14.5 mgO_2/g TS/h on day 46. Then SOUR decreased and reached 1.13 mg O_2/g TS/h after 135 days. The author explained that the decrease indicated a reduction in respiratory activity.

Bernard and Gray (2000) in their study investigated the sludges coming from three wastewater treatment plants aerobically digested at an ambient temperature of 16.5–20°C. SOUR rapidly decreased over the first 14 days of the process. After 35 days of the aerobic digestion reduction of SOUR ranged from 65.8–93.1% and reached less than 1 mg O_2/g TS/h. The sludges were fully stabilized after 7 days of aerobic digestion.

Cokgor et al. (2012) investigated the domestic sludge aerobically digested at room temperature of 20°C for 35 days. Scientists measured oxygen uptake rate (OUR) profile at the beginning and after 17 and 30 days of experiment. Maximum OUR value was observed at the beginning of aerobic digestion and was around 40.5 mg O_2/L/h and decreased over time to 18 mg O_2/L/h after 17 days and 21 mg O_2/L/h after 30 days.

Dehydrogenase activity

The dehydrogenases are the enzymes that transfer hydrogen. Their activity is associated with the presence of living bacterial cells. Dehydrogenase activity test is a simple way for an assessment of the stability of sludge (Stier and Fischer 1998). Assay consists in the reduction of colorless triphenyltetrazolium chloride to red triphenylformazan and spectrophotometric measurement of the color intensity (Bernat et al. 2007).

Sanchez et al. (2006) conducted research on sludge coming from the primary sedimentation tanks. Dehydrogenase activity was measured. In the early days of study a drop of microbial activity was observed, which was associated with their adaptation to the new conditions. Then reported a slight increase in this activity, which lasted until day 46, after which there was a clear decrease in the activity of microorganisms. This dehydrogenase activity correlated with esterase activity survey, carried out in this experiment.

Graczyk (1984) in her studies of highly concentrated organic wastewater revealed that the activity of dehydrogenases in this wastewater reached a maximum during the second day of the thermophilic aerobic digestion process. Then a significant decrease of the enzyme activity was reported. This decrease is explained by the author of the exhaustion of easily degradable substrates and the lack of a protein compounds.

Study by Oviedo et al. (2005) of the aerobic digestion of sludge originating from the primary sedimentation tanks, showed that the dehydrogenase activity is a good indicator of microbial activity. At the beginning of the process a drop of dehydrogenase activity was observed. The authors explain this fact with microbial adaptation to the new conditions, after this adaptation stage of the slight increase in activity was recorded up to 46 day, and then decrease of microbial activity was recorded. The authors did not explain the reasons for the increase, and then the decrease in dehydrogenase activity. However, this relationship correlates with studies of Graczyk (1984).

Analyzing studies concluded by Oviedo et al. (2005) and Sanchez et al. (2006) these two articles are based on the same investigation of aerobic digestion of sludge coming from the primary clarifiers.

Activity of dehydrogenases test can be successfully carried out as a routine assay of sludge stabilization stage. It is a simple, fast and inexpensive test (Sanchez et al. 2006).

CONCLUSION

There are several parameters use to estimate degree of sludge degradation. Usually a few of them are used at the same experiment. Remove of volatile suspended solids is commonly used parameter. However, attention should be paid to the fact, that in the literature different rates of removal of volatile suspended solids are given. The rate of removal has a significant impact on the effectiveness cost and efficiency of the process of receiving stabilized sludge. The longer stabilization time the better sludge is stabilized. With the increase of sludge digestion time, operating and investments costs associated with the maintenance of a sufficient concentration of dissolved oxygen in a digestion tank increases, as well as construction costs. Longer retention time of sludge is associated with higher amounts of sludge and thus the construction of a larger tank. This is the reason why it is important to determine the optimal time of digestion, which is highly dependent on the rate of degradation of suspended solids. For the sludge from wastewater treatment plants operating with activated sludge, the minimum time of digestion given in the literature at a temperature of about 20°C is about 14–18 days. However, inconsistent data involves the removal of volatile suspended solids, or the dry matter after this time. For stability boundary it is assumed that removal of volatile suspended solids is at 38–40%. Literature data show that after that time this ratio is in the range of 10–48%.

Temperature also has an impact on removal of volatile suspended solids. When the temperature increases, also the rate of removal of this compound increases. Also gas used for aeration of digestion tanks has an impact on removal of this compounds. The literature shows, that for a system using an oxygen, stabilization occurs more efficiently for the temperature range 25–30°C, and 38°C. The most efficient for system of air is thermophilic range of temperature.

TOC is a parameter which is important when sludge is landfilling.

COD correlates with VSS during aerobic digestion. It's also quite simple and quick parameters to assay.

SOUR is combined with removal of biological substrate and growth or decay of microorganisms. The sludge is fully stabilized when this parameter reach less than 1 mg O_2/g TS/h.

A good indicator is a test for dehydrogenase activity, which permits to evaluate the activity of microorganisms in sludge, which leads transformation in it. It is a fast and efficient test.

REFERENCES

BARTOSZEWSKI K. 1994: Technologie oczyszczania ścieków i przeróbki osadów stosowanych w warunkach krajowych [Technologies of wastewater treatment and sludge processing in Poland] . *Ochrona Środowiska* 3–4 (54–55), 43–48.

BERNARD S., GRAY N.F. 2000: Aerobic digestion of pharmaceutical and domestic wastewater sludges at ambient temperature. *Wat. Res.* 34, 725–734.

BERNAT K., ZIELIŃSKA M., WOJNOWSKA-BARYŁA I., ŁATA A. 2007: Zmiany aktywności dehydrogenaz osadu czynnego w reaktorze okresowym ze stałym napowietrzaniem [Changes in dehydrogenase activity of activated sludge in sequencing batch reactor under constant aeration]. *Czasopismo Techniczne 2-Ś.*

BIEŃ J. 2007: *Osady ściekowe. Teoria i praktyka* [Sewage sludge. Theory and practise]. Wydawnictwo Politechniki Częstochowskiej, Częstochowa.

BIEŃ J., WYSTALSKA K. 2005: Gospodarka osadami ściekowymi w krajowym programie oczyszczania ścieków komunalnych [The sludge management in the national programme of municipal wastewater treatment]. Instytut Inżynierii Środowiska. Materials of conference "Zintegrowane, inteligentne systemy wykorzystania energii odnawialnej", Częstochowa – Podlesice.

BOROWSKI S. 2000: Tlenowa stabilizacja termofilowa osadów ściekowych [Aerobic thermophilic stabilization of municipal sludges]. *Ochrona Środowiska* 4 (79), 21–25.

COKGOR E.U., OKUTMAN TAS D., ZENGIN G.E., INSEL G. 2012: Effect of stabilization on biomass activity. *Journal of Biotechnology* 157, 4, 547–553.

GRACZYK M. 1984: Kryteria stabilizacji stężonych ścieków i osadów ściekowych [The stabilization criteria of concentrated wastewater and sludge]. *Ochrona Środowiska* 2, 25–33.

HALICKA A., HEIDRICH Z. 2008: Zakres stosowalności tlenowej i beztlenowej stabilizacji osadów pochodzących z komunalnych oczyszczalni ścieków [The range of use of aerobic and anaerobic digestion of municipal wastewater sludge]. *Inżynieria i Ochrona Środowiska* 11, 2, 163–176.

HEIDRICH Z., WITKOWSKI A. 2005: *Urządzenia do oczyszczania ścieków. Projektowanie. Przykłady obliczeń* [Wastewater treatment devices. Design. Examples of calculations]. Wydawnictwo Seidel–Przywecki, Warszawa.

OKUTMAN TAS D. 2010: Respirometric assessment of aerobic sludge stabilization. *Bioresource Technology* 101, 2592––2599.

OVIEDO M.D.C., SANCHEZ B., ALONSO J.M.Q. 2005: Enzymatic estimation of biosolids stability in aerobic digestion systems. *Enzyme and Microbial Technology* 36, 191–197.

PODEDWORNA J., HEIDRICH Z. 2010: Kierunki ostatecznego unieszkodliwiania osadów ściekowych [Directives for final neutralization of sewage sludge]. *Gaz, Woda i Technika Sanitarna* 3, 25–28.

PODEDWORNA J., UMIEJEWSKA K. 2008: *Technologia osadów ściekowych* [The technology of the sludges]. Oficyna Wydawnicza PW. Warszawa.

ROMAN M. 1986: *Kanalizacja. Oczyszczanie ścieków* [The sewage system. Wastewater treatment]. Vol. 2. Arkady, Warszawa.

ROS M., ZUPANCIC D. 2002: Thermophilic aerobic digestion of waste activated sludge. *Acta Chim. Slov.* 49, 931–943.

SADECKA Z. 2002: Energooszczędne modyfikacje metod przeróbki osadów ściekowych [Energy-saving modifications in sewage sludge processing]. *Ochrona Środowiska* 86, 3, 27–30.

SANCHEZ B., ALONSO J.M.Q., OVIEDO M.D.C. 2006: Use of microbial activity parameters for determination of a biosolid stability index. *Bioresource Technology* 97, 562–568.

SIUTA J. 2003: Uwarunkowania i sposoby przyrodniczego użytkowania osadów ściekowych [Conditions and ways of natural utilisation of wastewater sludge]. *Inżynieria Ekologiczna* 9, 7–42.

STEINLE E. 1993: Sludge treatment and disposal system for rural areas in Germany. *Water, Science and Technology* 27, 9, 159–171.

STIER E., FISCHER M. 1998: *Podręczny poradnik eksploatacji oczyszczalni ścieków* [The quick guide of wastewater treatment plant maintenance]. 1st Polish Ed. Wydawnictwo Seidel-Przywecki.

ŚRODA K., KIJO-KLECZKOSKA A., OTWINOWSKI H. 2012: Termiczne unieszkodliwianie osadów ściekowych [thermal treatment of sewage sludge]. *Inżynieria Ekologiczna* 28, 67–81.

ZUPANCIC G.D., ROS M. 2008: Aerobic and two-stage anaerobie sludge digestion with pure oxygen and air aeration. *Bioresource Technology* 99, 100–109.

Streszczenie: *Wskaźniki stopnia ustabilizowania osadu w procesie tlenowej stabilizacji.* Surowe osady ściekowe są odpadem, który powstaje w procesie oczyszczania ścieków. Charakteryzuje je znaczna zdolność do zagniwania, co wiąże się z wydzielaniem przez nie odorów, cechuje je niska zdolność do oddawania wody. Ponadto w osadach ściekowych bytują bakterie chorobotwórcze, wirusy i pasożyty. W związku z powyższym muszą zostać poddane przeróbce i unieszkodliwieniu w celu eliminacji bądź zmniejszenia niepożądanych lub szkodliwych cech. Znanych jest kilka sposobów przeróbki osadów ściekowych, zalicza się do nich metody zarówno biologiczne, chemiczne, jak i termiczne. Metody biologiczne są jednak najpowszechniej stosowane. Najczęściej spotkać można technologie oparte na beztlenowej fermentacji bądź tlenowej stabilizacji. Tlenowa stabilizacja osadów stosowana jest głównie do niewielkich ilości osadów, a zatem w małych i średnich oczyszczalniach ścieków. Proces polega na rozkładzie substancji organicznej występującej w osadach w warunkach tlenowych przy udziale mikroorganizmów. Stosowane są różne odmiany tlenowej stabilizacji, różniące się od siebie temperaturą procesu, komorą w której prowadzony jest proces itd. W artykule omówione są wskaźniki stopnia ustabilizowania osadu, do których zaliczyć można: ubytek lotnych związków organicznych (ubytek strat przy prażeniu), całkowity węgiel organiczny, chemiczne zapotrzebowanie na tlen, szybkość poboru tlenu oraz aktywność dehydrogenaz i do nich odnosi się niniejszy artykuł. Omówiono także wpływ niektórych czynników na ubytek lotnych związków organicznych. Dokonano porównania wyników badań opublikowanych przez różnych naukowców.

Słowa kluczowe: tlenowa stabilizacja osadów, osady ściekowe, stopień ustabilizowania osadów.

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