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NEW SLUDGE MANAGEMENT FOR SAFE LAND APPLICATION

NOWA TECHNOLOGIA OBRÓBKI OSADÓW W ŚWIETLE ICH ZASTOSOWANIA DO REKULTYWACJI BEZ WPŁYWU NA JAKOŚĆ ZASOBÓW WODNYCH

Nowy proces przeróbki osadów ściekowyh BioElectro umożliwia dezynfekcję osadu w przeciągu jednej godziny. Stosując proste domieszki i pole elektryczne prądu stałego wytwarzane są reakcje egzotermiczne prowadzace do preferowanego poziomu dezynfekcji a nawet do niemal pełnej sterylizacji. Proces znajduje zastosowanie w dezynfekcji osadów przed lub po beztlenowej fermentacji lub tlenowej stabilizacji. Proces może być zastosowany do dezynfekcji i podgrzania osadu przed stabilizacją tlenową w warunkach naturalnych, zmieniając ten proces na proces termofilowy. Zwiększenie temperatury procesu stabilizacji wydatnie zwiększa przepustowość całego układu osadowego. Badania laboratoryjne procesu udokumentowały wzrost temperatury do 50 - 70^{o}C w przeciągu pół godziny. W zastosowaniu BioElectro do dezynfekcji osadu po stabilizacji beztlenowej, w ciągu 2 godzin uzyskano temperaturę bliską 90^{o}C i 9-krotną logarytmiczną obniżkę zarodników Clostridium perfringens, uznanych za organizm wskaźnikowy najbardziej odporny na wysoką temperaturę. Proces kwalifikuje się jako jednostopniowa operacja jenostkowa podnosząca jakość osadu do klasy A, tj. nadającego się do natychmiastowego wykorzystania w rolnictwie, bez okresów karencyjnych. W przypadku stosowania związków amoniaku jako dodatku przyspieszającego dezynfekcję może nastąpić zwiększenie zawartości azotu w osadzie, co jest korzystnie gdyż osady ściekowe z reguły posiadają niedobór azotu w stosunku do zawartości fosforu. Technologia może być zastosowana jako dodatkowa operacja jednostkowa w istniejących oczyszczalniach, bez kosztownych zmian procesu. Porównanie kosztu procesu BioElectro z kosztem zmiany stabilizacji tlenowej na termofilową stabilizację tlenową, wykazało że dezynfekcja metodą BioElectro może być zastosowana za niewiele ponad jedną piątą ceny stabilizacji termofilowej.

Proces BioElectro może byc zastosowany w formie porcjowej lub jako proces ciągły i nadaje się szczególnie do mniejszych oczyszczalni ścieków, nie przekraczających 60 000 RLM. Zastosowanie BioElectro chroni splyw powierzchniowy przed zanieczyszczeniem jeśli osad używany jest do rekultywacji.

1. Introduction

Sludge generated at each stage of wastewater or water treatment and requires costly management before disposal. Landfilling, incineration and land application are three main options for sludge elimination (Reimers et al. 2013). Sludge is rich in nutrients such as nitrogen and phosphorous and contains valuable organic matter and microelements that are useful when soils are depleted or subjected to erosion. The organic matter and nutrients are the two main elements that make the spreading of this kind of waste on land as a fertilizer or an organic soil improver suitable (Fritzmorris et al. 2011). For example, the Québec Residual Materials Management Policy (Quebec, 2016a), Government Sustainable Development Strategy (Quebec, 2016b) states: “The ultimate goal is to ensure that no sludge is landfilled until it has been demonstrated that recovery is not an economically viable option.” EU regulations (Art. 14 of 91/271/EEC) also recommend reutilization of sludge originated at wastewater treatment plant everywhere where it is possible, underlining that an adverse effect on environment should be attenuated (EU, 2010). Polish regulations comply with the EEC Sewage Sludge Directives (86/278/EEC) which “encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and man” (EU, 1986). Subsequently, the regulations prohibit the use of untreated sludge on agricultural land where treated sludge is defined as having undergone "biological, chemical or heat treatment, longterm storage or any other appropriate process so as significantly to reduce its fermentability and the health hazards resulting from its use". To provide protection against potential health risks from residual pathogens, sludge must not be applied to soil in which fruit and vegetable crops are growing or grown, or less than ten months before fruit and vegetable crops are to be harvested. Directive 86/278/EEC also sets limit values for seven heavy metals (cadmium, copper, nickel, lead, zinc, mercury and chromium). Due to potential content of metals and pathogens, it cannot be applied directly as fertile soil amendment because of safety concerns (LeBlanc et al., 2006). EU regulations restrict the amount of metals, while US focuses on pathogens content by classifying sludge into Classes B and A (Tab. 1), while Quebec focuses on pathogens, metals and odor contents which permit them to categorize sludge into P (pathogen level), C (metal level), and O (odor level). Generally, category P1C1 (MDDELCC, 2016) corresponds to Class A in US EPA regulations.

Tablela. 1. Regulacje USEPA
Table. 1. US EPA regulations with respect to municipal sludge quality category

Microorganisms	Class A	Class B
Fecal coliform	$<10^{3}$ organisms/g TS	$<2 \times 10^{6}$ org/g TS
Fecal Coliform Reduction	5 log reduction	2 log reduction *
Pathogens		
Bacteria	See above	2 log reduction*
Salmonella	<3 MPN/4g TS	1.5 log reduction *
Viruses	<1 PFU/4g TS	2 log reduction*
Protozoa	BDL	NR
Helminth	<1 viable egg/4g TS	NR

Since land application of sludge with pathogen inactivation (Class B or Process to Significant Reduce Pathogens - PSRP) is presently questioned, USEPA (2016) regulate criteria with respect to acceptable Class A digestion Process to Further Reduce Pathogens (PFRP) (Tab. 2).

Tablela. 2. Temperatury Class A PFRP
Table. 2. Temperatures to meet Class A or PFRP

Digestion Process	Operation Parameters
Thermophilic Aerobic	2 reactors in series with HDT of~ 10 days, during which temperature is 50°C for >23 hrs **or** 55°C for >10 **or** 60°C for >4 hrs
Thermophilic Anaerobic	Temperature of 50-55°C for > 48-72 hrs including > 1hr at 70°C followed by 2 hrs at 55°C **or** 4hrs at >50°C

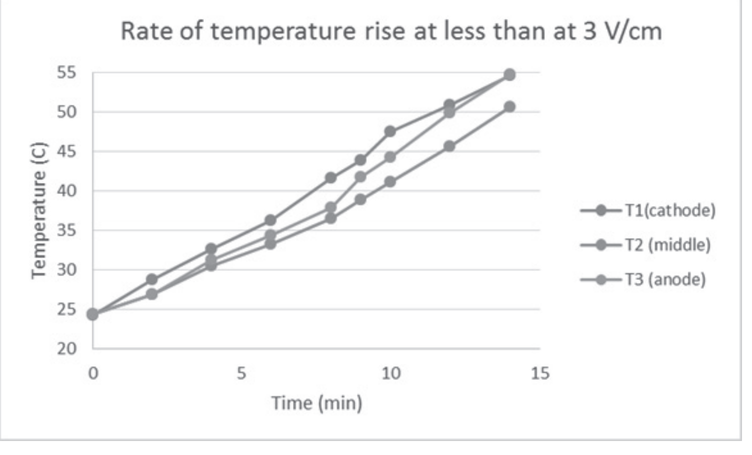
In Poland, regulations permit sludge application for biological re-cultivation under restrictions defined in Dz.U. 2014 poz. 1923 based on 91/689/EEC (MS, Poland. 2014). Sludge or sludge mixtures are defined by codes, and some types of sludge mixtures can be used in recultivation of industrial or mining areas. The recent tendency in Poland with respect of sludge incineration (MR, Poland, 2016) is contrary to Quebec vision where use of fertilizing properties of residual material is a priority (MDDELCC, 2016). A Canadian family of four can produce the equivalent of a 50 kg bag of NPK fertilizer from urine alone every year (Feineigle, 2014). Since landfilling and incineration each have their own environmental disadvantages, American regulators favor land application of sludge but after treatment to Class A (Tab. 2). Oleszkiewicz et al (2015) have determined that the most cost-effective and sustainable reuse of nutrients in Canadian conditions is through land application with or without phosphorus recovery.

The costs to convert to a Class A biosolids process is often prohibitive, particularly at small to mid-size facilities where there is a limited resale market. Subsequently, many municipalities in USA, Canada and worldwide are searching for alternative technologies. The patented process BioElectro might serve such purpose (Elektorowicz et al., 2012).

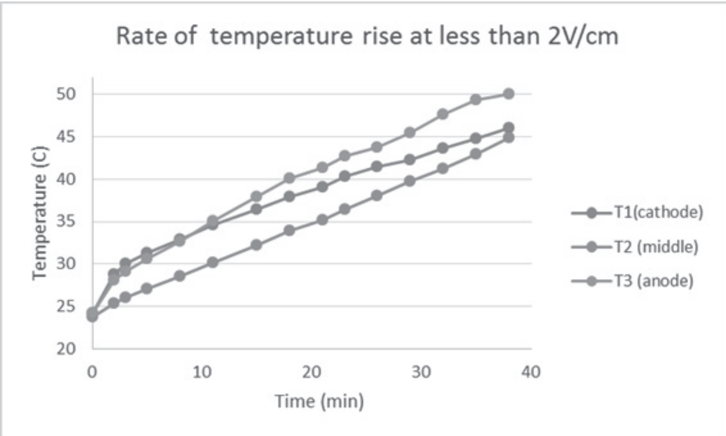
2. Description of BioElectro technology

The BioElectro process provides a potential solution to high-energy use options, since it generates exothermic reactions in sludge containing ammonia due to combination of a low voltage DC field with additives This approach is original and has great potential since preliminary work showed that temperature could rise to 50^{o}C and 70^{o}C within a less than half and an hour, respectively, using BioxyS in presence of ammonia and voltage gradient less than 5V/cm (Tab.3). In fact, the rate of temperature rise depends on voltage, the concentration of additives and initial temperature.

The lab scale studies were conducted on both anaerobic digested sludge and combined (primary and secondary sludge, WAS). The results carried on combined sludge having an initial temperature of 5, 15, 20 ^{o}C showed that the rising sludge temperature to 50 ^{o}C can take 35 min, 20 min and 12 min respectively, if an adequate combination of additives is applied to the same sludge. Besides, the rate of temperature rise increases with voltage gradient increase (Fig. 1 and 2). Furthermore, rather uniform distribution in an entire electrokinetic cell was observed in all tests (e.g. Fig 1).



Rysunek. 1. Szybkość wzrostu temperatury w osadzie
Figure. 1. Rate of temperature rise in combined sludge where DC voltage gradient less than 3V/cm was applied in presence of ammonia and BioxyS addition



Rysunek. 1. Szybkość wzrostu temperatury w osadzie
Figure. 2. Rate of temperature rise in combined sludge where DC voltage gradient less than 2V/cm was applied in presence of ammonia and BioxyS addition

The investigations were also carried out on an anaerobic digested sludge. The generated exothermic reactions, induced in BioElectro process, facilitated (enhanced) thermophilic digestion and decreased time of biosolids stabilization. The process assured biosolids disinfection, which can be controlled (from pasteurization to sterilization) (Tab. 3).

The BioElectro process was investigated through which C. perfringens spore inactivation in anaerobically digested sludge was achieved. Bioxy S, a source of peracetic acid (PAA) (Dagher and Dagher, 2006) in presence of ammonia and EK achieved disinfection of anaerobic digested biosolids. Its initial total solids (TS) averaged 2.4% (±0.2%) and pH was 8.17 units while C. perfringens spore ranged from 6.4 to 7.3 log CFUs/g TS. The BioElectro disinfection testes were carried out in a laboratory size prototype BioElectro system consisted of a regulated DC power supply and 3L rectangular batch EK reactors. The EK reactor was equipped with two pairs of perforated stainless steel electrodes. Underneath each electrode a 200 mL Nalgene bottle was installed to collect electroosmotic dewatering flow during the disinfecting process. The disinfection tests were run under different voltage gradients of less than 5 V/cm. At the end of each treatment (2 hours), samples were taken for microbial analyses (from different points of EK cell). Spores were counted based on the method developed by Reimers et al. (2002).

The fecal indictor organisms such as Clostridium perfringens spore was used to evaluate the hygienic characteristics of sludge indirectly since C. perfringens spores is the most resistant species; its three log reduction indicates Class A disinfection with respect to viruses, bacteria and helminth eggs (Blanker et.al., 1992). Sufficient reduction of potentially pathogenic bacteria can be accomplished by means of various physical, chemical or biological treatments; however, the spore elimination presents a challenge. Therefore, inactivation of spores shows simultaneous inactivation of other pathogenic compounds (bacteria, ova, viruses, etc.). In this study the spore viability in the presence of electric field of various voltage gradients and enhancement agents were investigated for duration of 2 hours. The final results of optimal conditions are presented in Table 3.

Tablela. 3. Proces BioElectro z dodaniem BioxyS™ w obecności amoniaku
Table. 3. BioElectro process with the addition of BioxyS™ in the presence of ammonia

Voltage gradient less than 5V/cm			
Time of sludge exposure (min)	**Log reduction (*C. perfringens* spores)**	**Measured temp. (°C)**	**Obtained effect**
20	1	45-55	
40	2	60-70	Near pasteurization
60	3	80-90	Indicates disinfection & pasteurization has occurred
80	6	95	Near sterilization.
100	9	95	Near sterilization.

Log 3 reduction was reached within less than an hour, and a complete inactivation (log 9 reduction) within less than 2 hours. It was demonstrated that the inactivation process can be fully controlled through the combination of conditioners and exposure time to an adequate DC field. Electrokinetics and conditioners applied alone at the same concentrations have not been successful in spore inactivation. The temperatures have risen to 90°C within almost 2 hours, and just from the temperature data, this process meets the requirements for pasteurization alone. In fact, the process may actually sterilize the sludge. This inactivation temperature is a result of the exothermic reaction caused by the BioxyS in presence of ammonia due the catalysis by the electrolytic current.

In case of spore inactivation, electrochemical redox reactions, which occurred simultaneously on the electrode surfaces, might also facilitate the production of hydrogen peroxide and chlorine (or subsequent hypochlorous acid), which infiltrated into the inner part of the spores and hastened the inactivation process. Since pH of the sludge increased significantly, it might rupture disulfide bonds in the spore's coat and lead to hydrolysis of the cortex.

The kinetic analysis of disinfectant residuals showed that there was a substantial decay of PAA produced by BioxyS. The decay rate of 0.293 (geometric mean) per min permits PAA to decompose within 15 minutes. Therefore, it was concluded that biocide was not considered as a major contributing factor in the disinfection process.

Furthermore, an impact of the degree of sludge dewatering was observed. Water content during such short period of time (2 hours) was decreased by 15%; however, longer exposure of sludge to electrokinetics permits to reach average total solids content of 85% (Huang et al., 2008), independently of the origin of sludge (anaerobic digestion, WAS, combine primary and secondary). Another study also demonstrated the feasibility of simultaneous metal removal (Elektorowicz and Oleszkiewicz, 2009).

3. Application of BioElectro technology

The investigation demonstrated that BioElectro process can be applied to both anaerobic digested sludge and to aerobic WAS. Process applied at full scale would require a small batch or continuous flow tank (due to short retention time) prior to existing digesters, with a system of electrodes supplied with a low DC voltage gradient The existing WAS feed can be diverted prior to digesters or a portion of existing digesters can be utilized. Such facilities do not require reconstruction of the wastewater treatment plant and can be added to existing systems. Target disinfection requirements and temperature at the end of the tests shall be defined to assess adequate electrical field and doses of additives.

Thus, the patented BioElectro process provides the potential to retrofit existing ambient temperature aerobic digesters to achieve a Class A biosolids through disinfection and thermophilic level of digestion without increasing the existing digestion volume (Elektorowicz et al., 2012). The anticipated capital cost of the BioElectro process may help many of the small to mid-size facilities make the conversion to create and beneficially reuse Class A biosolids. The process may also reduce existing digester volumes required for increasing capacity. Furthermore, the system through changing sludge properties improves dewatering, thus reduces operational costs and further enhances the economic viability of the process. The benefits also comprise reduction of air/electrical costs, lower transportation costs; lower re-use costs, and avoidance of expansion needs. For example, the estimated cost to retrofit the aerobic ambient temperature process at the 49 000 m^3/d Munster WWTP, St. Bernard Parish (LA) to a Class A product process, utilizing existing technology, could be in excess of approximately $9M. Utilizing the BioElectro process prior to the existing aerobic digestion process would carry a cost of less than $2M.

Furthermore, the addition of ammonia makes the final product more adequate as a fertilizer since an expected in agriculture ratio of phosphorous to nitrogen is always missing in sludge treated in a conventional way.

4. Conclusion

BioElectro is a breakthrough technology which presents a high potential of practical applications for the advanced sludge treatment and management as the product exceeds Class A regulatory compliance. The patented (Elektorowicz et al., 2012) process uses low voltage current and additives to raise temperature to disinfect sludge. The rate of temperature rise depends on voltage gradient and concentration of additives. The lab test showed possibility of temperature rise within the less than one hour to 50 - 70 ^{o}C, and within less than 2 hours to 90 ^{o}C. The tests were carried out in batch reactors and the batch system can be used in full scale. The concept can also be applied to a continuous flow system. Such disinfection facilities do not require reconstruction of the wastewater treatment plant and can be added to existing systems. Furthermore, BioElectro combined with EKDIM system (Elektorowicz and Oleszkiewicz, 2009) can remove simultaneously metals and dewater sludge to the level as high as 85% TS, while preserving the desired nutrient content. Subsequently, sludge after treatment can be used as a valuable, safe soil amendment in agriculture and horticulture sectors. Runoff free of pathogens and potentially heavy metals eliminate threat for water resources.

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