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# CONTROLLED PASTEURIZATION, DISINFECTION AND STERILIZATION OF SLUDGE BY BIOELECTRO$^{TM}$ PROCESS

## KONTROLOWANA PASTERYZACJA, DEZYNFEKCJA I STERYLIZACJA OSADÓW W PROCESIE BIOELECTRO

*Huge amount of sludge is produced by water and wastewater treatment facilities. In Quebec (Canada), there is a tendency to remediate such sludge and transform it into a "fertile material" serving agriculture, horticulture and gardening. Such applications require dewatering, as well as disinfection to reach Quebec standards with respect to pathogens, odor and metal contents. This paper describes a new process, BioElectro$^{TM}$, which is able to sterilize sludge within less than two hours. The process was proven on one of the most difficult indicators such as Clostridium perfringens spores. In this study, DC electric field coupled with enhancement agents permitted reach log 9 reduction of spores. It was concluded that the presence of unionized ammonia molecules along with the elevated temperature generated due to exothermic reactions may sterilize sludge. The process is ready to be used in batch and continue flow sludge treatment systems.*

## 1. Introduction

Landfilling, incineration and land application are main options for sludge elimination. Since landfilling and incineration have their own environmental disadvantages, regulators favor land application (agriculture) of such sludge. Current regulations restrict the amount of pathogens in sludge subjected to reuse or dispose. Generally, sludge contains high levels of pathogens which may threaten human health and environment if sludge is not being used safely in accordance with good practices (LeBlanc et al., 2006). Appropriate fecal indictor organisms such as *Clostridium perfringens* spore can be used to evaluate the hygienic characteristics of sludge indirectly. It should be noted that under anaerobic conditions *C. perfringens* spores is the most resistant microbe and with a three log reduction indicates P1 in Quebec (or Class A in Canada) acceptable disinfection with respect to viruses, bacteria and helminth ova (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 still presents a challenge. Therefore, a new approach to sludge management in this context is economically justified.

Objective of this study was to find a new method for inactivation of pathogens including *C. perfringens* spores in anaerobically digested sludge using electrokinetic processes, before its application as a valuable “fertile material” in the field.

## 2. Methods and materials

Electrokinetic (EK) treatment is based on the application of direct current (DC) within a contaminated matrix to remove pollutants through several electrokinetic phenomena (ion migration, electrophoresis, electroosomosis, oxidation, reduction, etc.). Previous EK studies (Elektorowicz et al., 2008; Elektorowicz et al., 2007; Safaei et al., 2009) have shown the effectiveness of conditioners such as ammonia salts (AS) and BioxyS™ (BS) (Dagher and Dagher, 2006). Therefore, AS and BS were used as enhancement agents in this research on EK sludge disinfection.

Anaerobically digested sludge was provided by Robert O. Pickard Environmental Center, Ottawa. Its total solids (TS) averaged 2.4% and pH was around 8; *C. perfringens* spore ranged from 6.4 to 7.3 log CFUs/g TS. The BioElectro™ disinfection tests were carried out in a laboratory size prototype BioElectro™ consisted of a regulated power supply (GENESYS 1500W, TDK Lambda Americas Inc) and a series of 3100 mL rectangular EK reactors (214 mm length × 214 mm width × 74 mm height) each. Each EK reactor was equipped with four perforated stainless steel (316SS) electrodes (10 mm diameter, 102 mm long) located at a distance of 172 mm from each other acting as anodes and cathodes. Underneath of each electrode a 200 mL Nalegene bottle was installed to collect electroosmotic dewatering flow during the experiment. Before tests, sludge was homogenized with agitation at 200 rpm for 5 minutes, then, AS and BS were applied, mixed at 300 rpm during two minutes, and poured into the EK reactors and one control reactor without electrodes. The disinfection tests were run under constant voltage gradients of less than 5 V/cm. Samples were taken (from different points of EK cell) in intervals, during 2 hour-experiments, for microbial analyses. Spores were analyzed based on method developed by Reimers et al. (2002). All tests were performed in quadruplicates, and no standard errors were higher than ±11%.

## 3. Results

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 in optimal conditions are presented in Figure 1. Results showed that log 3 reduction was reached within less than an hour, and a complete inactivation (log 9 reduction) within less than 2 hours. It was shown that spore inactivation can be fully controlled through the combination of the agent concentrations, exposure time, and voltage. The control cell tests showed that DC and conditioners applied alone at the same concentrations have not been successful in spore inactivation.

Furthermore, along with the action of electric field on spore, electrochemical reactions occurred. This also can be observed evidently by transmission electron microscopy examination of spores' samples before (Fig 2a) and after exposure to BioElectro$^{TM}$ process (Figure 2b). Transmission electron microscopy (TEM) analysis showed creation of nicks in spore membranes after treatment (Fig. 2b). .

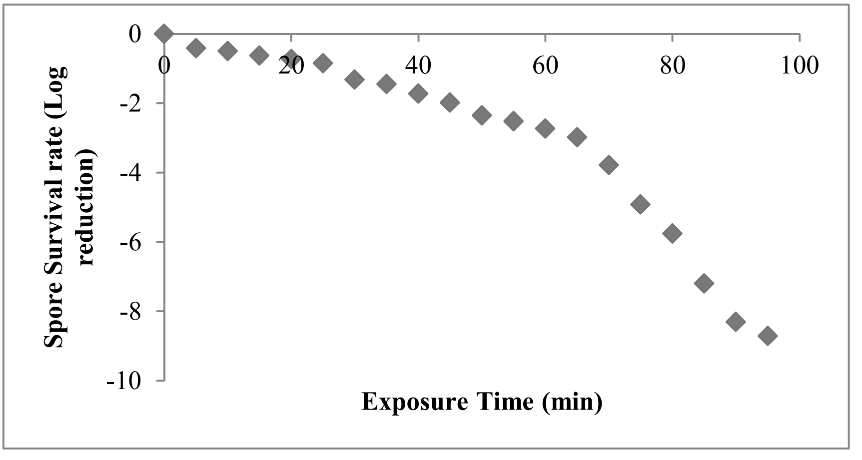


*Fig.1. Inactivation of Clostridium p. spore in anaerobically digested sludge treated with BioElectro$^{TM}$ process*

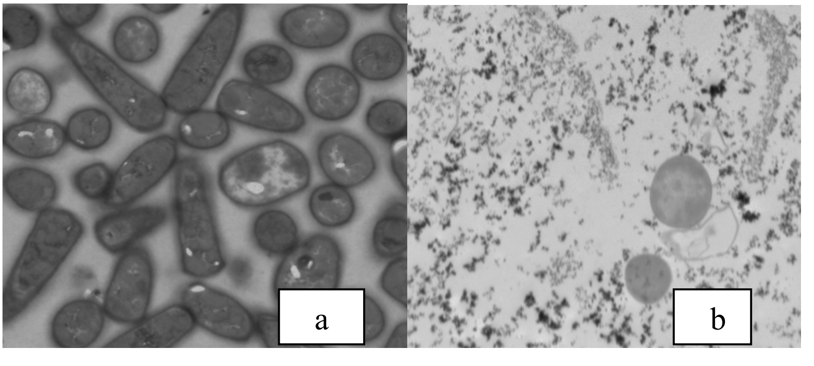


*Fig. 2. Clostridium p spores: before (a), after (b) BioElectro$^{TM}$ treatment (TEM scan)*

Electrochemical redox reactions occurred simultaneously on the electrode surfaces facilitate the production of hydrogen peroxide and chlorine or subsequent hypochlorous acid, both of which may infiltrate into the inner part of the spores and hasten the inactivation process (Fig. 3). Induced electrochemical reactions also bring about large pH changes in the vicinity of the electrodes with propagation fronts toward opposite electrodes. The pH of the sludge increased significantly, to a level that ruptures disulfide bonds in the spore coat leading to hydrolysis of cortex. Moreover, the elevated pH (> 10.7) is attributed to the generation of ammonia. The AS and BS enhanced the ionic strength, causing exothermic reactions and increasing biocidal stressors constituents.

Simultaneously, the temperatures have risen to 90°C within almost 2 hours, and just from the temperature data, this process met the requirements for pasteurization alone. This inactivating temperature is a result of the exothermic reactions caused by the BS and AN catalyzed by the electrolytic current. The results of this exothermic catalysis are shown in Table 1.

*Tab. 1 Control of disinfection, pasteurization and sterilization trough exothermic reactions and exposure to DC current.*

| **Voltage gradient (less than 5 V/cm)** | | | |
|---|---|---|---|
| **Time (min)** | **Log reduction (*C. perfringens* spores)** | **Temp. (°C)** | **Comments** |
| 20 | 1 | 45-55 | |
| 40 | 2 | 60-70 | Near **pasteurization** |
| 60 | 3 | 80-90 | Indicates that **disinfection** and **pasteurization** has occurred. |
| 80 | 6 | 95 | Near **sterilization** with the assistance of ammonia. |
| 100 | 9 | 95 | Potential **sterilization** with the assistance of ammonia. |

The primary stressor for disinfection is temperature caused by the electrolytic catalysis of BS and AN and current. In such condition, the process may actually sterilize the sludge. This process should work for aerobically digested sludge and raw municipal sludge. The exposure time is a controlling factor of the level of pathogen inactivation. The levels of pathogen inactivation can be categorized as disinfection, pasteurization and sterilization as defined below:

1. Disinfection processes inactivate just the vegetative pathogens.
2. Pasteurization processes inactivate all the vegetative microbes except the spore forming bacteria (greater than 70°C for 30 minutes).
3. Sterilization processes inactivate all microbes including spores

Disinfection for the sludge pathogens occurs at 70°C above the range defined for pasteurization, but at temperatures around 95°C, the combination of AN and BS in the BioElectro™ process can reach near sterilization level. Process indicates near sterilization of the sludge inside 2 hours. At a temperature of 95°C, the pKa for $NH_3/NH_4^+$ should be in the range of 7 (Tab. 2), which means that the ammonia concentrations should be a viable disinfectant for the spores and assists in the sterilization process.

The DC field appears to enhance the treatment as noted with the greater temperature rise, pH fluctuations at the cathode and anode, and the *Clostridium perfringens* log reductions for inactivation. Sludge disinfection would occur at temperatures 70°C inside 60 minutes, but the *Clostridium perfringens* inactivation results at 90 °C indicates that sterilization is occurring related to the double stressors of temperature and ammonia.

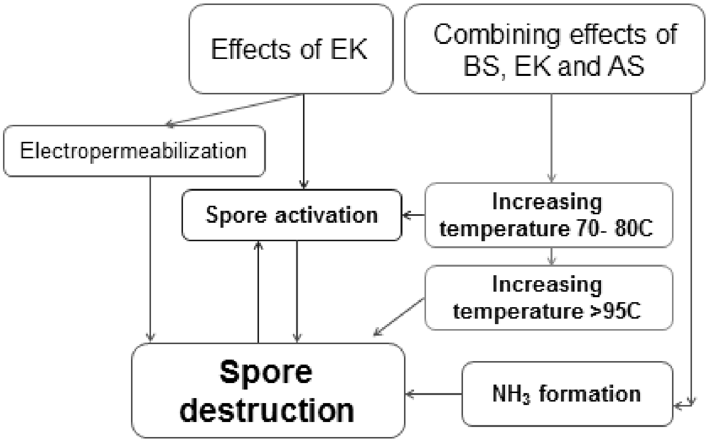


*Fig. 3. Schematic representation of hypothesized pathways leading to inactivation of spores in the BioElectro™ process*

*Tab. 2 Computed pKa and $NH_3$ in various experimental conditions of BioElectro™ process*

| (V/cm) | Temp. (°C) | pKa | pH | f* | $(NH_3)_t$(mg/L) | $NH_3$(mg/L) |
|---|---|---|---|---|---|---|
| Higher voltage gradient | 95 | 7.46 | 7.80 | 0.69 | 489 | 337 |
| Lower voltage gradient | 95 | 7.50 | 8.15 | 0.82 | 194 | 159 |

* f = Fraction of total ammonia that is unionized

## 4. Conclusion

BioElectro™ is a breakthrough technology which presents a high potential of practical applications for the advanced sludge treatment and management since exceed P1 (Class A) regulatory compliance. The patented (Elektorowicz et al., 2012) process uses low voltage current and generates near sterilized solids within less than two hours. The level of pathogen inactivation can be controlled through shorter or longer exposure to DC field in presence of conditioners. The tests were carried in batch reactors and the batch system can be used in full scale; however, the concept can be also applied to a continuous flow system. 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 nutrient content. Subsequently, sludge after treatment can be used as a valuable, safe soil amendment in agriculture and horticulture sectors.

## 5. Acknowledgement

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## References

[1] Blanker, E.M., Little, M.D., Reimers, R.S., and Akers, T.G., (1992) Evaluating the use of *Clostridium perfringens* spores as indicator of the presence of viable *Ascaris ova* in chemically treated municipal sludge, Proceedings of Municipal Sludge Management - Where We Are and Where We're Going (Volume I), Water Environmental Specialty Conference Series, Alexandria, VA, pp. 187-201 July, 1992.

[2] Dagher, F. and Dagher, D. (2006) Powdered composition for the generation of peracetic acid and use thereof to sanitize surface, Patent CA2569025.

[3] Elektorowicz, M., Oleszkiewicz J., 2009, A method of treating sludge material using electrokinetics, applied US Patent 8329042

[4] Elektorowicz, M., Oleszkiewicz, J., Huang, J., Safaei, E., Abdoli, H. and Habel, H. (2008) EKDIM: an electrokinetic process treats municipal wastewater sludge for safe land application. Volume 7, pp 276-287, Seoul, South Korea.

[5] Elektorowicz, M., Safaei, E., Oleszkiewicz, J., and Reimers, R. (2007) Electrokinetic remediation of sludge through inactivation of Clostridium perfringens spores, Vigo, Spain.

[6] Elektorowicz, M., Safaei, E., Reimers, R., Oleszkiewicz, J., and Dagher F., 2012, Process for treatment of residuals, Provisional US Patent. 6171838

[7] LeBlanc, R.J, Matthews, P. and Richard. R.P. (2006) Global atlas of excreta, wastewater sludge, and sludge management: Moving forward the sustainable and welcome uses of a global resource. Technical report, Greater Moncton Sewage Commission.

[8] Québec Residual Materials Management Policy, 1998-2008, Quebec Government, www.mddep.gouv.qc.ca

[9] Safaei, E., Elektorowicz, M. and Reimers, R. (2009) Bench-scale trial of electrokinetic treatment on anaerobically digested biosolids; microbial inactivation. 8$^{th}$ World Congress of Chemical Engineering, Montréal, Canada.

[10] Reimers, R.S., Oleszkiewicz, J., Bowman, D.D and Faulmann, E.L. (2002) PEC application for the national classification of the J-Vap process to the category of PFRP, Report for Paradigm International, Inc. Louisiana, USA.