Using of Pulsed Electrical Field (PEF) as an innovative technology for Sludge Pretreatment

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Abstract

The pulsed electric field (PEF) technology has a potential use in several disciplinarians such as the food industry for bacterial inactivation, molecular biology for electroporation, biomedicine, DNA insertions, medical therapies, and genetic. Although PEF technology has been used in wastewater treatment for the effective elimination of organic compounds in environmental science, PEF is quite new used for sludge pretreatment. There are only a limited number of researches on these subjects. The success of this technique is depending on the formation of strong electrical field discharge, which can be generated by applying high pulsed voltage (10–50 kV) to electrodes. Various parameters might be effective on PEF process performance including the type of microorganisms, field intensity, pulse wave shape, conductivity, pH and temperature of the medium, treatment time (flow rate), and energy input. In this paper, we describe such a pulsed electric field (PEF) technology that was developed as a sludge treatment process. We were performed simulations of electric field distributions inside the lab-scale PEF treatment chamber using a CST Studio software and PEF treatment reactor tested under laboratory conditions. The optimum PEF operation conditions was achieved at 4 mS/cm of conductivity, 5 ml/min. of flow-rate and 54 kV voltage for waste sludge treatment.

Key words: sludge treatment, pulsed electrical field, PEF

1. Introduction

Pulsed electric field (PEF) technology is an innovative technology which could be used as an alternative to the traditional process in several sciences. The pulsed electric field (PEF) technology has a potential use in several sciences such as the food industry for bacterial inactivation, molecular biology for electroporation, biomedicine, DNA insertions, medical therapies and genetic [1].

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Although PEF technology has been widely used in wastewater treatment for the effective elimination of organic compounds in environmental science; It is fairly new in the sludge treatment. Wastewater treatment plants in word widely uses to in both domestic and industrial wastewater treatment. Sewage sludge is generated during the treatment process in the primary and secondary clarifiers. This sludge must be treated and disposed safely due to environmental, economic, social and legal factors [2]. Anaerobic digestion is the most widely used process for treatment of sewage sludge. The process produces a biogas containing methane and releases the stabilized sludge.

PEF is an innovative technology developed to improve of digester performance. PEF technology disrupts sludge flock structure and reduces complex organic molecules to simpler forms. These effects increase dissolved organic material in sludge WAS. Anaerobic microorganism in the anaerobic digester uses this dissolved organic material as substrate to generate methane. Thus, anaerobic digester performance is increased and the more methane is produced. Choi et al. [3] reported that after PEF treatment SCOD/TCOD ratio and exocellular polymers (ECP) content of WAS increased 4.5 times and 6.5 times, respectively. The methane gas shows 2.5 times higher production than that of untreated sludge.

The success of this technique depends on the formation of strong electrical field/arc discharge, which can be generated by applying high pulsed voltage to electrodes. When the high pulsed voltage applied to electrodes into aqueous phase besides the physical phenomena such as strong electric fields, shockwave produces chemical phenomena such as intense ultraviolet radiation, and free radical reactions including the formation of short-live reactive radicals, such as hydroxyl radicals, hydrogen radicals, superoxide radicals, perhydroxyl radicals, and the simultaneous production of long-lived molecular species such as hydrogen peroxide, O_3 [3].

The basic principle of the PEF technology is the application of very short electric pulses of high electric fields in the range 15-40 kV/cm. The treatment efficiency during the PEF processing depended on critical factors include the field strength, pulse shape, treatment time, treatment temperature, solution conductivity, and type of waste.

In this paper, we describe a pulsed electric field (PEF) technology developed as a sludge treatment process. We were performed simulations of electric field distributions inside the lab-scale PEF treatment chamber using a CST Studio software and PEF treatment reactor tested under laboratory conditions. The optimum PEF operation conditions was achieved at 4 mS/cm of conductivity, 5 ml/min. of flow-rate and 32 kV_{rms} voltage.

2. Materials and Method

2.1. Pulsed Electrical Field (PEF) System

A PEF system consists of a treatment reactor, a pulsed high-voltage power supply, a pulse generator, a pump to pass the waste sludge through the treatment reactor. The process flow diagram of the experimental setup is shown in Figure 1. PEF reactor was a co-linear cylindrical chamber design made from stainless steel. A co-linear cylindrical chamber consists of two electrodes and a insulator custom made by CAD/CAM (production center of Suleyman Demirel University, Isparta, Turkey). Electrodes were separated by an insulator at both ends to create electrical field. The one of the electrodes were attached to the reactor as a high voltage electrode, and the other connection was used as a ground electrode. Cylindrical body of reactor has a 5-ringed outer electrode and pure cylindrical inner electrode. When sludge flows through reactor it must touch both inner and outer electrodes. Schematic of the reactor is seen in Figure 2. Produced from DC the peak voltage was 0–36 kV_{rms} and the pulse frequency was 50 Hz.

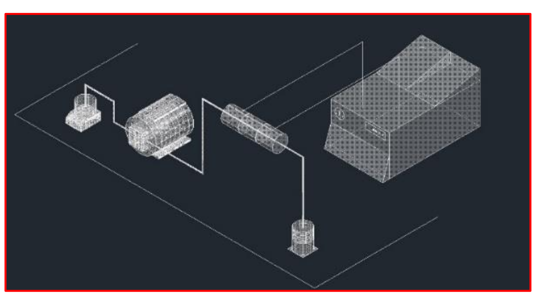

Figure 1. The schematic diagram of PEF system

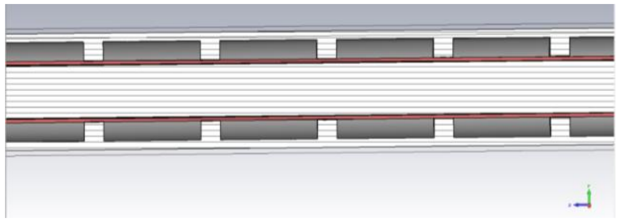

Figure 2. The drawing of presented reactor

In this study, simulation studies of the reactor were performed by CST Studio (CST AG, Darmstadt Germany). Simulations were made inside and outside of the reactor in order to get a realistic electromagnetic model by means of electric field strength in the unit of volts per meter.

The wave shape of pulsed high voltage supply can be seen in Figure 3. Electric-arc spark could be occurred in the reactor while it is empty and it is because that the shape of sine-wave turned to pulsed. In other words, if the reactor is supplied with this pulsed voltage there could be a high density electric field in the cavity of the reactor. So, pulsed high voltage can create pulsed high density electric field. A 80 MHz digital storage oscilloscope (EZ Digital Co., Ltd., Seoul, Korea) was used for monitoring the wave shape of E-field inside the reactor.

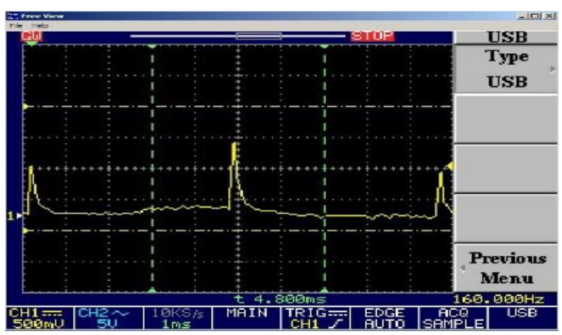

Figure 3. Oscilloscope screen with empty reactor. While the reactor is empty, spark might occurs inside the reactor due to high intensity E-field. Sharp peaks can show sparks (electric arcs)

In Fig. 4, voltage wave shape can be seen while the reactor is filled the sludge with the conductivity of 6.3 mS/cm. Due to the conductivity of sludge electric-arc diminished and only effect is because of the electric field. Rapid rise time of saw tooth wave shape shows beginning of pulse. Settling time is greater than rise time because conductive sludge can convert the sine wave to saw tooth without spark in operation.

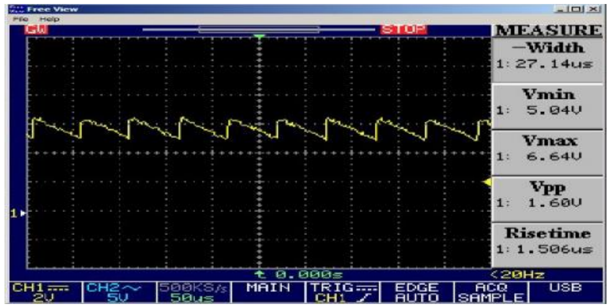

Figure 4. Rectified and pulsed high voltage supply to the reactor. The real value of peak voltage is 50760 V by setting the selector switch to the level 6. But the induced voltage can be seen as 1.6 V_{pp}.

Supply voltage was obtained from a power transformer (Turkoglu Trafo Co.,Istanbul, Turkey) with output of half-wave rectified, pulsed high voltage sinus. 10 HV diodes (15 kV-1 microampere, NTE Electronics, New Jersey, USA) were connected in series for getting rectification. HV transformer was connected to the 220 V_{rms} mains which has a selector switch to get 6 level outs. As an example, while this switch is set to level 6, output of transformer is 36 kV_{rms}. This means that peak value of output will be 1.41 times 36 000 Volts. So, peak value of rectified, pulsed sine wave has 50760 Volts in this case. In Fig. 2.4, this value can be seen as 0.8 V of induced voltage on the probe of oscilloscope.

2.2. Effect of PEF on waste active sludge (WAS)

PEF system was used to enhance sludge digestion performance of anaerobic digester. In this study, the waste active sludge (WAS) was treated by PEF system. The WAS was taken from the secondary clarifier after a classical aeration activated sludge process at a full scale municipal wastewater treatment plant in Isparta.

The digester performance of the raw WAS and WAS treated with PEF was determined by soluble chemical oxygen demand (COD) and biological methanogenic activity (BMA) test. The soluble chemical oxygen demand (SCOD) was determined by closed reflux colorimetric method [4]. The increase in COD concentration into WAS is a good indicator to enhanced anaerobic digester performance. BMA tests were performed using serum bottles according to the procedures of Owen et al. [5]. The inoculums sludge and the waste active sludge were poured at 1/1 (volume) ration into serum bottle of 150 ml. The anaerobic inoculums sludge was provided from a full scale anaerobic stabilization reactor treating domestic wastewater of Isparta.

The pH of mixture was adjusted 7 by $NaHCO_3$ solution to create optimal pH for methane bacteria. 30% CO_2 and %70 N_2 gas mixture was passed from each serum bottles to provided reducing condition. The serum bottle was then capped with rubber septum and sealed aluminum cover and incubated at 37 °C into a shaker (160 rpm). Methane gas production was measured daily with a liquid displacement method using distilled water containing 3% NaOH (w/v) [6].

3. Results

3.1. Simulation results

In this study we used different prototypes with different gaps between inner and outer electrodes. By thinking that electrode gaps would be critical factor; some simulations were created with different values. In Figure 5 two simulations can be seen with 23 mm and 28.5 mm electrode gap.

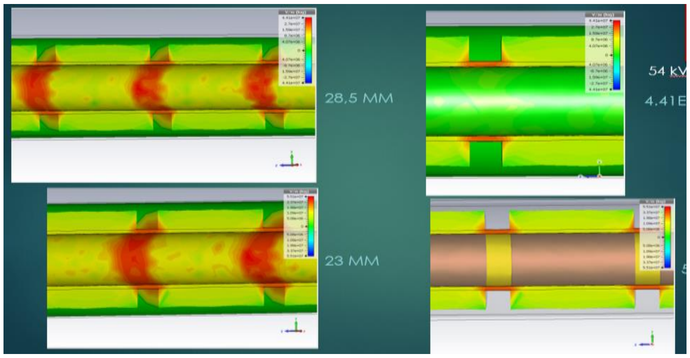

Figure 5. While supply voltage is 54 kV and electrode gap are 23 mm and 28.5 mm maximum electric field intensities are 4.41e7 and 5.51e7 V/m respectively.

Some cases were possible in the experimental state. Six different cases were simulated and can be seen in Figure 6.

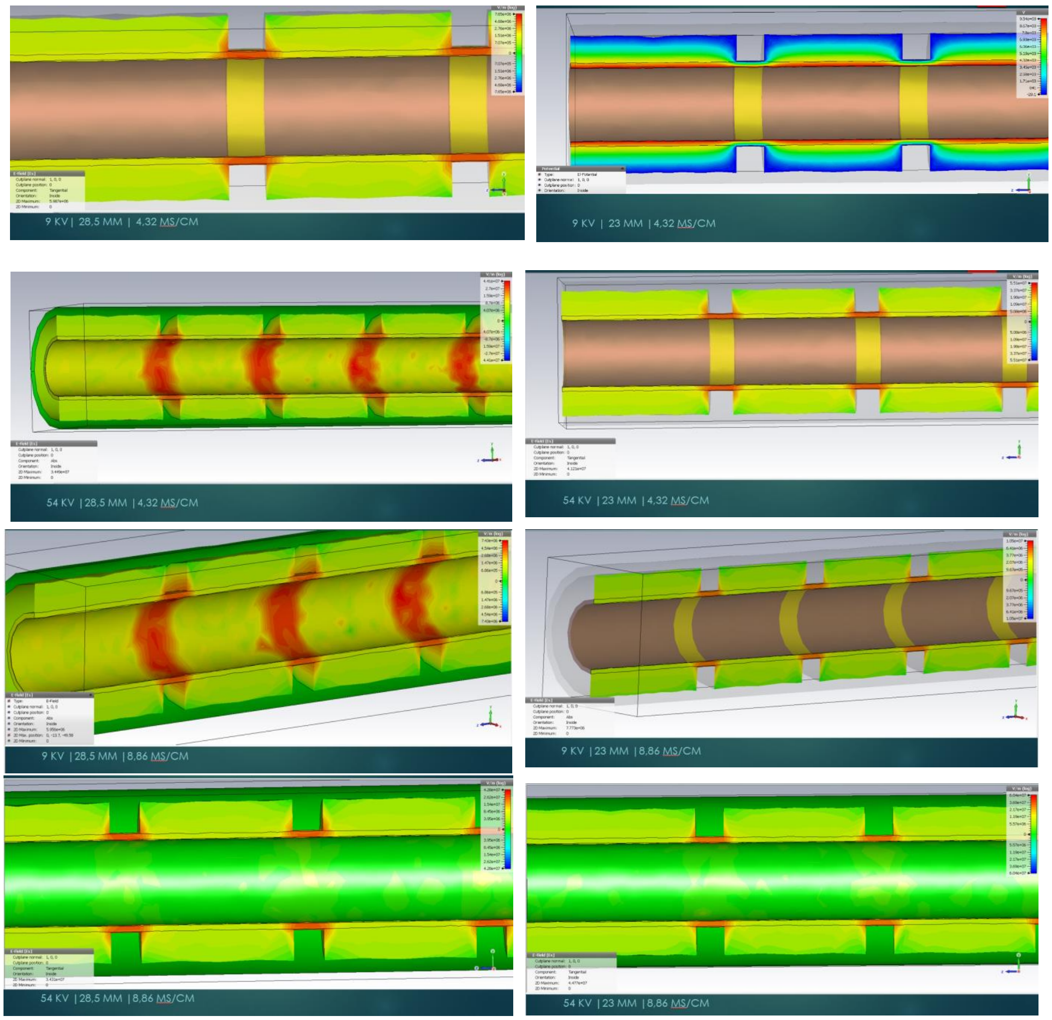

Figure 6. The E-field simulations with the value of 9 kV-54 kV voltages, 28.5 mm-23 mm electrode gap, and 4.32 mS/cm, 8.86 mS/cm

3.2. Results of WAS treatment

SCOD concentration reached maximum at 54 kV peak voltage applied to WAS in PEF system. Table 1 indicates SCOD concentration of PEF-treated WAS as comparing with raw WAS at different voltage studies. SCOD concentration was maximum at 32 kV effective (half-wave rectified 54 kV peak sinus PEF) voltage. This shown high treatment efficiency of raw sludge by

PEF system. The methane production of PEF treated sludge was found higher as compering with raw sludge. Figure 7 shows methane products for raw sludge and PEF-treated WAS.

The total methane productions were measured as 1960 ml and 2680 ml for WAS and PEF treated WAS, respectively, at the end of the 30 days of incubation. The methane production increased 1.36 fold the anaerobic digestion of PEF-treated sludge as compared with raw WAS. Also it can be understood that electric field may seem more insensitive around the rings. We can see the electric field value was 5.51e7 V/m with 54 kV voltages, 23 mm electrode gap, and 8.86 mS/cm. In these conditions we were able to reach maximum efficiency.

Consequently, the anaerobic digestive efficiency of PEF- treated sludge enhanged as compered with raw WAS without PEF pretreatment. This was a result of the reduction of large amount of retain organic matter in the excess sludge. The organic matter into PEF- treated sludge was easily converted to methane gas.

Although PEF treatment mechanism is understood fully, the arc discharge and electrical field produced from PEF process are considered to be effective on sludge treatment. When the high pulsed voltage applied to electrodes into sludge phase, pulsed high density electric field produces into PEF reactor. This electrical field provides break down of sludge cell and reduces complex organic solids to simpler organic solids. After PEF pretreatment of WAS, the formed soluble organic solids are quickly consumed by the methane-forming bacteria to utilize for biogas production. This will improve the performance of anaerobic digesters widely used at sludge treatment in the conventional wastewater treatment plant. Additionally, the enhanced of anaerobic digester performance will provide a reduction in the amount of waste in the wastewater treatment plant.

Table 1. SCOD concentration of PEF-treated WAS and raw WAS

Half-wave rectified effective PEF voltages (kV)	SCOD concentration (mg/l)	
	Raw sludge	PEF-pretreated sludge
6	320	320
12	320	325
18	320	335
24	320	380
30	320	440

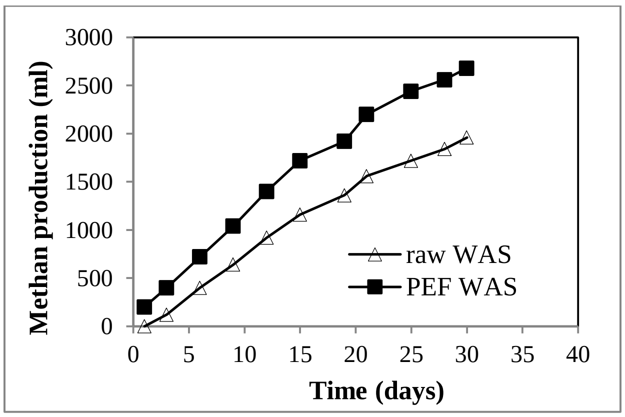

Figure 7. Methane production of raw WAS and PEF treated WAS in SMA test

Conclusions

The study showed that PEF system can be used effectively in sludge treatment. PEF system varies the sludge characteristics and enhances methane production. The strict environmental requirements have shown the need to minimize the waste sludge. Our study showed that PEF system is an important process to sludge minimization and enhancing methane production in wastewater treatment plant. PEF system was increased 1.36 fold the methane production of sludge in anaerobic digester. This case offered high energy efficiency and increasing the process efficiency.

Acknowledgements

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