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# The effects of the frequency and waveform of the activating current on physicochemical oxidation of organic wastes

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ABSTRACT

The study describes the process of organic waste mineralization in an $H_2O_2$ aqueous medium activated by alternating current, which is intended to enhance the cycling rates in closed life support systems (CLSS) for space missions. The focus of this study is the relationship between the energy consumption and duration of the process and oxidation level of organic wastes on the one hand and the frequency and waveform of the electric current activating $H_2O_2$ decomposition, on the other. Energy consumption and duration of the complete waste mineralization process have been reduced by about 17–18%. A physical model of the process and the applicability of the results for both space and terrestrial purposes have been discussed.



## 1. Introduction

Closed life support systems for long-duration space missions are being constructed in many countries (Liu et al., 2008; Souza et al., 2000; Hashimoto et al., 2007; Lasseur et al., 2010). One of the crucial issues that remain unresolved is the development of an effective and eco-friendly method for involving human wastes and inedible plant biomass in the material cycles in the system.

Over the past 15 years, researchers of the Institute of Biophysics SB RAS have made substantial progress toward a solution of this problem. One of the major achievements has been the development of an efficient physicochemical method of liquid-phase oxidation of human wastes and inedible plant biomass (wet combustion) (Kudenko and Zolotukhin, 2000). The method is based on waste oxidation in an $H_2O_2$ solution activated by alternating electric current. Hydrogen peroxide necessary for waste treatment can be produced in the system (Kolyagin et al., 2013). Liquids and gases produced by this method were used to grow plants in a number of experiments, which showed similar plant productivities in the control and treatment, within limits of error of measurement (Tikhomirov et al., 2012, 2011; Ushakova et al., 2012).

However, the process of organic waste oxidation in the reactor of the physicochemical system has not been properly optimized yet. Among other things, this process may be considerably influenced by the frequency and waveform (Fig. 1) of the activating current. Thus, the duration of the oxidation process, energy consumption, and the oxidation level of the end products may vary. That was confirmed by preliminary experiments in the initiation phase of oxidation reaction performed on organic wastes in a small-scale laboratory prototype of the system (Morozov et al., 2014a). Therefore, the purpose of this research was to study the full cycle of oxidation of organic wastes in a laboratory reactor for physicochemical oxidation as related to the frequency and waveform of the activating current.

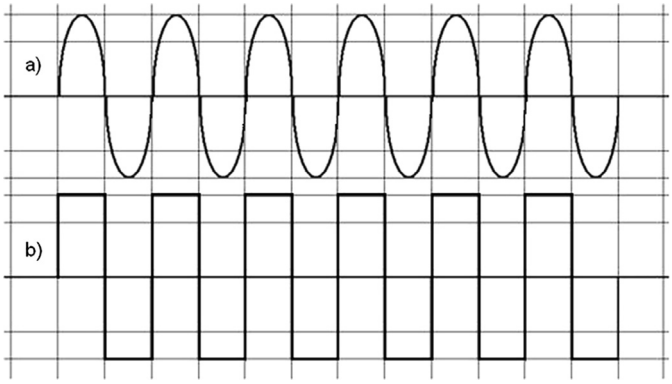


**Fig. 1.** Waveform: a) sinusoidal and b) meander.

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**Table 1**
The amount of $H_2O_2$ used to oxidize different types of organic wastes.

| Urine | Native solid waste |
|---|---|
| 0.5 ml $H_2O_2$ (33% w/w) per ml waste | 4 ml $H_2O_2$ (33% w/w) per g waste |

## 2. Material and methods

In this study, we used the method of "wet combustion" of organic wastes in the $H_2O_2$ medium activated by alternating current, whose step-by-step description and application were presented elsewhere (Kudenko and Pavlenko, 1998; Trifonov et al., 2014).

Approaches used to determine the optimal frequency and waveform of the current activating $H_2O_2$ decomposition were described by Morozov et al. (2014a). In a small volume (about 100 ml), in the initial reaction phase, the highest gas release rate was achieved at 35 Hz meander current (Fig. 1).

At 35 Hz, the gas release rate was twice higher than at 50 Hz; when the sinusoidal current waveform was replaced by the meander current, the gas release rate increased by about 10%. Based on these data, in this study, we estimated the effects of electric current parameters in four modes: 1) at 50 Hz sinusoidal current; 2) at 50 Hz meander current; 3) at 35 Hz sinusoidal current; and 4) at 35 Hz meander current.

Comparison of mineralization processes at different parameters of the activating current was done in a laboratory reactor that contained 1.25 L of the solution (2.2 L total volume), with the voltage of a preset frequency and waveform supplied from the system consisting of a G3-112 9 generator (Russia) and a DiGi 1050 amplifier (China). The use of the frequency optimization method was described in more detail in Morozov et al. (2014b).

Reaction rate was controlled by varying the voltage supplied to the electrodes. The process occurred in three phases: 1) initiation by high voltage (80 V) to speed up the reaction rate; 2) sustaining the process at a voltage reduced to 50 V, to avoid uncontrollable foaming, which could cause a reactor breach; and 3) a voltage increase to 80 V to accelerate the decomposition of $H_2O_2$ traces. The current varied during the reaction between 2 and 7 A.

The amount of $H_2O_2$ used for waste treatment is given in Table 1. Mineralization of human wastes was conducted in 24 h after they were mixed with $H_2O_2$ (the initial $H_2O_2$ concentration in the mixture was 8% w/w). The process was over when no foam was formed, as the absence of foam indirectly indicates the absence of large amounts of under-oxidized organics. Titration with potassium permanganate was used to ascertain that there was no hydrogen peroxide left. After mineralization, we measured COD (chemical oxygen demand) of the solutions to evaluate the quality of the end product by its oxidation level.

Oxidation of organic waste in $H_2O_2$ proceeds via a radical chain mechanism, and alternating current speeds up the formation of such radicals as O• and OH•, which trigger the chains of oxidation reactions. However, as the reaction proceeds, the number of organic radicals increases considerably, and the importance of the electric current for sustaining the reaction decreases. This is the reason why we reduce the voltage when the process is being sustained. If the mixture of the aqueous solution of $H_2O_2$ and organic waste has been kept for a long time, the solution contains many organic radicals. Thus, in order to get better insight into the mechanism of the influence of electric current parameters on the process of waste mineralization, we studied the effects of different parameters in a month after the wastes were mixed with $H_2O_2$. In those experiments, we used solutions of human wastes prepared simultaneously with the solutions used in mineralization experiments conducted in 24 h after mixing.

In all experiments, we used identical amounts of $H_2O_2$, and its efficiency was determined by COD.

**Table 2**
Comparison of duration of the organic waste oxidation process and energy consumption by this process at different parameters of the activating current in 24 h after preparation of the mixture.

| | 35 Hz meander | 35 Hz sinusoid | 50 Hz meander | 50 Hz sinusoid |
|---|---|---|---|---|
| Process duration, min | 115 | 123 | 132 | 141 |
| Energy consumed, kW h | 0.599 | 0.645 | 0.664 | 0.724 |
| COD, g/L | 2.589 | 2.995 | 2.746 | 2.933 |

**Table 3**
Comparison of duration of the organic waste oxidation process and energy consumption by this process at different parameters of the activating current in 30 d after preparation of the mixture.

| | 35 Hz meander | 35 Hz sinusoid | 50 Hz sinusoid |
|---|---|---|---|
| Process duration, min | 93 | 94 | 95 |
| Energy consumed, kW h | 0.487 | 0.477 | 0.484 |
| COD, g/L | 2.746 | 2.81 | 2.995 |

Energy consumption by the complete process of activation was calculated by using the formula

$$W = \sum_i U_i \cdot I_i \cdot \Delta t_i,$$

where $W$ is total energy consumption, $t_i$ is a point on the time axis (recorded every 5–10 min), $U_i$ is the voltage at the time at which a given measurement is performed, and $I_i$ is the current at the time at which a given measurement is performed.

## 3. Results

Two series of experiments were carried out to study the effects of electric current parameters on the process of human waste mineralization: 1) waste mineralization in 24 h after the waste was mixed with $H_2O_2$ and 2) waste mineralization in 30 days after the waste was mixed with $H_2O_2$. Results of thee series of experiments are given in Tables 2 and 3, respectively.

The accuracy of COD measurement was within the range of 10%; the difference in energy consumption and duration of the process between replicates was no more than 7%; the theoretical initial COD of the wastes was 20.1 g/L; the volume of the wastes mixed with $H_2O_2$ was 1.25 L (0.42 of the daily waste per human).

The values of COD of the solutions were suitable for growing plants (Ushakova et al., 2012), whereas further raising of the mineralization level would require too much energy, time, and hydrogen peroxide.

As can be seen from the data in Table 2, in experiments with mineralization carried out in 24 h after preparation of the solutions, the change of the parameters of the activating current from the 50 Hz sinusoid to the 35 Hz meander saved 18% time and 17% energy.

The accuracy of COD measurement was within the range of 10%; the difference in energy consumption and duration of the process between replicates was no more than 7%; the volume of the wastes mixed with $H_2O_2$ was 1.25 L (0.42 of the daily waste per human).

Table 3 shows that after 30 days, the difference between the effects produced by the electric current modes used to activate $H_2O_2$ becomes negligible. There are no significant differences in process parameters between modes. The process rate and complete energy consumption after 30 days were about 33% lower than the corresponding parameters recorded in the process of waste mineralization in 24 h after the waste was mixed with $H_2O_2$.

As can be seen from Tables 2 and 3, differences between COD values in all experiments are non-significant. Thus, under the opti-