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Research paper

The use of urban sewage sludge as a substrate in a microbial fuel cell

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Abstract

The possibility of using urban sewage sludge from the silt areas of the sewage treatment facilities of the left bank of Irkutsk as a substratum in microbial fuel cells (MFC) was studied. The characteristics of voltage and current intensity generated by the microbiological preparation "Doctor Robik 109" in MFC without taking into account and taking into account the resistance of the external electric circuit are obtained. It is shown that sewage sludge with the addition of peptone and acetate (without the introduction of microorganisms-bioagents) is also capable of generating electricity. Presumably, this is due to the presence in the sewage sludge of a large number of microorganisms and their spores. An increase in the total microbial number in the investigated wastewater sediments supports the above hypothesis. The carried out researches testify to the prospects of using MFC for municipal sewage sludge utilization.

Keywords: *excess sludge, microbiological preparations, microbial fuel cell, municipal wastewater, sewage sludge.*

1. Introduction

Sewage volumes increase due to population growth, agglomeration of populated areas, construction of industrial facilities, development of sewerage systems. Huge volumes of excess active sludge are formed during biological treatment of domestic sewage water in sewage treatment plants. For example, the design capacity of sewage treatment facilities on the left riverside of the city of Irkutsk is 170.000 m^3/day. In this case, the actual volumes of pumped excess sludge, varies within the range of 150-180 m^3/day. The sludge is transported to sludge ponds in the form of a wet cake. Excess activated sludge is one of the major sources of soil pollution, groundwater and air [2, 3, 4, 5, 7, 8, 9]. At the same time, it is rich in various organic and inorganic substances. Therefore, the search for ways to use sewage sludge in the technological scheme of sewage treatment plants is an important task. It is assumed that the use of microbial fuel cells (MFC) will not only eliminate sludge, but also generate electrical energy, using them as a substrate for microorganisms [6, 12].

2. Materials and methods of research

In the conducted experiments, a sewage sludge was used from the secondary settling tanks of sewage biological treatment facilities for treatment of domestic wastewater. It was taken from silt areas, sewage treatment plants on the left bank of the city of Irkutsk. The composition of the sewage sludge is given in Table 1.

Table 1: The composition of the sewage sludge from the silt areas of sewage treatment facilities on the left bank of the city of Irkutsk

The indicator studied	Normative document (ND) on test methods	The value of the indicator under study	The standard in accordance with the relevant ND
Moisture content,%	GOST* 26713-85	32.0+/- 0.26	Not more than 70
pH	GOST 27979-88	5.8+/- 0.3	6.0-8.0
mass fraction of total nitrogen,%	GOST 26715-85	1.6+/- 0.2	Not less than 0.6
mass fraction of total phosphorus,%	GOST 26717-85	1.8+/- 0.1	Not less than 0.7
mass fraction of total potassium,%	GOST 26718-85	0.32+/- 0.03	Not less than 0.1
mass fraction of total organic matter,%	GOST 27980-88	17.0+/- 0.3	Not less than 30.0
Gross form of copper mg / kg	GOST P 53218-2008	175.0+/- 36.8	Not more than 750.0
Gross form of zinc, mg / kg		243.0+/- 51.0	Not more than 1750.0
Gross form of nickel, mg / kg		70.5+/- 24.7	Not more than 200.0
Gross form of cadmium, mg / kg		5.5+/- 1.9	Not more than 15.0
Gross form of lead, mg / kg		94.0+/- 32.9	Not more than 250
Mercury, mg / kg	MG**	1.69+/- 0.3	Not more than 7.5
Arsenic, mg / kg	MG***	2.75+/- 0.69	Not more than 10.0

GOST* (Russian: ГОСТ) – Government Standard, State Standard, Russian National Standard; MG** – Methodical guidelines for the determination of heavy metals in soils of agricultural lands and plant growing products. Ministry of Agriculture, CINAO, M 1992; MG*** – Methodical guidelines for the determination of arsenic in soils using the photometric method, CINAO, M 1993

Investigation of the processes of generation of electricity by microorganisms in the utilization of sewage sludge was carried out using models of MFC [1]. It is a two-chamber structure made of plexiglas (Plexiglas XT 20070, 3 mm). The volume of each chamber is 350 ml.

The anode chamber has an opening for receiving the working electrode. It is sealed and prevents oxygen from entering the chamber. The second chamber (cathode) has 2 holes. One hole is necessary to accommodate the working electrode. The second hole serves to aerate the catholyte (fig. 1).

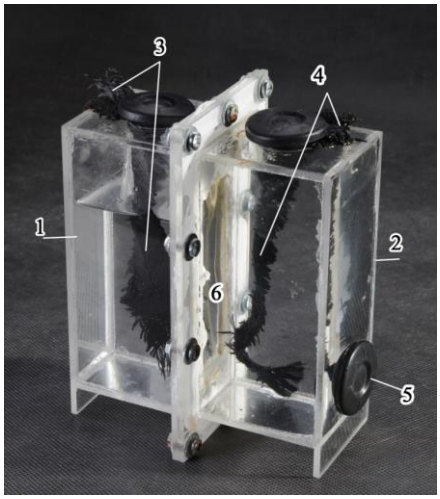

Fig. 1: Model of the microbial fuel cell [1]. 1 – cathode chamber, 2 – anode chamber, 3 – cathode electrode of carbon cloth, 4 – anode electrode of carbon cloth, 5 – a cap made of polypropylene rubber for sampling anolyte, 6 – proton exchange membrane "MF-4SK" (JSC Plastpolymer, Russia)

As the cathode and anode electrodes, carbon fabric «URAL T-22P A» (OJSC "Svetlogorsk Khimvolokno", Belarus) was used in the studies. It was cut into strips measuring 16 × 4 cm. One of the ends of the fabric was passed through a hole in the rubber plug, by means of which the electrode was sealed in the MFC chamber. Connect the measuring wires to the end of the carbon-electrode electrode located outside the MFC (fig. 2).

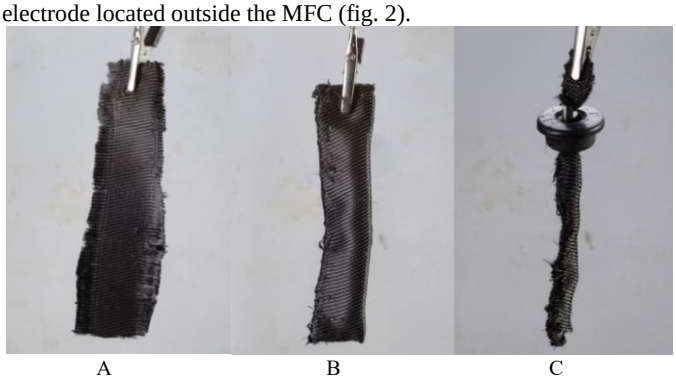

Fig. 2: Electrode from carbon fabric URAL T - 22R A (JSC "Svetlogorskkhimvolokno", Republic of Belarus). A – a strip of carbon cloth measuring 16 × 4 cm; B – flashing carbon fiber to reduce the shedding of carbon fibers; C – fixing a strip of carbon cloth in a rubber stopper, which secures the electrode in the MFC.

The microbiological preparation "Doctor Robik 109" was used as bioagents for the operation of the MFC based on sewage sludge. It is designed for cleaning cesspools and septic tanks (LLC VIPEKO, Russia). This is an effective composition of 4 specially selected spore cultures of soil microorganisms of the genus *Bacillus*. Strains, which are part of this drug, are able to utilize fats, proteins, starch, cellulose, urea. Earlier, we showed the electrogenic activity of this microbial consortium in MFC in the utilization of plant mass [10], peptone [13], glucose [14].

To study the dynamics of the electrical characteristics of the MFC, model wastewater was poured into the cathode and anode cells [11]. The anode chamber was filled completely, to maximally completely expel oxygen from the chamber. The cathode chamber of the MFC was filled 2-3 cm below the upper level of the MFC. The catholyte was aerated with air using laboratory microcompressors Dezzie D-044 (China). The bioagent (studied microbiological preparations (~ 104-105 cfu / ml)) and the substrate (sewage sludge of 50 g / l) were placed in the anode chamber of the MFC. The current in the MFC was recorded with a digital multimeter "DT-266". The voltage was measured using an automatic data recording system based on the microprocessor board "Arduino Mega 2560" [11].

All experiments were carried out in at least 5 independent experiments with 3 parallel measurements in each. Statistical processing of the experimental data was carried out using the Excel software package. The results represent the average values for the sample and their standard deviations. The conclusions are made with the probability of an error-free forecast $P \geq 0.95$.

3. Results and discussion

In experiments in which the bioagent was the microbiological preparation "Doctor Robik 109", for 6 days of incubation it was possible to achieve a stable voltage production. The voltage of the open circuit increased to 595.6 ± 25.3 mV, the current strength in the short-circuit mode was up to 600.9 ± 29.8 μA. When measuring with an external resistance of 1 kΩ, the parameters studied were 300.0 ± 16.1 mV and 212.0 ± 15.2 μA, respectively, for 6 days of incubation (fig. 3, 4).

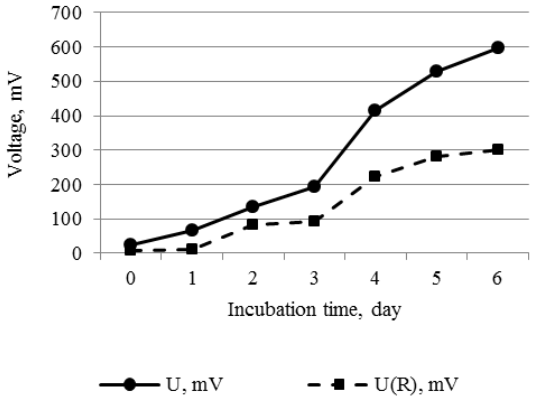

Fig. 3: Dynamics of voltage generated in the MFC by the microbiological preparation "Doctor Robik 109K" using sewage sludge as a substrate (U – measurement of the indices without external resistance; U (R) – the measurement was made at a resistance of 1 kΩ)

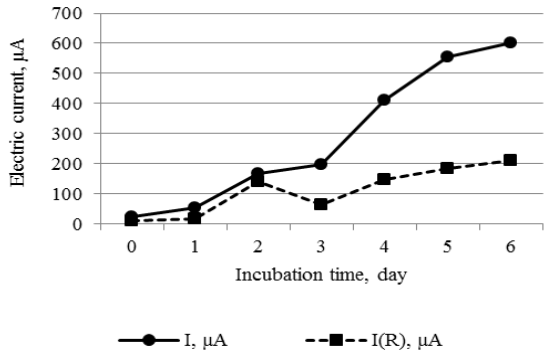

Fig. 4: Dynamics of current intensity generated in the MFC by the microbiological preparation "Doctor Robik 109K" using sewage sludge as a substrate (I – measurement of the indices without external resistance; I (R) – the measurement was made at a resistance of 1 kΩ)

The obtained data testified to the ability of sewage sludge to serve as a substrate for the microorganisms that make up the microbiological preparation used.

We hypothesized that the sewage sludge itself contains microorganisms and their spores. Therefore, they can be activated and produce electrical energy by adding water and missing nutrients, using the introduced substrate as a power source. Confirmation of this can be seen in an increase in the total microbial number in MFC with sediment without the addition of a microbiological preparation during exposure (Table 2).

Table 2: The dynamics of the number of microorganisms of sewage sludge and the drug "Doctor Robik 109" with their incubation in MFE for 7 days

Option of experience	The number of viable cells of microorganisms, CFU / ml	
	0 day	7 day
sewage sludge	$(2.11\pm0.35)\cdot10^4$	$(1.20\pm0.83)\cdot10^7$
sewage sludge + a drug "Doctor Robik 109"	$(1.25\pm0.02)\cdot10^5$	$(1.46\pm0.76)\cdot10^8$

The lack of organic nitrogen is one of the possible reasons for stopping the destruction of organic matter in sewage sludge. This is confirmed by the materials presented in fig. 4. Experiments have shown that when peptone was added to sewage sludge in MFC, a significant voltage increase occurred – up to 568.0 mV for 4 days of incubation. At the same time, the introduction of sodium acetate slightly increased the voltage in the MFC – only up to 150.1 mV. With a high degree of probability, we can say that the result is due to the absence of nitrogen (fig. 5, 6).

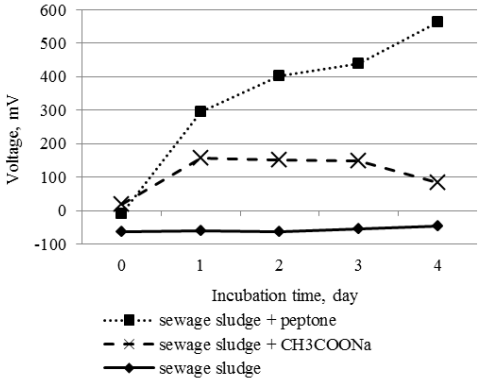

Fig. 5: Dynamics of the voltage generated by the microorganisms of sewage sludge in microorganisms during the utilization of peptone and sodium acetate (medium is model wastewater, the amount of wastewater introduced into the anolyte is 50 g / l, the concentration of peptone and CH_3COONa is 0.15 g / l)

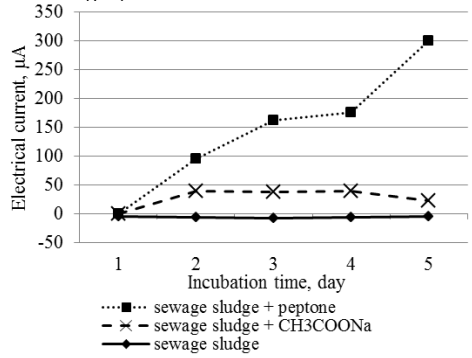

Fig. 6: Dynamics of the current intensity generated by the microorganisms of sewage sludge in microorganisms during the utilization of peptone and sodium acetate (medium is model wastewater, the amount of wastewater introduced into the anolyte is 50 g / l, the concentration of peptone and CH_3COONa is 0.15 g / l)

3. Conclusion

Thus, microbial fuel cells based on sewage sludge can stably generate electricity. In this case, the microbiological preparation "Doctor Robik 109" is a promising bioagent. It is important that the technology of microbial fuel cells is an effective method for solving the most serious environmental problem in the work of biological treatment facilities – the utilization of sewage sludge. Microorganisms and spores that persist in sewage sludge, when added to MFC substrates, are also capable of oxidizing them with parallel generation of electricity.

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