

Waste water treatment by exoelectrogenic bacteria isolated from technogenically transformed lands

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Abstract. The capacity of sulfur-reducing bacteria *Desulfuromonas acetoxidans* IMV B-7384, *Geobacter* sp. CB35 and *Desulfuromusa* sp. CB30 and green photosynthesizing bacteria *Chlorobium limicola* IMV K-8 for exoelectrogenesis was investigated during their growth in wastewater of industrial and municipal origin. The strains of exoelectrogens, which are characterized by resistance to heavy metal ions, were isolated from the man-made Yavorivske lake located in the Lviv Oblast in Ukraine (*D. acetoxidans* IMV-7384, *Ch. limicola* IMV K-8) and mine waste heaps of the Chervonohrad mining industry region (*Geobacter* sp. CB 30 and *Desulfuromusa* sp. CB 35). Bacteria *D. acetoxidans* IMB B-7384 proved to be the most effective exoelectrogens. The power density of a microbial fuel cell (MFC) with the application of *D. acetoxidans* IMV B-7384 and the infiltrate of the Lviv solid waste landfill was 2.0 ± 0.05 W/m² and the reduction of chemical oxygen demand of wastewater was 99%. The new approach to improving the MFC performance was investigated. It includes a combination of phototrophic microorganisms *Ch. limicola* and heterotrophic microorganisms, which reduce the content of nitrates, nitrites, ammonia, sulfates, sulfites, hydrogen sulfide, while simultaneously generating electric current.

Key words: wastewater, bioremediation, microbial fuel cell, bacteria-exoelectrogens.

1. Introduction

Wastewater has an energy potential due to the high concentration of bioconversion organic compounds (Do et al., 2018). Among the most polluted waste industries is the waste of alcoholic production plants that characterizes by low pH, high temperature, high ash content, dissolved organic and inorganic substances, high biochemical oxygen demand (BOD) and chemical oxygen demand (COD). High amounts of COD and BOD results in high content of organic compounds, in particular, polysaccharides, reducing sugars, lignin, proteins, melanoidins etc (Kharayat,

2012). Yeast production plants also produce significant amounts of wastewater containing high concentrations of nitrogen compounds (Włodarczyk B & Włodarczyk P., 2017). Infiltrates of lakes of solid waste landfills are as well the source of chemical and biological environment contamination. It may be compared with the poisonous herbicides by the content of carcinogens (Sereda, 2018). The issues of infiltrates purification of solid waste landfills are considered during design, operation and planned closure of these facilities. The infiltrates of lakes of Lviv solid waste landfills contain heavy metal ions, ammonium compounds, phenol and chlorine, which concentrations

considerably exceed the maximum permissible limits (Sereda, 2018).

Application of microbial fuel cells (MFC) is promising for bioremediation of wastewater of municipal, domestic or industrial origin with the simultaneous generation of electric current (Do et al., 2018). MFC provides bioconversion of substances with simultaneous formation of electric current (Dowdy et al., 2017). This technology is characterized by the absence of necessity of active sludge excess, which is an advantage over other methods of bioremediation e.g. application of active sludge or methane-tanks (He et al., 2017; Santoro et al., 2017; Gajda et al., 2018). There are known investigations of application of various origins wastewater for electric current generation in an MFC, in particular domestic wastewater, sewage of pig farms, food industry, brewery (Chaturvedi & Verma, 2016; Tharali et al., 2016). Complex substrates of wastewaters of various origins may cause difficulties for electric current generation by microorganisms-exoelectrogens in comparison with pure substrates, e.g. while use of acetate, butyrate or propionate. In addition, wastewater contains high concentrations of ammonium compounds, heavy metals and other toxic substances that may cause a detrimental effect on microorganism cells (Chaturvedi & Verma, 2016; Tharali et al., 2016). With the purpose of water and soils bioremediation that are contaminated by heavy metal compounds and other xenobiotics, it is important to use bacteria strains that were isolated from man-made environments and possesses such properties, as psychrotolerance, resistance to high concentrations of hydrogen sulfide, nitrates, nitrites, sulfates, heavy metals and others. The search for strains, which are resistant to the components of wastewaters and capable to electric current generation while bioconversion of these substrates, discovers the new avenues for improvement of MFC technology.

Several groups of bacteria that belong to classes *Alfa-*, *Beta-*, *Gamma-* and *Deltaproteobacteria* are characterized by exoelectrogenic properties. A significant number of exoelectrogenic strains supports sulfur cycle (Logan, 2009). Sulfur-reducing bacteria *Desulfuromonas acetoxidans* are among the first investigated microorganisms that possesses exoelectrogenic properties. A characteristic feature of *D. acetoxidans* is their ability to oxidize organic compounds in tricarboxylic acids cycle with simultaneous reduction of extracellular electron acceptors, in particular, Fe (III) ions (Vasyliiv, 2013; Maslovska, 2017). The strain *Desulfuromonas acetoxidans* IMV B-7384 was isolated from anthropogenous-created lake Yavorivske as the result of flooding of the sulfur quarry territory (Lviv Oblast, Ukraine). *D. acetoxidans* IMV B-7384 possesses resistance to the influence of heavy metal ions, in particular, ferrum, cooper, cobalt and nickel in concentrations that exceeds the allowable

maximum (Vasyliiv, 2013). This bacterium also capable to oxidize organic compounds (acetate, higher fatty acids, propionate and others) with simultaneous sulfur reduction (Gudz et al., 2013). Such properties of *D. acetoxidans* IMV B-7384 provide its prospect for being used as the effective anode biocatalyst in MFC with simultaneous wastewater pollution control. Isolated from coal pit waste heaps of the mines of Chervonohrad mining region sulfur-reducing bacteria *Desulfuromusa* sp. CB30 and *Geobacter* sp. CB35 carry out dissimilatory sulfur-, nitrate-, nitrite- and metal-reduction while oxidation of various organic substrates. These strains reduce Mn (IV), Cr (VI), Cu (II) and Fe (III) and are resistant to Cr (III)- and Cr (VI)-compounds (Diakiv et al., 2017). Taking into consideration the physiological and biochemical properties of these strains, we assume that they are capable to exoelectrogenesis. Sulfur-reducing bacteria *D. acetoxidans* are often found in consortium with green photosynthetic bacteria *Chlorobium limicola* that are also characterized by exoelectrogenic properties (Badamenti, 2013). Green photosynthetic bacteria *Chlorobium limicola* IMV K-8 are producers of glycogen (Patent of Ukraine, 2011) and pigments. Produced glycogen as a result of photosynthesis may subsequently be a substrate for electric current generation by exoelectrogenic bacteria.

Therefore the aim of work was to investigate the electric current generation by bacteria-exoelectrogens, which were isolated from technogenically transformed territories, while growth in wastewater of industrial and municipal origin.

2. Material and methods

2.1. Microorganisms

The ability to exoelectrogenesis of bacteria, which were isolated from technogenically transformed territories, has been investigated while its growth in the infiltrate of Lviv solid waste landfill and in wastewater from the yeast and alcohol production plants. The strains-exoelectrogens were isolated from an anthropogenous-created Yavorivske lake (Lviv Oblast, Ukraine) (*Desulfuromonas acetoxidans* IMV B-7384, *Chlorobium limicola* IMV K-8) and coal pit waste heaps of the mines of Chervonohrad mining region (*Geobacter* sp. CB 30 and *Desulfuromusa* sp. CB 35) and identified by the staff of Department of Microbiology of Ivan Franko National University of Lviv (Diakiv et al., 2017).

2.2. Microbial fuel cell

In this work the one-chamber microbial fuel cell was applied. It consisted of the anode chamber (50 ml) that was inserted into the cathode chamber (250 ml) and

separated by the proton-exchange membrane (Millipore, pore size: 0.20 μm , 44 cm^2). 0.1% solution of KMnO_4 was used as the catolyte. As the anolyte bacterial suspensions of *D. acetoxidans* IMV B-7384, *Geobacter* sp. CB 30, *Desulfuromusa* sp. CB 35 and *Ch. limicola* IMV K-8 at the exponential phase of growth with an initial biomass 0.2 g/l were separately applied. Wastewater of various origins, such as yeast factory and alcoholic production plant, and infiltrate of Lviv solid waste landfill, diluted by 10 times with distilled water, were separately added into the MFC anode chamber with the aim to investigate electric current generation by investigated bacteria. Study of exoelectrogenic properties of applied bacteria species at MFC was carried out under anaerobic conditions and temperature +28...+30°C during 5-15 days.

2.3. Measurement of chemical oxygen demand and inorganic compounds content

COD was determined according to (Wang & Dong, 2018). BOD and inorganic compounds content were determined

by the method (Methods for chemical analysis of water and wastes, 1983; ISO 17381:2003; Protocol for the Sampling and Analysis Of Industrial/Municipal Wastewater, 2016).

The ability of microorganisms to form a biofilm on the electrode surface was determined by scanning electron microscopy (scanning electron microscope JEOL JSM-T220A).

2.4. Statistic processing of results

Experiments were repeated three times with three parallel formulations for each variant of experimental and control conditions. The obtained data were processed by generally accepted methods of variation statistics. The reliability of the difference was evaluated by using ANOVA. Differences between the samples were considered reliable at $P < 0.05$.

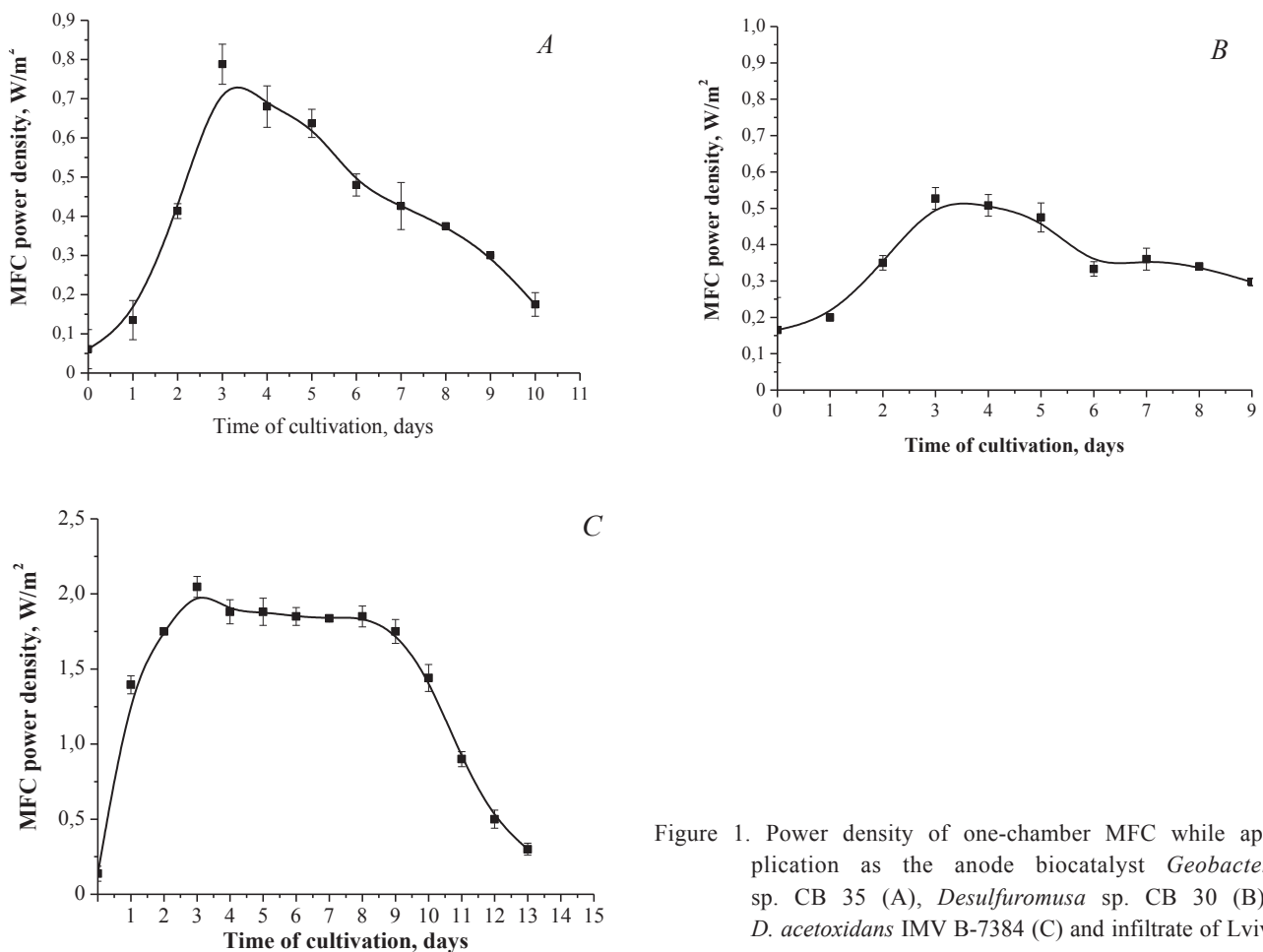


Figure 1. Power density of one-chamber MFC while application as the anode biocatalyst *Geobacter* sp. CB 35 (A), *Desulfuromusa* sp. CB 30 (B), *D. acetoxidans* IMV B-7384 (C) and infiltrate of Lviv solid waste landfill

3. Results and discussion

3.1. Electric current generation by sulfur-reducing bacteria-exoelectrogenes while growing on infiltrate of solid waste landfill

It has been determined that *Geobacter* sp. CB 30, *Desulfuromusa* sp. CB 35 and *D. acetoxidans* IMV B-7384 are capable to generate electric current while growth on infiltrate of Lviv solid waste landfill (Fig. 1). The highest MFC power density was observed while application of *D. acetoxidans* IMV B-7384 bacteria. Its maximum value (2.0 ± 0.05 W/m²) was obtained during the third day of bacteria growth. MFC power density slightly decreased with increase of duration of *D. acetoxidans* IMV B-7384 cultivation, but remained stable for 10 days.

Power density of one-chamber MFC while *Geobacter* sp. CB 35 and *Desulfuromusa* sp. CB 30 growth on infiltrate of Lviv solid waste landfill was lower by 2.5 and 3.5 times respectively.

3.2. Electric current generation by *Desulfuromonas acetoxidans* IMV B-7384 while growing on wastewater of yeast production plant

It was determined that *D. acetoxidans* IMV B-7384 is capable to generate electric current in MFC while growth on wastewater of yeast production plant (Fig. 2).

The highest MFC power density was observed on the third day of bacterial cultivation. MFC power density

decreased by 26% compared to maximum value, but was stable during 4-9 days of bacterial cultivation at these conditions.

The chemical composition of wastewater of yeast production plant after incubation in MFC with *D. acetoxidans* IMV B-7384 as the anode biocatalyst has been determined after 12 days of cultivation (Table 1).

The content of organic and inorganic compounds of wastewater of yeast production plant significantly changed after its incubation in MFC with application of *D. acetoxidans* IMV B-7384. The content of SO₄²⁻, SO₃²⁻, S⁰, NO₃⁻, NO₂⁻ and others decreased during twelve days of bacteria incubation. Since *D. acetoxidans* IMV B-7384 are sulfur-reducing microorganisms, therefore decrease of S⁰ content was probably due to the process of sulfur-reduction carried out by these bacteria. It is known that *D. acetoxidans* IMV B-7384 do not use SO₄²⁻ and SO₃²⁻ as electron acceptors during dissimilatory sulfate-reduction (Vasyliiv, 2013). Further studies are needed to determine the biochemical processes that cause decrease of these anions content in wastewater of yeast production plant after *D. acetoxidans* IMV B-7384 incubation in MFC. However, we assume that *D. acetoxidans* IMV B-7384 can use SO₄²⁻ and SO₃²⁻ in the process of assimilatory sulfur-reduction.

Significant decrease in NO₃⁻ and NO₂⁻ content may occur as the result of nitrate or nitrite respiration carried out by these bacteria. Also, NO₃⁻ and NO₂⁻ may be assimilated by bacteria *D. acetoxidans* IMV B-7384 in the processes of assimilatory nitrate- and nitrite-reduction.

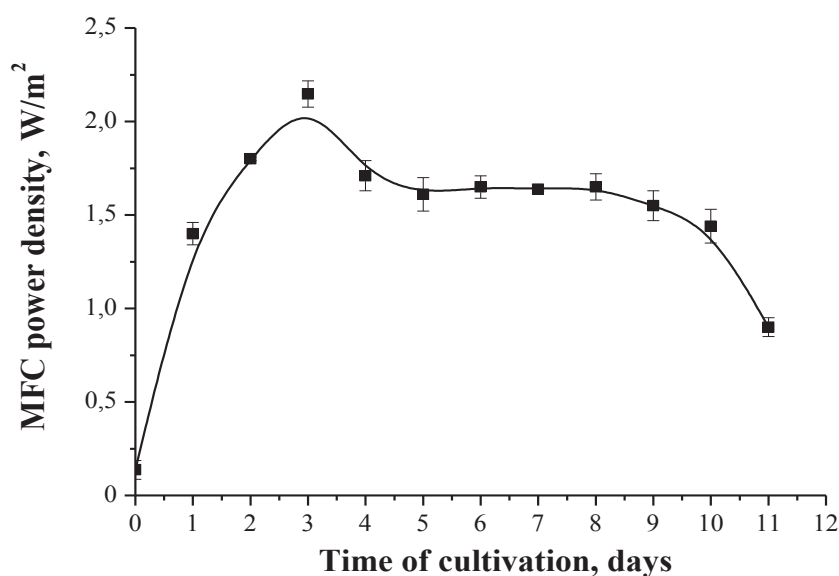


Figure 2. Power density of one-chamber MFC while application of *D. acetoxidans* IMV B-7384 as the anode biocatalyst and wastewater of yeast production plant

Table 1. The content of wastewater of yeast production plant after *D. acetoxidans* IMV B-7384 cultivation in MFC

Index	Content of wastewater compounds, g/l	
	before cultivation	after cultivation
HCO ₃ ⁻	9.8±0.4	14.6±0.2
CO ₃ ²⁻	9.6±0.03	7.4±0.02
Mg ²⁺	7.3±0.3	0.9±0.04
SO ₄ ²⁻	30.3±0.6	2.8±0.1
SO ₃ ²⁻	25.9±0.5	2.4±0.1
S ⁰	20.2±0.5	1.8±0.02
H ₂ S	21.5±0.4	1.0±0.02
NO ₃ ⁻	2.7±0.02	1.3±0.02
NO ₂ ⁻	2.0±0.03	0.9±0.01
P ₂ O ₅	1.1±0.03	1.7±0.02
PO ₄ ³⁻	0.8±0.01	1.2±0.01
P _i	0.2±0.01	0.4±0.01
NH ₄ ⁻	0.5±0.01	1.7±0.02
Fe ²⁺	0.006±0.0001	0.016±0.001
Fe ³⁺	0.004±0.0001	0.066±0.002
Organics content, %	78.4±0.4	25.6±0.3
Conductivity, mS	46±0.2	66±0.8
Dry residue	128.0±0.4	63.0±0.3
COD, g O ₂ /l	240.0±0.4	1.2±0.04
BOD, mg O ₂ /l	40.0±0.4	7.2±0.02

The electrical conductivity of wastewater significantly decreased after its incubation in MFC, which probably indicates on decrease of organic and inorganic substances content. Important indicators of wastewater indices are COD, BOD and total organic compounds content. After *D. acetoxidans* IMV B-7384 cultivation in MFC with wastewater of yeast production plant COD decreased by 200 times, BOD by 5.5 times, and organic compounds content decreased by 3 times. At these conditions the content of HCO₃⁻/CO₃²⁻ significantly increased, which probably indicates on complete oxidation of organic compounds by investigated bacteria.

The increase of electric current value while reduction of organic compounds content during growth of *D. acetoxidans* IMV B-7384 bacteria probably indicates on oxidation of organic matter to CO₂. As the result released

electrons are transported to the electrode of MFC, which is the final electron acceptor.

Three pathways by which electrons are transferred to an electrode are known so far. They include transport by artificial mediators, by endogenous microorganism mediators and by direct contact with the electrode surface (Shrivastava & Bundela, 2013). *D. acetoxidans* IMV B-7384 formed biofilm on the electrode surface while growing on wastewater of yeast production plant in MFC (Fig. 3). Formation of biofilm by *D. acetoxidans* IMV B-7384 bacteria may cause electrons transfer by cytochromes from reduced equivalents to the electrode surface in MFC.

3.3. Application of green photosynthesis bacteria for electric current generation while growing in wastewater

Anoxygenic phototropic bacteria cause a major role in functioning of biogeochemical cycles and provides transformation of light energy into chemical energy in the process of photosynthesis. Photosynthetic MFC is promising biotechnology that shows avenues in purification of contaminated areas with simultaneous electric current generation (Badalamenti, 2014; Qi et al., 2018). The ability to generate electric current by *Ch. limicola* IMV K-8 bacterium was investigated. These bacteria were cultivated in MFC on GSB medium, which contained Na_2CO_3 as a source of CO_2 , sodium pyruvate and sodium acetate as additional sources of carbon. As a result of carried out research it was determined that the maximum MFC power density was $1.2 \pm 0.07 \text{ W/m}^2$ on the seventh day of *Ch. limicola* IMV K-8 cultivation (Fig. 4). The maximum value of electric current was observed from sixth to eighth days of investigated bacteria cultivation. MFC power density equaled $0.90 \pm 0.05 \text{ W/m}^2$ on the eighth day of *Ch. limicola* IMV K-8 cultivation in MFC and gradually decreased with an increase of cultivation duration.

It is known that *C. limicola* IMV K-8 are photosynthetic bacteria that are capable to glycogen synthesis at the

presence of light (Patent of Ukraine, 2011). Synthesized glycogen by *Ch. limicola* IMV K-8 while photosynthesis is hydrolyzed to glucose at the absence of light and can be metabolized to acetate, which may serve as a substrate for exoelectrogenic bacteria. *Ch. limicola* IMV K-8 bacteria were grown during 20 days on the wastewater of yeast production plant. Then *Geobacter* CB35 with primary biomass 0.3 g/l was added to obtained *Ch. limicola* IMV K-8 bacterial culture. Obtained co-culture together with the wastewater of yeast production plant was added into the anode chamber of MFC. Generated power density equaled $0.95 \pm 0.05 \text{ W/m}^2$ after 2 days of co-culture growth. It's value decreased while further cultivation, however, on the seventh day of growth it increased up to $0.92\text{--}0.95 \text{ W/m}^2$ and remained stable for the next two days. We assume that *Ch. limicola* IMV K-8 bacteria and *Geobacter* CB35 oxidize available organic compounds contained in wastewater during six days of growth. The hydrolysis of glycogen, which was accumulated during the photosynthesis of *Ch. limicola* IMV K-8, occurred when content of these compounds reduced. Obtained results require more detailed further investigation and, in particular, determination the glycogen concentration in the cells of investigated bacteria.

We assume that *Ch. limicola* bacteria IMV K-8 are able to metabolize compounds contained in wastewater

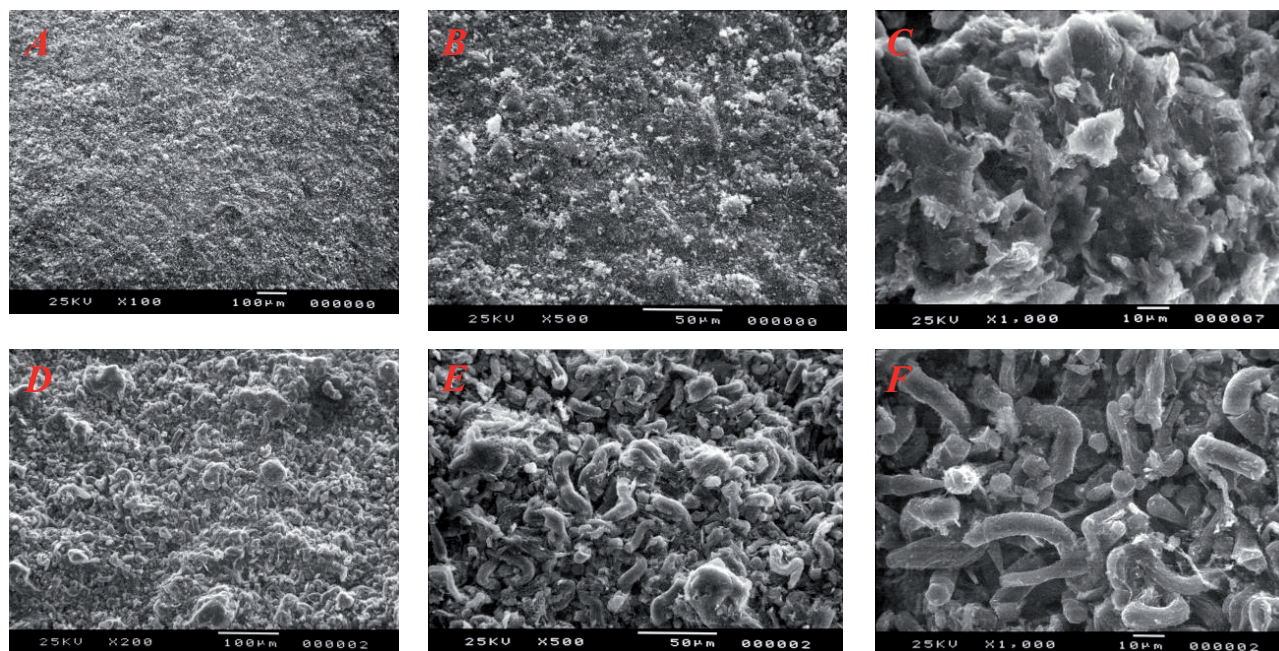


Figure 3. Biofilm formation by *D. acetoxidans* IMV B-7384 bacteria on the electrode surface in MFC while growth on yeast production plant wastewater (A, B, C – electrode surface before bacteria cultivation in MFC anode chamber; D, E, F – electrode surface after 10 days of bacteria cultivation in MFC)

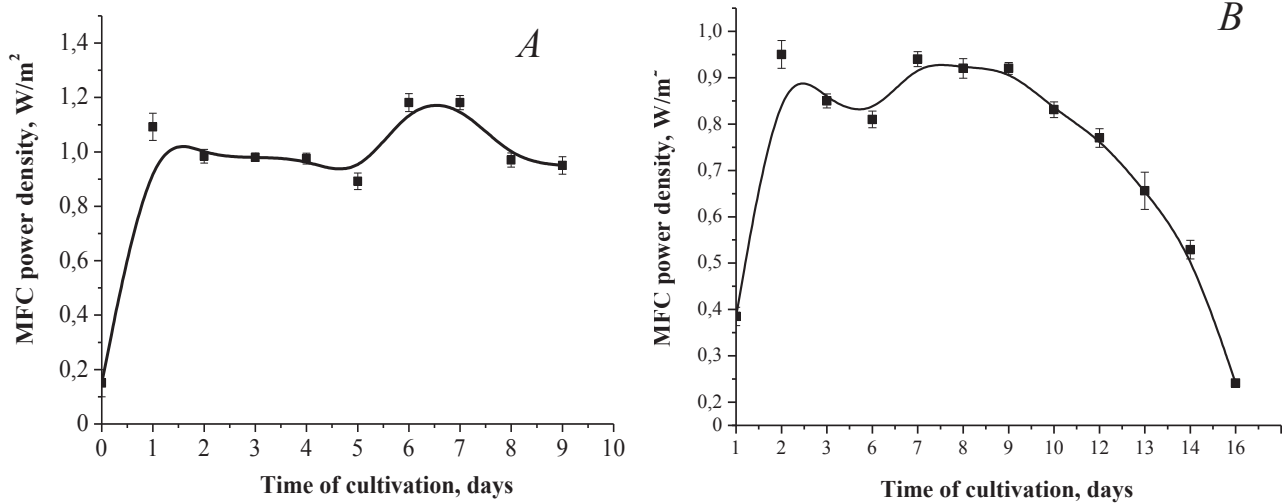


Figure 4. Power density of one-chamber MFC during ten days of *Ch. limicola* IMV K-8 cultivation while growing on GSB medium (A) and while co-cultivation of *Ch. limicola* IMV K-8 and *Geobacter* CB35 with addition of wastewater of yeast production plant (B)

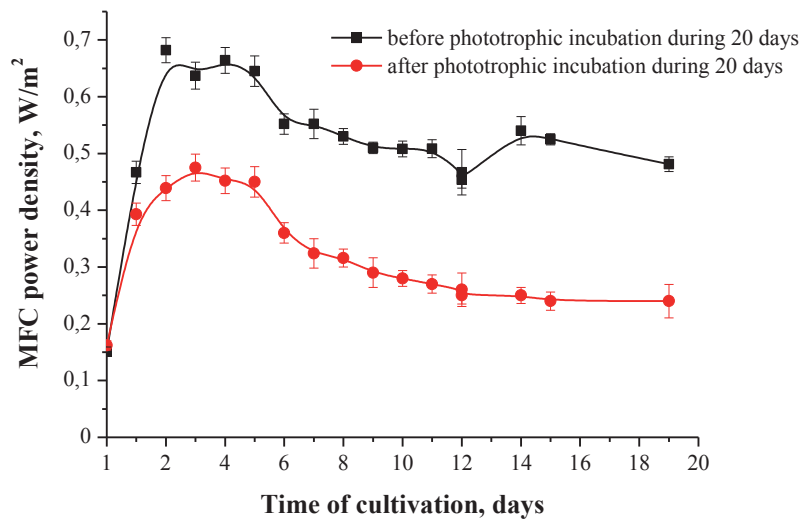


Figure 5. Power density of one-chamber MFC while *Ch. limicola* IMV K-8 cultivation with wastewater of alcohol plant

of alcohol plant and as a result cause it's bioremediation. Electric current generation has been determined while *Ch. limicola* IMV K-8 growing on wastewater of alcohol plant and after 20 days of cultivation at phototropic conditions (Fig. 5).

Power density of MFC reaches it's maximum (0.68 ± 0.02 W/m²) during second day of *Ch. limicola* IMV K-8 bacterium cultivation with waste water of alcohol plant and it was stable during next five days. MFC power

density decreased at sixth day by 24% in comparison with the maximal obtained value. Power density of MFC decreased with further *Ch. limicola* IMV K-8 bacterium cultivation.

The power density of MFC while adding into the anode chamber waste water of alcohol plant and *Ch. limicola* IMV K-8 cells after 20 days of cultivation at phototropic conditions was lower by 1.5 times during the whole time of cultivation in comparison with obtained values while

adding waste water that was not incubated with *Ch. limicola* IMV K-8 before. We assume that bacteria *Ch. limicola* IMV K-8 metabolized available substances from waste water while phototropic cultivation during twenty days. Therefore the value of generated electric current was lower in comparison with application of waste water, in which *Ch. limicola* IMV K-8 was not incubated before.

The content of compounds in the wastewater of alcohol plant after 20 days of phototropic growth of *Ch. limicola* IMV K-8, 20 days of its heterotrophic growth, and after 20 days of its growth in the anode chamber of MFC has been investigated (Table 2).

It was determined that during phototropic and heterotrophic growth, as well as while prolonged growth in the anode chamber of MFC, bacteria oxidize organic compounds that results in increase of $\text{HCO}_3^-/\text{CO}_3^{2-}$ con-

tent. After *Ch. limicola* IMV K-8 cultivation in wastewater of alcohol plant COD decreased by 3.5-7.5 times. We assume that at the excess of organic matter in wastewater the dominant process in *Ch. limicola* IMV K-8 cells was catabolism of organic substances in glycolytic or pentose phosphate pathways resulting in CO_3^{2-} formation. H_2S content, which is one of the major electron donors for these bacteria during photosynthesis, is also significantly reduced. We assume that at these conditions, processes of photosynthesis may occur, however, with reduced intensity. H_2S may also be utilized by *Ch. limicola* IMV K-8 bacteria in the processes of assimilatory sulfur-reduction. During bacteria growth in the wastewater of alcohol plant, the content of SO_4^{2-} , SO_3^{2-} and S^0 decreases. We assume that these compounds may also be substrates for assimilative sulfur-reduction.

Table 2. Content of waste water of alcohol plant before and after *Ch. limicola* IMV K-8 cultivation

Index	Content of compounds, g/l				
	Before bacteria cultivation	After 20 days of phototropic bacteria growth	After 20 days of heterotrophic bacteria growth	After 20 days of bacteria growth in the anode chamber of MFC	After 20 days of bacteria phototropic growth and 20 days of growth in the anode chamber of MFC
HCO_3^{2-}	13.4±0.64	31.7±1.59	35.4±1.81	37.1±1.86	24.4±1.18
CO_3^{2-}	6.8±0.31	16.1±0.73	18.0±0.77	18.8±0.91	12.4±0.48
Ca^{2+}	9.3±0.44	6.0±0.25	8.0±0.31	6.3±0.34	8.0±0.39
Mg^{2+}	6.5±0.33	2.4±0.12	2.4±0.12	1.5±0.07	4.3±0.22
Cl	10.9±0.47	12.9±0.92	10.3±0.46	14.2±0.68	8.6±0.42
Na^+	10.1±0.55	8.4±0.39	6.7±0.29	9.2±0.54	5.6±0.27
K^+	1.9±0.09	2.8±0.13	2.2±0.09	3.1±0.12	1.9±0.07
SO_4^{2-}	28.6±1.26	18.1±0.91	18.6±0.89	16.4±0.59	268.2±13.2
SO_3^{2-}	23.8±1.19	15.5±0.67	15.9±0.69	14.0±0.51	229.0±10.76
S^0	19.1±0.92	12.1±0.61	12.4±0.65	10.9±0.48	178.7±9.89
H_2S	39.2±1.96	12.8±0.59	13.2±0.67	11.6±0.52	189.9±8.47
NO_3^-	5.0±0.28	1.8±0.09	0.8±0.04	0.4±0.02	2.0±0.08
NO_2^-	3.7±0.18	1.3±0.06	0.6±0.03	0.3±0.01	1.5±0.07
NH_4^+	3.2±0.13	2.7±0.14	2.5±0.12	0.2±0.01	1.5±0.07
P_2O_5	7.3±0.34	8.2±0.39	8.2±0.38	4.2±0.21	4.4±0.21
PO_4^{3-}	4.9±0.24	5.5±0.27	5.5±0.27	2.8±0.14	2.9±0.14
P_i	1.6±0.11	1.8±0.07	1.8±0.09	0.9±0.08	0.9±0.06
COD g O_2 /l	3172±18	423±9	634±11	846±9	646±9

Decrease of the content of NO_3^- , NO_2^- and NH_4^+ ions was observed while *Ch. limicola* IMV K-8 growth in wastewater. NH_4^+ is known to be a source of nitrogen for *Ch. limicola* IMV K-8 therefore its elimination may be a result of its assimilation (Moroz & Rusyn, 2012). It was determined that *Ch. limicola* IMV K-8 does not use NO_3^- and NO_2^- as the source of nitrogen. These ions inhibit metabolism of nitrogen in ammonium form, growth and photoassimilation of H_2S in comparison with control (Moroz & Rusyn, 2012). However, the genes whose products are involved in assimilatory and dissimilatory nitrate reduction and denitrification have been identified in the genome of green photosynthetic bacteria *Chlorobium phaeovibrioides* (https://www.genome.jp/kegg-bin/show_pathway?pvi00910). We assume that *Ch. limicola* IMV K-8 cells adapt and metabolize NO_3^- and NO_2^- while growth on wastewater of alcohol plant.

The content of P_2O_5 , PO_4^{3-} , and P_i significantly reduced while wastewater incubation in MFC. The content of these compounds in wastewater after phototrophic or heterotrophic growth of *Ch. limicola* IMV K-8 was higher in comparison with the primary value. We assume that changes of the phosphorus compounds content in wastewater are dependant on metabolic processes of *Ch. limicola* IMV K-8 bacteria.

Further studies are needed to investigate more detailed causes of changes of wastewater content of alcohol plant while *Ch. limicola* IMV K-8 bacteria growth. Understanding the metabolism processes of organic compounds, sulfates, nitrates, phosphates will allow to create optimal conditions for bioremediation of wastewater of industrial origin, in particular, wastewater of alcohol plants.

Hence green photosynthetic bacteria *Ch. limicola* IMV K-8 oxidize organic compounds with simultaneous electric current generation while growth on waste water as the carbon source. Also these bacteria metabolize sulfates, nitrates and phosphates and therefore support wastewater bioremediation.

4. Conclusions

Bacteria-exoelectrogens, which were isolated from technogenically transformed territories, are able to generate electric current while growth on wastewater of industrial or municipal origin with its simultaneous bioremediation. The most effective exoelectrogen was *D. acetoxidans* IMV B-7384 bacterium among investigated strains. It was determined that biofilm formation on the surface of the electrode is crucial for electric current generation by bacteria. Probably *D. acetoxidans* IMV B-7384 bacteria are capable to oxidize much wider range of organic compounds and are more resistant to the influence of toxic compounds in comparison with *Geobacter* sp. CB35 and *Desulfuromusa* sp. CB30.

Application of the consortium of phototrophic and heterotrophic microorganisms in MFC is an effective approach to wastewater treatment that provides elimination of pollution by organics, nitrates, nitrites, ammonium, sulfates, sulfites and others with simultaneous generation of electric current.

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