Streszczenie w języku angielskim

The use of fossil fuels in the global economy damages natural resources and contributes to their depletion and environmental pollution. In view of these problems, research into alternative energy sources is becoming increasingly important. One of the promising technologies is microbial fuel cells (MFCs), which use microbial processes to convert organic substrates into electrical energy. The practical use of this technology can not only reduce the emission of harmful greenhouse gases, but also reduce dependence on fossil fuels. Factors limiting the large-scale use of MFCs, such as low output power, high internal resistance, or the lack of knowledge about the relationship between microorganisms and electrical energy production, are prompting research into the development and improvement of MFCs. This work aimed to determine the effects of anode size, anode modification Fe_2O_3, reduced graphene oxide (rGO), and rGO-Fe composite on MFC efficiency, anode microbiome composition, and biofilm metabolic potential.

Initially, the study tested the effect of anode size on MFC operation. Volatile fatty acids (VFA) from anaerobic fermentation of primary sewage sludge were introduced into the MFC. In the MFC with an anode surface of 600 cm^2 operated at a load of 69.12 mg COD/(g d.m.·d), a cell power of 15.3 mW/m^2 was obtained. Increasing the anode surface to 1200 cm^2 (load of 36.21 mg COD/(g d.m. ·d)) did not increase the power density, but improved the efficiency of organic compound removal. *Deftia* sp. and *Methanobacterium* sp. were abundant in the anode biofilm during the MFC development phase. In the stable phase of MFC operation, the share of exoelectrogens of the genus *Rhodopseudomonas* sp. increased in the biofilm, contributing to more efficient and stable electricity production. In the MFC with a larger anode surface, *Leucobacter* sp., *Frigoribacterium* sp., and *Phenylobacterium* sp. were abundant in the biofilm, which resulted in high and stable COD removal (over 85%). In the next stage of the study, in the MFC powered by waste VFA, the anode was modified with Fe_2O_3 at a dose of 2.5 g/m^2 of anode. The modification improved electron transfer to the anode, increasing power density, current density, and voltage, respectively, 3.6-fold, 1.8-fold, and 1.4-fold compared to the MFC with an unmodified anode. The addition of Fe_2O_3 significantly affected the microbiome of the biofilm, contributing to the development of *Pseudomonas* sp. and *Geothrix* sp. with high potential for electricity production. This proves that the modification of the Fe_2O_3 anode can have a beneficial effect on the microbiological composition of the biofilm on the anode, which translates into the efficiency of the MFC. To investigate the effect of the Fe_2O_3 dose on the MFC efficiency, the anode was modified with Fe_2O_3 at a dose of 1.25, 2.5, 5.0, and 10 g/m^2 of

the anode surface. Fe_2O_3 at a dose from 1.25 to 5.0 g/m^2 improved the electricity generation, with the highest power density (1.39 mW/m^2) obtained in the MFC with anodes modified with 2.5 and 5.0 g Fe_2O_3/m^2. The power of the cells with 2.5 and 5.0 g Fe_2O_3/m^2 of the anode was 2.8 times higher, and the resistance was 5.6 and 4.7 times lower, respectively, than in the control reactor. The study showed that the dose of 10 g Fe_2O_3/m^2 of the anode resulted in a twofold reduction in power density compared to the unmodified anode. The removal of organic substances from wastewater was more stable in the MFC with anodes modified with lower doses of Fe_2O_3. Although acetate was the main source of carbon in the wastewater, propionic and valeric acids dominated among the VFA in the wastewater discharged from the MFC; the proportion of propionic acid to other VFA increased with the increase in the dose of Fe_2O_3 used for anode modification. Fe_2O_3 anode modification stimulated the growth of microorganisms producing extracellular polymers from the genera *Zoogloea* and *Acidovorax*, which promoted the formation of a biofilm. In the microbiomes of anodes modified with doses of 1.25 and 2.5 g Fe_2O_3/m^2, the dominant bacteria, potentially responsible for electricity production, were *Pseudomonas* sp., *Oscillochloris* sp., and *Rhizobium* sp., while at 5 and 10 g Fe_2O_3/m^2 – the exoelectrogens *Dechloromonas* sp. and *Desulfobacter* sp. In the last stage of the study, the anodes were modified with Fe(III) ions (in doses of 34 and 68 mg per anode surface, corresponding to 0.85 and 1.7 g Fe/m^2 of anode) and rGO (fixed dose: 200 mg per anode surface). The highest power density (8.55 mW/m^2) and voltage (342.7 ± 72.8 mV) were achieved in the MFC with an anode modified with rGO/68 mg Fe composite. Total internal resistances and charge transfer resistance in this MFC were approximately 4 and 2 times lower, respectively, than in the control MFC. The levels of double-layer capacitance, i.e. the ability to store charge at the interface of the electrolyte and conductive electrode surfaces of the modified anodes, measured at a potential of 900 mV, were up to 3.7 times higher (MFC with an anode modified with rGO/68 mg Fe) than in the control MFC. Anodic microbiome sequencing and statistical analysis indicated that the percentage of *Pseudoxanthomonas* sp. *Themomonas* sp., *Dechloromonas* sp., *Microcystis* sp., *Sphingopyxis* sp., and *Paracoccus* sp. in the biofilm positively correlated with electricity production in MFC. Analysis of the metabolic potential of anodic microbiomes showed that electricity production was mainly related to the reverse citric acid cycle. The highest metabolic potential of energy production and conversion, bacterial cell defense against adverse environmental conditions (e.g. oxidative stress), DNA replication, recombination, and repair was found in MFC with rGO/34 mg Fe composite modified anode.

The study has shown that modifying the anode with both iron compounds and rGO-Fe composite allows an increase in the power density generated by the MFC cell by improving the capacitive properties of the electrode and reducing the internal resistance of the cell. The microorganisms played a key role in power generation, and their composition and metabolic potential depended on the method of anode modification. Modifying the anodes with an rGO-Fe composite increased the metabolic potential of the microbiome in terms of energy production and conversion, highlighting the importance of materials engineering in optimizing the operation of MFCs. The results obtained indicate the possibility of improving power generation from waste and wastewater in MFCs by modifying the anodes and gaining new insights that can be used for sustainable electricity production, promoting ecological and efficient use of natural resources.

Keywords: microbial fuel cells, volatile fatty acids, iron, reduced graphene oxide, microbial communities