Abstract

Microbial fuel cells (MFCs) are bioelectrochemical systems that enable the conversion of organic matter to electricity through the catalytic activity of anodic bacteria. Microorganisms that form anode biofilms can simultaneously convert organic substrates into useful products. Biosurfactants are an interesting group of biochemically synthesised compounds with unique properties and wide applications. However, despite the great importance of biosurfactants for the industry and their impact on increasing the efficiency of MFCs, only a few works have been published in which biosurfactants were the target of synthesis in bioelectrochemical systems, and the results obtained indicate low performance of the system.

The main objective of the research presented in the doctoral thesis was to investigate the possibilities of biosurfactants production in microbial fuel cells from waste vegetable oil during electricity production and to assess the possibility of using biosurfactants to increase the efficiency of MFCs. Solving the problem of low performance and a systematic approach to optimising the production of biosurfactants in MFCs from waste vegetable oils is the first step towards scaling up this process in the future.

The first work concerns the comparison of two different commercially available activated carbons, as well as the modification of carbon with silica nanoparticles in terms of improving the efficiency of air cathodes in MFCs. Almost a year of operation of materials with different specific surface areas and microporous structures revealed significant differences in their dynamic behaviour. The results showed that pore size distribution and the resulting susceptibility to chemical contamination is a key factor in maintaining high performance of the MFC system. It has been proven that unmodified, cheap, and commercially available activated carbon can be a high-performance air cathode material, but its activity and long-term properties depend on its porosity characteristics.

The next article proposed a horizontal MFC system enabling the synthesis of biosurfactants from waste cooking oil. The efficiency of biosurfactant production and electricity generation was compared in a horizontal and classical vertical arrangement of the MFC. The results showed that the horizontal MFC arrangement resulted in a significant increase in the power density production and biosurfactants synthesis. Furthermore, it was demonstrated for the first time that the biosurfactants synthesis is directly correlated with electricity generation in the MFC. Thus, it was proven that a properly designed MFC system can enable energy net-positive production of biosurfactants and monitoring of the biosynthesis of surfactants solely using an electrical signal.

The third experimental work analysed the influence of nitrogen source concentration on the production of biosurfactants and electricity from waste cooking oil. The study

showed that the concentration of the nitrogen source in the culture medium is one of the key factors in maintaining the high degradation efficiency of the oil substrate, energy production, and simultaneous synthesis of biosurfactants. Furthermore, the results showed a strong correlation between changes in power density and decrease in surface tension as a function of nitrogen concentration in the medium, which proves that the synthesis of biosurfactants and the degradation efficiency of waste vegetable oil in MFCs depend directly on the concentration of the nitrogen source. This is the first work in which nitrogen optimisation was studied to improve the synthesis of biosurfactants and energy production in a bioelectrochemical system, which brings the effective synthesis of biosurfactants in these types of systems closer to real application.

In the last article, a polyvinylidene fluoride (PVDF) nanofibers membrane and PVDF modified by alkaline treatment and rhamnolipids treatment were investigated as the inner layer of a ceramic membrane to control the negative effects of biofouling. The electrochemical and surface characteristics of the materials showed that the use of the PVDF layer did not give satisfactory results, while the modification of the PVDF with rhamnolipids resulted in increased resistance of the coating to contamination. Therefore, it was demonstrated that natural products such as biosurfactants can be used to modify MFC membranes, as well as, for the first time, the mechanisms of biosurfactant interaction with membranes were discovered.

The results of the performed experiments showed that efficient biosynthesis of surfactants in microbial fuel cells from waste vegetable oil is possible but requires the use of a properly designed MFC system and efficient construction materials of the MFC. Furthermore, the presented results showed a direct correlation of the electricity and biosurfactant production in horizontal MFC from waste oil and a strong dependence of these parameters on the concentration of the nitrogen source in the medium. The research results obtained in this work are the basis for the development of bioelectrochemical systems using waste vegetable oils from the food industry in the future. In addition, efficient synthesis of biosurfactants, generation of electricity, and simultaneous use of waste products from the food industry perfectly fit the goals of sustainable development and circular economy. Future research should focus on further optimisation of the system operation and MFC construction materials to produce biosurfactants and electricity, as well as scaling up the process and developing inexpensive, fast, and less environmentally invasive biosurfactant separation and purification processes.