Bioelectricity Generation in Sludge Microbial Fuel Cells (MFCs) Coupled with Iron-based Nanoparticles

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論　文　内　容　の　要　旨
Thesis Summary

The energy demand has been increasing worldwide, and the scarcity of fossil fuels has urged the necessity for environmental and eco-friendly energy sources. The search for novel energy solutions has grown tremendously. The urge to limit the consumption of carbon-based energy resources has been raised to restrain greenhouse gas emissions and environ-mental pollution. Moreover, water depletion is emerging as a vital issue, and it becomes crucial to define sustainable water conservation and wastewater treatment techniques in the present situation. In this context, microbial fuel cell (MFC) technology has been gaining popularity over the past decades. Biofuel cells are at an early stage of development compared to other fuel cell technology. Significant research studies are still needed to approach technology integration and commercialization. In a typical fuel cell, expensive fuel and catalysts are needed. A catalyst is what gets a chemical reaction going, and therefore an electrical current is generated as a result of these chemical reactions. In contrast, in microbial fuel cells, catalysis is done by living bacteria, which break down the waste and release electricity in the process. An MFC is an anaerobic container of concentrated bacteria that feed biodegradable material. It operates via biochemistry, meaning that the energy used to run the cell is generated from electron transfer from bacteria to electrodes with no outside energy source is needed. Such a process would simultaneously reduce the waste treatment costs, unlike conventional fuel cells. Microbial fuel cell systems are recognized as energy production systems with great potentials.

This research's overall objective was to study the effects of iron-based nanoparticles on the performance of a lab-scale microbial fuel cell (MFC). The specific objectives are improving the bacterial growth owing to their critical role in microbial fuel cell technology, implementing the iron nanoparticles technology in the anode chamber as it represents the powerhouse of MFCs, and improve the iron performance and understand the factors that affect the MFC response. In our study, MFC systems showed a potential for sustainable wastewater treatment and simultaneous power harvesting from domestic waste sludge. This study has focused on nanoparticle technology's effect on power generation. We developed a set of experimental studies to improve a lab-scale MFC performance.

In contributing to the enhancement of bioenergy generation, we have been involved in the design and study of microbial fuel cell technology. Developed in Kyushu University, our works are synthesized in the present dissertation, which is structured in five chapters:

The first chapter is devoted to state of the art regarding microbial fuel cell technology. A background related to the principle of operation of MFCs is recalled. The chapter aims to review nanoparticles technology, and their advantages and challenges are analyzed.

The second chapter aims to discuss material and experimental methods used in this study. We started our research by collecting domestic waste sludge taken from the Mikasagawa wastewater treatment plant as a source to have a wide variety of the exoelectrogens bacteria needed for the MFC operation. The waste sludge analysis was a crucial step to identify the available nutrients and organic matter. The MFC performance investigation went through design and construction, voltage control, power density calculations, and organic matter degradation

analysis. Besides, iron-based nanoparticle synthesis and preparation were an essential and delicate process, where any leakage of oxygen can affect the nanoparticles' reactivity.

The third chapter investigates the response of bacterial growth under iron-based nanoparticles treatment. TEM characterizations showed that Fe^0 morphology had crystalline and pure structure. The introduction of Cu particles led to a larger surface area and more ductile chain. Examining the consequences of adding Fe^0 particles on bacterial communities was reflected through bacterial growth and biological wastewater treatment. Afterward, we discussed how bacteria use the anode as an electron acceptor and to what extent they generate electrical output. This study demonstrated that it is possible to enhance bacterial growth and accomplish biological wastewater treatment using Fe^0-based nanoparticles. Bacterial growth increased to 84.61 % under Cu/Fe^0 treatment added with an optimum concentration. The improvement was also reflected through chemical oxygen demand (COD) removal efficiency, which reached 33.21 %, 55.30 %, and 61.24 % for control, Fe^0, and Cu/Fe^0 reactors, respectively. We investigated the medium change effect on bacterial cell growth, and results showed that microbial colonies exhibited higher sensitivity to Fe^0 treatment in a different studied medium. System conditions were varied, and the variation of oxygen concentration could alleviate the negative effect. The study proved that Fe^0 and copper/Fe^0 nanoparticles exhibited a positive effect on bacterial growth originated from a mixed culture inoculum as well as on the biological wastewater treatment. However, the medium showed high sensitivity with different wastewater. The effectiveness of the obtained results was examined for bioelectricity generation in the MFCs system. The use of bimetallic Cu/Fe^0 nanoparticles enhanced the maximum voltage value by 43.33 % and the power density by 65.57 %. However, the overall performance was not high as was expected. Such an improvement is essential for microbial fuel cell applications.

The fourth chapter considers the most promising material among those proposed in chapter 3. An experimental study is carried out aiming at the improvement of the system performance. A new proposed approach leads to selecting a set of parameters making the MFC reach the required arrangements. Two different samples of sludge were used, and the maximum daily voltage obtained in the control MFC filled with S2 (COD= 37802 mg/L) increased by 182 % compared to the MFC filled with S1 (COD= 5561 mg/L). The addition of Fe nanoparticles reduced the daily voltage by 31 % and 9 % for the MFCs filled with S1 and S2, respectively. These results highlight the effect of organic matter content on the MFC response. In addition, the use of copper /Fe^0 bimetallic nanoparticles enhanced the maximum voltage value by 43.33 % and the power density by 65.57 %. However, the overall performance was not high as was expected. The ferric iron's reduction and the biomass growth can justify the increase of the anode chamber's internal resistivity. Moreover, Fe^0 salts' addition exhibited a higher power output and a shorter start-up time. Fe^{3+} addition exhibited a higher power output by 295 % and a shorter start-up time. The microbial growth increased by 92.18 % and the anolyte's resistivity decreased with an increase in the organic matter digestion by 52.78 %. However, the amount of power generated in these MFCs was limited by the biological ferric iron reduction rate that was high enough to restrict the produced current. Fe^0 coated nanoparticles with $Mg(OH)_2$ coating shell were introduced to the anode chamber of lab-scale microbial fuel cells (MFCs). Results proved that the iron-based nanoparticles effectively enhanced the MFCs voltage by more than 4 times and controlled the $Mg(OH)_2$ coating shell's dissolution and, therefore, the release of Fe^{2+}. This latter consequently increased the anolyte conductivity, enhanced the bacterial growth, and improved the organic matter degradation. However, the MFC response still low, and the use of real waste sludge is challenging.

In chapter five, significant findings of this dissertation are summarized with some recommendations for future work.