

Review of the Doctoral Thesis Dissertation Entitled “Study of the microbial fuel cell and its circuit modeling to improve its performance as a source of electric energy combined with wastewater treatment”

Review

The doctoral thesis titled "Study of the Microbial Fuel Cell and its Circuit Modelling to improve its performance as a source of electric energy combined with wastewater treatment", written by Szymon Potrykus, under the supervision of Prof. Dr. Hab. Inz. Piotr Musznicki and the co-supervision of Dr. Francisco Jesús Fernández Morales, demonstrates excellent quality, further validated by the articles derived from this work (Potrykus et al. 2021, 82th percentile, FWCT 1.54, PlumX, 37 readers Mendeley; Potrykus et al. 2020, 29th percentile, FWCT 0.14, PlumX, 21 readers Mendeley), which were published in *Energies*, a scientific journal with a high impact factor (Q1, $IF_{(JCR)}=3.0$). The quality indicators show a significant degree of international dissemination for these works. In less than four years, more than 70% of the citations and views have been made by researchers from different countries (France, United States, China, India, Iran...) and also in journals from various disciplines (Engineering, Biochemistry, Agriculture...).

The multidisciplinary collaboration of two research groups for the development of this thesis, the Faculty of Electrical and Control Engineering (Gdansk University of Technology, Gdansk Tech) and the group of Chemical and Environmental Technology (Department of Chemical Engineering, University of Castilla La Mancha), has allowed for an in-depth analysis of the results from two areas of knowledge: Chemical Engineering and Electrical Engineering.



The Microbial Fuel Cells (MFC) are an emerging technology aimed at addressing serious problems such as the energy crisis or the pollution in wastewater. The commitment to this type of clean technology (low carbon emissions) is in line with the goals (6, 9, 11, and 14) of the 2030 Agenda for Sustainable Development.

In reviewing this thesis, it is clear that the introduction provided for each of the studies excellently presents the state of the art regarding MFCs. The objectives are especially interesting for the field of study of this type of technology and allowed for a deeper understanding of how electrical variables (voltage, current) and non-electrical variables (flow rate, substrate concentration, pH, hydraulic retention time) affect the performance of these MFCs. Knowing the evolution of these parameters makes it possible to establish optimal operating conditions to achieve an effective performance in terms of (1) electric power generation and (2) wastewater treatment. The importance of these objectives is evident from an economic perspective, considering that the operating costs of Wastewater Treatment Plants (WWTP) are mainly associated to aeration, and from an environmental perspective, due to the need to achieve discharge water with physicochemical characteristics that do not cause adverse effects on receiving water systems.

From Chapter 4 to Chapter 8 we find innovative and highly necessary studies for the technological design of MFCs at an industrial scale. Although there are published studies on the behavior of batch-operated MFCs, it is crucial to study these MFCs operating in a continuous mode for large-scale implementation and for process automation. This is successfully undertaken in the works presented in this thesis.

In Chapter 4, the influence of flow rate variation on the performance of MFCs is addressed from an energy standpoint (electricity generation capacity and Coulombic efficiency) and an environmental perspective (COD removal rate). The identification of the key mechanisms affecting energy generation and pollutant removal in wastewater when the influent flow rate is modified is a novel approach. The results show that variations in the influent flow rate do not have a significant impact on the performance of the MFC, neither in the electrogenic aspects nor in the pollutant removal aspects. In addition, the work

presented in Chapter 5 corroborates the significant influence of the external load on the distribution of microbial populations, thereby affecting operational variables, including output current density. As for Chapters 6 and 7, two interesting tools are proposed for the creation of MFC prototypes. On one hand, an equivalent circuit model of MFC in the MATLAB Simulink simulation environment is proposed and, on the other hand, a maximization method. The performance of MFCs in terms of energy efficiency and COD reduction is accurately predicted. Modelling these processes improves operational procedures for COD removal in WWTPs. Finally, in Chapter 8, the discussed tools were applied and validated to effectively maximise the performance of MFCs with regards to variables such as energy generation, electrical efficiency, and COD removal. The results improved the existing models in the literature, achieving RMSE values below 4% for voltage and below 15% for current.

Based on the review conducted and the comments provided, as a reviewer, I consider this Doctoral Thesis outstanding, as it demonstrates high scientific quality both in the methodology applied for the development of the experiments and in the results and conclusions detailed in this work.



Antonio Rosal Raya
University Professor
Department of Molecular Biology and Biochemical Engineering
University Pablo de Olavide of Sevilla
Spain

ROSAL RAYA

ANTONIO - 30822564B

Firmado digitalmente por ROSAL
RAYA ANTONIO - 30822564B

Fecha: 2024.12.23 14:47:31 +01'00'

The review should contain answers for the following questions:

1. What is the scientific subject (thesis) of the dissertation? Is it stated accurately and clearly?

The theme of this doctoral thesis focuses on the study of microbial fuel cells and their circuit modeling to enhance their performance as an energy source combined with wastewater treatment. The focus of the thesis transcends the simple traditional purpose of reducing the organic load of wastewater. This work is presented in a clear and precise manner in each of the chapters of the dissertation. The results are presented in the format of scientific articles, in English, and in which the main topics raised in the objectives of the thesis are adequately discussed and analyzed. The results are organized into specific chapters and each dataset is analyzed in a comparative manner with appropriate controls, which facilitates the interpretation of the improvements achieved and their practical relevance. In addition, the use of graphs and tables reinforces the understanding of the results, highlighting the relationships between the variables studied and their impact on the efficiency of the process.

2. Did the author solve the problem and did he/she use appropriate methods, thus proving that he/she acquired skills in the teaching methods and methodology of conducting scientific research?

The methodology applied to achieve each of the milestones set out in the thesis has been appropriate, and all the objectives proposed have been satisfactorily met. The experimental approach, based on controlled parameters and detailed analyses, ensures reproducible and industrially scalable results in those production sectors that present the need to treat the wastewater generated in their activity.

3. Is the subject of the dissertation up to date and substantial enough?

The topic of this thesis, both current and extremely interesting, is related to the optimization of the use of microbial fuel cells (MFCs) in wastewater treatment plants. This is an emerging technology that tries to address critical issues such as the energy crisis and wastewater pollution.

4. What are the original scientific achievements of the author and what is their cognitive significance or practical applicability for science or technology?

From Chapter 4 to Chapter 8 we find innovative and highly necessary studies for the technological design of MFCs at an industrial scale. In Chapter 4, the influence of flow rate variation on the performance of MFCs is addressed from an energy standpoint (electricity generation capacity and Coulombic efficiency) and an environmental perspective (COD removal rate). The identification of the key mechanisms affecting energy generation and pollutant removal in wastewater when the influent flow rate is modified is a novel approach. The results indicate that variations in the influent flow rate do not have a significant impact on the performance of the MFC, neither in the electrogenic aspects nor in the pollutant removal aspects. The work presented in Chapter 5 confirms the significant influence of the external load on the distribution of microbial populations, thereby affecting operational variables, including output current density. As for Chapters 6 and 7, two interesting tools are proposed for the creation of MFC prototypes. One is an equivalent circuit model of MFC in the MATLAB Simulink simulation environment while the other is a maximization method. The performance of

MFCs in terms of energy efficiency and COD reduction is accurately predicted. Finally, in Chapter 8, the discussed tools were applied and validated, effectively maximising the performance of MFCs with regards to variables such as energy generation, electrical efficiency, and COD removal. The results improved the existing models in the literature, achieving RMSE values below 4% for voltage and below 15% for current.

5. Does the dissertation prove the appropriate knowledge of the author and his/her advanced knowledge on the basic level in technical sciences and on the complex level in the area of conducted scientific research?

The thesis is effectively addressed in each chapter, which demonstrates the author's adequate knowledge to address the problem, propose the solution hypothesis, outline the objectives, develop the experimental methodology, obtain and treat the results, and draw meaningful conclusions for each milestone.

6. Does the dissertation feature the newest scientific research and proves the knowledge of the author of the contemporary scientific literature of the respective scientific field?

In reviewing this thesis, it is clear that the introduction provided for each of the studies excellently presents the state of the art regarding MFCs. In the work, an adequate choice and management of the bibliography is observed. The author resorts to relevant and current scientific sources that support the proposed strategies and approaches, and the oldest references keep their postulates and criteria valid. In addition, the articles cited reflect an interdisciplinary approach, covering technical and environmental aspects.

7. What are the flaws and the weaknesses of the dissertation?

Each of the studies presented in the thesis have been developed appropriately and the conclusions are well supported by the results obtained through the methodology applied. Considering this, there are no significant flaws or weaknesses in the thesis.

8. The Reviewer deems the dissertation to:

- a/ be below requirements,
- b/ require corrections and an additional review,
- c/ fulfil the requirements satisfactorily,

d/ be notably above average (fulfil requirements and contain additional work),

e/ be outstanding.



Distinguishing the dissertation:

if the Reviewer classifies the dissertation under the category d) or e) and decides that it should be distinguished, he should include an appropriate application in the review along with its justification, taking into account the attached rules for distinguishing doctoral dissertations.

The objectives set out in this thesis, along with the results obtained and the conclusions provided are highly relevant to the field of study of this type of technology (MFC). The

work has contributed to a deeper understanding of how both electrical (voltage, current) and non-electrical variables (flow rate, substrate concentration, pH, hydraulic retention time) influence the performance of these MFCs. Knowing the evolution of these parameters makes it possible to establish optimal operating conditions to achieve an effective performance in terms of (1) electric power generation and (2) wastewater treatment. The importance of these objectives is evident from an economic perspective, considering that the operating costs of Wastewater Treatment Plants (WWTP) are mainly associated to aeration, and from an environmental perspective, due to the need to achieve discharge water with physicochemical characteristics that do not cause adverse effects on receiving water systems.

*Based on the review and the comments provided, I consider this Doctoral Thesis **outstanding**, as it demonstrates high scientific quality both in the methodology applied for the development of the experiments and in the results and conclusions presented in this work.*

The reviewer is also asked to complete the attached questionnaire for statistical and analytical purposes.

ROSAL RAYA	Firmado digitalmente
ANTONIO -	por ROSAL RAYA
30822564B	ANTONIO - 30822564B
	Fecha: 2025.01.28
	17:03:06 +01'00'