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SISTEMA FOTOBIOELETROQUÍMICO PARA AVALIAÇÃO DA GERAÇÃO DE BIOELETRICIDADE E BIORREMEDIAÇÃO EMPREGANDO EFLUENTE URBANO (SINTÉTICO) E COMBINAÇÃO DE BACTÉRIAS E MICROALGAS

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Dissertação apresentada ao Programa de Pós-Graduação em Tecnologia Ambiental – Mestrado, Universidade de Santa Cruz do Sul – UNISC, como requisito parcial para o título de Mestre em Tecnologia Ambiental.

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RESUMO

Na atualidade há uma crescente preocupação com a crise global de energia e seu impacto sobre o meio ambiente, impulsionando as pesquisas de produção de energia utilizando tecnologias mais limpas a fim de mitigar esse problema. Os sistemas bioeletroquímicos (BES), podem ser uma alternativa para a recuperação de energias e ainda proporcionar a biorremediação de águas residuárias bem como produzir biomassa de valor agregado. Neste contexto, esta dissertação teve como objetivos analisar a literatura científica sobre o uso de células de combustível microbianas (MFCs) para a geração de bioeletricidade, e fornecer um quadro teórico-conceitual para a revisão da literatura a respeito da geração de bioeletricidade pelas MFCs utilizando análise bibliográfica e uma abordagem multicritério, bem como montar um sistema do tipo *microalgae-microbial fuel cell* (MMFC) de bancada para avaliar a produção de bioeletricidade e a biorremediação de um efluente urbano sintético. As combinações testadas foram compostas pela bactéria *Escherichia coli* (PBES 1) e pela bactéria *Pseudomonas aeruginosa* (PBES 2) nas câmaras anódicas e pela microalga *Desmodesmus subspicatus* nas câmaras catódicas em ambos os experimentos. Uma terceira combinação foi composta pela *E. coli* e a microalga *Pseudokirchneriella subcapitata* (PBES 3). A partir de análises bibliométricas sobre estes sistemas encontrou-se, uma tendência de aumento nas pesquisas sobre a geração de diferentes bioenergias, produção de bioprodutos de valor agregado bem como a remediação de águas residuárias. A base de dados *Science Direct* apresentou o maior número de documentos e a China é o país com maior percentual de estudos sobre o tema bioeletricidade. No ranqueamento das publicações com o uso da análise multicritério verificou-se que a bioeletricidade ainda é um tema pouco desenvolvido e com boas perspectivas de projeção no cenário acadêmico-científico. Na análise dos experimentos desenvolvidos concluiu-se que dentre os três sistemas testados a configuração PBES 1 foi a mais efetiva na resposta eletroquímica gerando bioeletricidade de 560 mV ao final dos 7 dias de tratamento. As microalgas presentes nas câmaras catódicas dos sistemas PBES 2 e PBES 3 tiveram melhor desempenho na biorremediação de fósforo total do efluente. Na remoção de COT os resultados obtidos foram estatisticamente significativos (p<0,05) apenas para as microalgas, nos três experimentos PBES 1, PBES 2 e PBES 3. Assim, os sistemas MMFC podem ser considerados uma alternativa viável e eficiente na geração de bioeletricidade e na biorremediação de nutrientes. A presença de organismos fotossintéticos em BES, que atuam na captura de CO_2, traz mais eficiência a estes sistemas tornando-os sustentáveis, renováveis e ambientalmente corretos.

Palavras-chave: Sistemas Bioeletroquímicos. Bactérias. Microalgas. Bioeletricidade. Biorremediação.

ABSTRACT

PHOTOBIOELETROCHEMICAL SYSTEM FOR EVALUATION THE BIOELECTRICITY GENERATION AND BIORREMEDIATION USING URBAN EFFLUENT (SYNTHETIC) AND COMBINATION OF BACTERIA AND MICROALGAE

Currently, there is a growing concern about the global energy crisis and its impact on the environment, boosting energy production research using cleaner technologies to mitigate this problem. Bioelectrochemical systems (BES), can be an alternative for energy recovery, bioremediation of wastewater and producing value-added biomass. In this context, this dissertation aimed to analyze the scientific literature on the use of microbial fuel cells (MFCs) for the bioelectricity generation, to provide a theoretical-conceptual framework for a literature review regarding the bioelectricity generation by the MFCs using bibliography analysis and a multicriteria approach, as well as setting up a microalgae-microbial fuel cell (MMFC) type bench system to evaluate the bioelectricity production and the synthetic urban effluent bioremediation. The experiments were composed by the bacterias *Escherichia coli* (PBES 1) and *Pseudomonas aeruginosa* (PBES 2) in the anodic chambers and by the microalga *Desmodesmus subspicatus* in the cathodic chambers in both experiments. The third combination was composed of *E. coli* and the microalga *Pseudokirchneriella subcapitata* (PBES 3). Based on bibliometric analyzes of these systems, there was a trend towards an increase in research on the generation of different bioenergies, the production of value-added bioproducts as well as the remediation of wastewater. The Science Direct database has the largest number of documents and China is the country with the highest percentage of studies about bioelectricity. In ranking publications with the use of multicriteria analysis, it was found that bioelectricity is still undeveloped topic and with good prospects for projection in the academic-scientific scenario. In the analysis of the experiments developed, among the three systems tested, the PBES 1 configuration was the effective one in the electrochemical response bioelectricity generating of 560 mV at the end of the 7 days of treatment. The microalgae present in the cathodic chambers of the PBES 2 and PBES 3 systems had a better performance in the bioremediation of total phosphorus in the effluent. In the removal of TOC, the results obtained were statistically obtained (p<0.05) only for microalgae, in the three experiments PBES 1, PBES 2 and PBES 3. Thus, MMFC systems can be considered a viable and efficient alternative in the bioelectricity generation and nutrient bioremediation. The presence of photosynthetic organisms in BES, which act in the capture of CO_2, brings more efficiency to these systems making them sustainable, renewable, and environmentally friendly.

Keywords: Bioelectrochemical systems. Bacteria. Microalgae. Bioelectricity. Bioremediation.

SUMÁRIO

1. INTRODUÇÃO

Considerando que vivemos em uma era tecnológica, a utilização de tecnologias pouco ou nada sustentáveis e a demanda por energia elétrica, trazem consigo sérios efeitos deletérios sobre o meio ambiente, pois ainda somos supridos por fontes energéticas extraídas a partir de combustíveis fósseis. Diante desta realidade, estudos de métodos economicamente viáveis, sustentáveis e efetivos vêm ganhando espaço entre as pesquisas científicas.

O consumo excessivo de energia pelos seres humanos é agravado pela poluição ambiental, o efeito estufa e pelos impactos das mudanças climáticas (Saratale *et al.*, 2017). Na próxima década espera-se que, seja intensificada a pesquisa e o desenvolvimento de células de combustível microbianas (MFCs, do inglês *microbial fuel cells)* (Fischer, 2018), e o uso de biomassa de algas se torne foco nesta área de pesquisa uma vez que corresponde à ideia de uma fonte de energia renovável cíclica, onde ocorre a recuperação sustentável da captura de carbono (Gajda *et al.*, 2015).

Sabemos da importância dos microrganismos para processos biotecnológicos e de remediação, então estudos com diferentes empregos de microrganismos estão se destacando na atualidade. As microalgas são organismos fotossintéticos que a muito tempo vem sendo estudadas para biorremediação, produção de bioprodutos e biocombustíveis bem como fungos e bactérias, porém uma inovação tecnológica que une estes microrganismos onde se complementam, são os sistemas fotobioeletroquímicos (PBESs, do inglês *photobioelectrochemical systems*) trazendo ainda mais eficiência nas suas aplicações.

Estes PBES podem ser efetivos para diferentes processos, e as células de combustível microbiana microalgais (MMFCs, do inglês *microalgae-microbial fuel cells*) representam uma tecnologia inovadora e promissora pois, utilizam organismos fotossintéticos para atuarem no tratamento de águas residuais, e a partir das reações metabólicas microbianas levam à geração de energia elétrica. Ainda há sistemas como, célula de eletrólise microbiana (MEC, do inglês *microbial electrolysis cell*), que fazem principalmente tratamento de águas residuais e produção de biohidrogênio (bio-H_{2}); os sistemas de eletrossíntese microbiana (MES, do inglês *microbial electrosynthesis*) que são capazes de gerar diversos bioprodutos como bio-H_{2}, biometano, bioálcool entre outros; a célula solar microbiana (MSC, do inglês *microbial solar cell*) é capaz de gerar bioeletricidade e também fazem o tratamento de águas residuárias; e por fim, a célula de dessalinização microbiana (MDC, do inglês *microbial desalination cell*) em que atuam na recuperação de energia, bio-H_2 e dessalinização. São inúmeros os benefícios que as a interação entre microalgas, bactérias e fungos podem proporcionar pelos PBES, e até mesmo a biomassa microalgal pode ser utilizada para outros fins. Em uma visão geral essa tecnologia é ambientalmente favorável.

Além da aplicação tecnológica para a geração de bioeletricidade, esse sistema é efetivo no tratamento de efluentes de diferentes fontes residuais (Do *et al.*, 2018), como a biodegradação de poluentes refratários, corantes, metais pesados, lixiviados, nitrogênio, sulfato e efluentes ricos em sulfeto, entre outros (Kumar *et al.*, 2019). O futuro da biorremediação será basicamente a partir do uso de microrganismos e a MMFC será importante para os estudos de remediação (Sivasankar *et al.*, 2019). Além de ser uma tecnologia promissora para o tratamento de águas residuais ainda oferecem uma alternativa verde para produção de energia com baixo custo (Kumar *et al.*, 2019).

Nesse contexto, o desenvolvimento desta pesquisa objetiva, realizar a revisão da literatura de como os PBES podem ser uma alternativa para produção de tecnologias limpas bem como, quanto o desenvolvimento científico com base nestas tecnologias. E, a montagem e adaptação de um sistema PBES, do tipo MMFC para produção de bioeletricidade, utilizando combinações de microrganismos (microalgas e bactérias), em que as bactérias fazem parte da geração de elétrons e as microalgas parte do tratamento da água residuária utilizada. Considerando-se que a combinação entre microalgas e comunidades bacterianas têm eficiência na produção de bioeletricidade, enquanto tratam águas residuais, o uso de microalgas vem ganhando grande interesse para produção de bioenergia (Saba *et al.*, 2017). E ainda oferecem vantagens como, a síntese de produtos de alto valor agregado e principalmente pela capacidade das algas de utilizar o CO_2 (dióxido de carbono) atmosférico, produzir biomassa e oxigênio, facilitando assim a reação catódica, portanto, considerada um novo biomaterial que promete atender à crescente demanda por energia (Saratale *et al.*, 2017).

Atualmente, sabe-se que os efluentes industriais e domésticos são os principais contaminantes dos recursos hídricos. Com isso, pesquisas utilizando esses efluentes com MMFC são de grande interesse, visto que irá conciliar o potencial remediador das microalgas com o metabolismo das bactérias para produção de bioeletricidade; e assim, mitigar dois problemas atuais, a geração de energia sustentável e a despoluição dos recursos hídricos.

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