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Yunkun Wang

Development of Novel Bioelectrochemical Membrane Separation Technologies for Wastewater Treatment and Resource Recovery

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Development of Novel Bioelectrochemical Membrane Separation Technologies for Wastewater Treatment and Resource Recovery

Doctoral Thesis accepted by
Department of Chemistry, University of Science and Technology of China, Hefei, China

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Supervisor's Foreword

Water pollution, energy, and resources shortage are three of the major global challenges faced by human society. One possible way to address these issues is to harvest energy and resources (such as nitrogen and phosphate) from wastewater and in the meantime to recover clean water for reuse. However, for traditional biological wastewater treatment plant, many problems were left behind, including low sustainability of the treatment processes, underdeveloped resource recovery, and questionable effluent discharge standards.

At the same time, the fast development of membrane separation and bioelectrochemical system technologies, as well as their widely application in wastewater treatment, provides an opportunity to recover water and nutrients from wastewater. It can be hypothesized that the combination of membrane technique and bioelectrochemical system may offer an attractive option for wastewater treatment and energy recovery. Such coupling system may overcome the drawbacks of bioelectrochemical system and membrane separation for wastewater treatment, such as the low biomass content and organics removal efficiency in bioelectrochemical system, as well as the high cost of membrane and serious membrane fouling in membrane processes.

Accordingly, Dr. Wang's research was focused on developing novel electrochemical membrane bioreactor (EMBR), which takes advantage of membrane separation and BES techniques, for wastewater treatment and simultaneous recovery of energy and resources. In his thesis, Dr. Wang designed several EMBRs and evaluated their performance in terms of energy consumption and recovery, nutrients removal and recovery, and membrane fouling property. Results clearly indicate that this innovative system holds great promise for sustainable wastewater treatment and energy recovery. Moreover, this work provides proof-of-concept studies of that the membrane fouling can be controlled and nutrients can be recovered by in situ using the generated electricity in EMBRs.

I believe that the research results of this thesis will contribute significantly to the sustainable development of wastewater treatment, as well as the establishment of new-generation wastewater treatment plants with the vision of turning wastewater plant from a site of pollutant removal into a plant of energy, water, and fertilizer recovery.

Hefei, China
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Prof. Guo-Ping Sheng

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Yunkun Wang, Wenwei Li, Guoping Sheng*, Bingjing Shi, Hanqing Yu. In-situ utilization of generated electricity in an electrochemical membrane bioreactor to mitigate membrane fouling, Water Research, 2013.10.1, 47(15), 5794–5800. (Reproduced with Permission).

Yunkun Wang, Guoping Sheng*, Bingjie Ni, Wenwei Li, Raymond J. Zeng, Bingjing Shi, Hanqing Yu. Simultaneous carbon and nitrogen removals in membrane bioreactor with mesh filter: An experimental and modeling approach, Chemical Engineering Science, 2013.3.22, 95, 78–84. (Reproduced with Permission).

Yunkun Wang, Xinrong Pan, Guoping Sheng*, Wenwei Li, Bingjing Shi, Hanqing Yu. Development of an energy-saving anaerobic hybrid membrane bioreactors for 2-chlorophenol-contained wastewater treatment, Chemosphere, 2015.12, 140, 79–84. (Reproduced with Permission).

Yunkun Wang, Xinrong Pan, Yikun Geng, Guoping Sheng*. Simultaneous effective carbon and nitrogen removals and phosphorus recovery in an intermittently aerated membrane bioreactor integrated system, Scientific Reports, 2015.11.6, 5. (Reproduced with Permission).

Yunkun Wang, Yikun Geng, Xinrong Pan, Guoping Sheng*. In situ utilization of generated electricity for nutrient recovery in urine treatment using a selective electrodialysis membrane bioreactor, Chemical Engineering Science, 2017.6.1, 171, 451–458. (Reproduced with Permission).

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Dr. Yunkun Wang

Contents

Chapter 1
Introduction

1.1 Background

Environmental pollution and water, food, as well as energy shortage are the major issues facing the world today [5, 9]. The over-exploitation and irrational use of resources by human beings has leaded to the current energy and resource crisis, and also caused adverse effects on the environment. Water pollution and the resulting shortage of water resources also seriously threaten human health and social development. Therefore, while developing new energy, it is of great significance to recycle energy and resources from waste. For wastewater treatment, while removing pollutants in wastewater and obtaining clean and recycled water, recovering the energy and other resources (such as nitrogen and phosphorus) contained in the wastewater is in line with the current situation and necessary for achieving sustainable development [2].

After a century of development, biological wastewater treatment technology based on activated sludge method has become the most widely used wastewater treatment method attributing to its stable operation and efficient organic pollutants removal. However, such conventional wastewater treatment technologies still present severe technical, economical and sustainability limitations caused by their complex operation and sludge disposal, high energy requirements, poor effluent quality, and no nitrogen and phosphorus recovery process [7]. Therefore, from the perspective of sustainable development, it is necessary to improve the current wastewater biological treatment process to achieve energy and resource recovery during wastewater treatment.

The fast development of membrane separation technology and bio-electrochemical system (BES), as well as their widely application in wastewater treatment, provides an opportunity to recover water and useful resources from wastewater [1, 4, 8]. However, there are still some problems to be solved before more widespread application of membrane separation technology, such as high costs of membrane materials, severe membrane fouling and high energy consumption for aeration [6].

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At the same time, for wastewater treatment, BESs usually have poor effluent quality and low treatment efficiency because of their limited biomass retention, which necessitates a further treatment with additional operation costs [3]. It can be hypothesized that the combination of membrane separation technology and BES may offer an attractive option for wastewater treatment and energy/nutrient recovery. Such coupling system may overcome the drawbacks of BES and membrane bioreactor (MBR) for wastewater treatment, such as the low biomass and low organics removal efficiency in BES, as well as the high cost of membrane and serious membrane fouling in MBR.

Herein, in this work, a novel bioelectrochemical membrane separation technology, which take the advantages of membrane separation technology and BES, was developed for wastewater treatment and simultaneous recovery of energy and resource.

1.2 Main Objectives and Significance of This Thesis

1.2.1 Main Objectives

In this thesis, by integrating BES into MBR process, the electrochemical membrane bioreactors (EMBRs) are constructed, and then a new bioelectrochemical membrane separation technology is developed and applied to wastewater treatment. The EMBRs system performance in terms of wastewater treatment as well as energy and resources recovery are evaluated. The main objectives includes the following aspects:

(1) Developing intermittently aerated MBRs with stainless steel mesh as filter for simultaneous carbon, nitrogen and phosphorous removal, as well as phosphorus recovery.
(2) Developing energy-saving anaerobic hybrid membrane bioreactor with mesh filter, which takes advantage of anaerobic membrane bioreactor and fixed-bed biofilm reactor for chlorophenol-contained wastewater treatment.
(3) Developing EMBR systems by integrating BES into MBR for sustainable wastewater treatment and energy recovery.
(4) Developing in situ membrane fouling mitigation and cleaning strategies by using the generated electricity in EMBRs and exploring membrane fouling inhibition process and mechanism.
(5) Developing strategies and processes of in situ utilization of generated electricity by integrating electrodialysis into EMBRs for the treatment of source-separated urine and nutrient recovery.

1.2.2 Significance of This Thesis

The most commonly used biological wastewater treatment technologies still have serious technical-economical and sustainability-related limitations, due to their high energy-consuming, poor effluent quality, and lack of energy and resource recovery processes. In this thesis, the novel electrochemical membrane bioreactors (EMBRs), which take the advantages of membrane separation technology and BES, are developed for wastewater treatment and the simultaneous recovery of energy and resource. Above all, this innovative system holds great promise for the efficient treatment of wastewater and energy recovery. It can potentially recover net energy from wastewater while at the same time harvesting high-quality effluent. The book also provides a proof-of-concept study showing that electrochemical control might offer a promising in situ means of suppressing membrane fouling. Lastly, by integrating electrodialysis into EMBRs, phosphate separation and recovery are achieved. Hence, these new EMBR techniques provide viable alternatives for sustainable wastewater treatment and resource recovery.

1.3 Thesis Structure

Chapter 1 Introduction. A brief introduction about the background, research objectives and structure of the thesis.

Chapter 2 Research background. In this section, previous studies on MBR, nutrients and pollutants removal in MBR, BES and electrochemical wastewater treatment systems are reviewed.

Chapter 3 Intermittently aerated MBR for nutrients removal and phosphorus recovery. In this section, intermittently aerated membrane bioreactors with stainless steel mesh as filter is developed for simultaneous chemical oxygen demand, total nitrogen and phosphorous removal, followed by an anaerobic digester for phosphorus recovery. This integrated system shows enhanced performances in nitrification and denitrification and phosphorous recovery without excess sludge discharged.

Chapter 4 Anaerobic hybrid MBR for refractory organic pollutant removal. In this section, a novel energy-saving anaerobic hybrid membrane bioreactor with mesh filter, which takes advantage of anaerobic membrane bioreactor and fixed-bed biofilm reactor, is developed for chlorophenol-contained wastewater treatment. The system performance in term of chemical oxygen demand and 2-chlorophenol removal are evaluated. The feasibility of membrane fouling mitigation without additional energy input was investigated. Moreover, the mechanism of fouling reduction as well as energy demand of the system are discussed.

Chapter 5 Development of electrochemical membrane bioreactor technologies for sustainable wastewater treatment. In this section, a novel electrochemical membrane bioreactor, which takes advantages of membrane bioreactor and bioelectrochemical system, is developed for wastewater treatment and energy recovery. By optimizing the system structure and operational conditions, net electricity can be recovered from the wastewater and high-quality effluent was obtained. Therefore, it is possible that this novel system might become a net energy producer, rather than a consumer for clean water harvest from wastewater.

Chapter 6 In situ utilization of generated electricity to mitigate membrane fouling. In this section, we propose a novel concept for in situ mitigation and cleaning of membrane fouling by using the generated electricity in an electrochemical membrane bioreactor. We investigate the system performance in terms of membrane fouling mitigation, power generation and nutrient removal, and elucidated how the membrane fouling was suppressed in this system.

Chapter 7 In situ utilization of generated electricity for nutrient recovery. In this section, by integrating electrodialysis into an electrochemical membrane bioreactor, a novel, selectively electrodialysis membrane bioreactor was developed for the treatment of source-separated urine and nutrient recovery. The electricity generation of the system under different resistances is evaluated, and the phosphate and sulfate separation performances and recoveries, as well as desalination utilizing the generated electricity in situ, are investigated.

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