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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　Rocco Cordon Michael Joseph

学 位 論 文 題 名

Establishment of High-Rate MBRs for Effective Recovery of Organic Matter from Municipal Wastewater: Fouling Mitigation for Long-term Operation
(都市下水からの効率的有機物回収を行う高速 MBR の確立: 長期運転のためのファウリング軽減)

Wastewater should be regarded as a resource for the establishment of a sustainable society as opposed to a waste product that needs to be dealt with. A combination of high-rate activated sludge and membrane separation (high-rate membrane bioreactors (HR-MBRs)) is considered a viable option for efficient recovery of organic matter from wastewater. Simultaneously, high effluent water quality can be achieved. However, operation of HR-MBRs suffers from extremely severe membrane fouling caused by short solid and hydraulic retention times. The establishment of the HR-MBR as a working process for organic matter recovery was aimed for in this study, and it was believed that fouling control should be the starting point. Although fouling observed during operation has been reported in studies focusing on HR-MBRs, a clear lack of research on fouling mitigation techniques applied to HR-MBRs was evident.

Control of membrane fouling in HR-MBRs, while extremely difficult, was nonetheless attempted. The effectiveness of a strategy combining granular scouring and frequent chemically enhanced backwashing was assessed. This approach was made possible through the use of robust flat-sheet ceramic membranes. Experiments were conducted at an existing wastewater treatment plant, where the MBR was operated as a high-rate system by setting solid residence time (SRT) and hydraulic residence time (HRT) at 0.5 days and less than 2 hours, respectively. With these settings in place and after the initial stages of operation had had their fouling controlled, an attempt was made to optimize the cleaning protocol for the HR-MBR mentioned previously. Improvements to the reactor design allowed for increased membrane area to be used, and a lower flux was needed to achieve the required HRT (i.e., 0.8 hours). To facilitate a long-term operation (e.g., 1 month) of the HR-MBR under the condition of a practical net flux, a novel in-situ CEB, termed air-exposed CEB (AECEB), was developed in this study. Optimization of the AECEB parameters including choice and concentration of chemicals, duration, and flux were investigated. Following these developments, due to the operational conditions employed, the concentrated stream was found to still be high in volume and low in volatile solids for subsequent resource recovery (e.g., anaerobic digestion). Addition of a secondary process was thought to be a suitable solution. Due to its reduced energy consumption and relative ease of implementation, gravity separation process with overflow into the reactor was employed to try and solve the concentration issue. The effect of fouling induced by the secondary process was focused on to ensure that the process could still function effectively.

Even though a relatively high flux of 20 L m^{-2} h^{-1} was applied, the proposed HR-MBR exhibited a very low fouling rate of 1.3 kPa/day in the first four days of operation. In this timeframe, the system could

recover more than 70 percent of the organic matter from raw wastewater, whereas the concentration of chemical oxygen demand (COD) in the effluent was lowered to less than 20 mg/L. After significant fouling was observed on the membrane, optimized AECEB achieved almost complete cancellation of the fouling developed in long-term experiments. However, transmembrane pressure surged when the operation of the HR-MBR was resumed after implementing the AECEB. It was found that scouring agents made from polyethylene glycol released foulants during the AECEB. Based on this finding, alternative scouring agents made from polyurethane were used. The final recovery of the HR-MBR was more than 70 percent and the permeate COD concentration was also below 20 mg/L. Following this result, when gravity separation was introduced as a secondary concentration process, an increase in concentration by 8.3 times and a reduction in volume by 11.5 times showed that the combination was successful in concentrating the sludge. However, gravity separation increased fouling in the HR-MBR which resulted in a much faster transmembrane pressure increase and the deterioration of filterability in the reactor. This addition also lowered the total amount of recovered organic matter because of the increased SRT and mineralization.

The low SRT and HRT set in this study enabled efficient recovery of organic matter, whereas the severe fouling in the HR-MBR could be controlled by the intensive membrane cleaning. The performance of the proposed HR-MBR observed in this study was clearly superior in the initial stages to those reported in previous studies with related operational conditions. The combination of AECEB and granular scouring using the polyurethane agents worked exceptionally well. The fouling in the HR-MBR could be almost completely controlled and long-term operation was deemed possible. Additionally, AECEB did not negatively impact the HR-MBR operation.

Although concentration of the organic matter was achieved, the drawbacks show a need for a more optimal system to concentrate the organic matter without having the negative impact observed in this study. Other options, such as chemically enhanced clarification or direct membrane filtration, should also be considered for a secondary concentration process, although they come with significant drawbacks such as the cost of coagulants or additional energy requirements.