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ADVANCED MBR PROCESSES FOR WASTEWATER TREATMENT AND ENERGY PRODUCTION

PROCESSI MBR AVANZATI PER IL TRATTAMENTO DELLE ACQUE REFLUE E LA PRODUZIONE DI ENERGIA

ABSTRACT

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ABSTRACT

More stringent standards on water quality along with the shortage of water resources have led to the development of advanced wastewater treatment processes, in order to ensure the respect of discharge limits and the reuse of treated water. Membrane bioreactors (MBRs), combining biological processes with membrane filtration, are becoming increasingly popular as wastewater treatment due to their unique advantages such as high effluent quality, low production of excess sludge and small reactor volume. However, membrane fouling is still gaining the research attention for improving the performance of this technology since it still involves high operating costs due to the energy consumption for contrasting this phenomenon. Several factors like the type of influent wastewater, sludge loading rate, sludge age, MLSS concentration and microbial products, such as bound extracellular polymeric substances (bEPS), soluble microbial products (SMP) and, only recently and in few studies, transparent exopolymer particles (TEP), are thought to influence membrane fouling.

Recent studies have proven that the application of electrochemical and bioelectrochemical processes to membrane bioreactors represents a promising technological approach for membrane fouling control. In the last years, electrochemical processes have been applied to membrane bioreactors to limit membrane fouling by integrating these processes into the reactor itself (electro MBR) or applying electrocoagulation as a pre-treatment. These studies, however, did not highlight the mechanisms of nutrient removal, in particular of ammonia compounds, inside the electro membrane bioreactor. Furthermore, the influence of electrochemical processes on activated sludge flocs hydrophobicity and TEP concentration in a membrane bioreactor and the possibility of recovery hydrogen from this system have not been investigated yet.

In wastewater, an internal energy exists which can be extracted as electricity or hydrogen and be used to reduce fouling directly and to lessen input of external energy. Microbial fuel cells (MFCs) and microbial electrolysis cells (MECs) are two types of bioelectrochemical systems (BES) that use exoelectrogenic microbes to produce energy from

wastewater by converting biodegradable organic matter directly into electricity and hydrogen, respectively. Only recently, MBRs have been combined with bioelectrochemical systems (BES), as an internal or external configuration, for cost-effective wastewater remediation, overcoming the problem of high energy consumption of MBR and avoiding dissolved methane that results in anaerobic MBR. However, few studies are available regarding the combination of MBRs with MFCs in an external configuration and they did not assess the main electron transfer mechanism governing the anode electro-active biofilms.

The Ph.D. research project aimed to control fouling in membrane bioreactors and enhance the treatment performance through the integration of electrochemical and bioelectrochemical processes. A further objective was to assess the energy production in the combined systems in terms of electricity and hydrogen.

The experimental activity was divided in following four phases: design and construction of the membrane bioreactor at laboratory scale; integration of electrochemical processes into the membrane bioreactor (electro MBR); application of a microbial fuel cell (MFC), as a down-stream process for treating the excess sludge from a MBR pilot plant; evaluation of the hydrogen production in the electro MBR at anoxic conditions. The first two phases and the last phase of research activity were conducted at the Sanitary Environmental Engineering Division (SEED) of Salerno University (Italy). The third phase was performed for three months at the Laboratory of Chemical and Environmental Engineering (LEQUIA) of the University of Girona (Spain).

Regarding the electro MBR, two intermittent voltage gradients (1 V/cm and 3 V/cm) were applied between two cylindrical perforated electrodes, immersed around a membrane module, with the aim of investigating the treatment performance and the membrane fouling formation. In particular, the impact of electrochemical processes on transmembrane pressure variation over time, on sludge relative hydrophobicity and on TEP, proposed as a new membrane fouling parameter, compared with the conventional precursors such as bEPS and SMP, was investigated. Furthermore, mechanisms of nutrient removal were studied. For comparison purpose, the reactor also operated as a conventional membrane bioreactor. All the results indicate that the integration of electrochemical processes into a membrane bioreactor has the advantage of improving the treatment performance especially in terms of nutrient removal and of reducing membrane fouling through the increase of floc hydrophobicity up to 71.7%, the decrease of membrane fouling precursors' concentrations and, thus, of membrane fouling rate until to 54.3% at 3 V/cm. The relationship found between the TEP concentration and the membrane fouling rate confirms the applicability of this parameter as membrane fouling indicator.

Closing the electro MBR and working at anoxic conditions like a MEC, hydrogen production was detected in the electro MBR with a maximum volumetric production rate of around 18 $mg(H_2)m^{-3}min^{-1}$, highlighting the possibility of energy production by the combined system.

With reference to the combination of a MFC with a MBR, a potentiostatic controlled microbial fuel cell (MFC) was fed in batch with activated sludge from a membrane bioreactor (MBR), characterized by a different influent total suspended solids (TSS) content, in order to understand the bioelectrochemical response of the system and the impact of the treatment on the sludge characteristics and membrane fouling parameters. An open circuit voltage microbial fuel cell (OCV-MFC) was operated as a control test. Regarding sludge degradation, the MFC showed higher COD removals than the control test and a reduction of the sludge highlighting its stabilization. Electricity production in the MFC increased with the increase in the sludge of the influent COD and TSS content achieving a maximum current density of 2.0 A m^{-2} and a voltage output of 100 mV. The electrochemical characterization indicated that the oxidation of the sludge took place at a formal potential of -0.211 ± 0.040 V vs. SHE with a direct electron transfer (DET) mechanism. An increase of sludge hydrophobicity, a reduction of protein extracellular polymeric substances (EPSp) and carbohydrate soluble microbial product (SMPc), along with an increase of SMPp/SMPc ratio, were obtained in the MFCs which could limit membrane fouling in the case that the treated sludge is recirculated to the MBR reactor. The results observed indicated that sludge reduction, electricity production and a variation of membrane fouling parameters could be obtained in a MFC treating MBR sludge.

Therefore, the combination of membrane bioreactors with electrochemical and bioelectrochemical processes represents an innovative and promising method for the increase of treatment efficiencies, sludge reduction, fouling control and energy production.