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Performance of a hybrid membrane bioreactor treating a low strength and alkalinity wastewater

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ABSTRACT

A pilot-scale Hybrid Membrane Bioreactor (HMBR) containing both suspended biomass and biofilm was tested for the treatment of a low strength municipal wastewater. The wastewater fed was characterized by a high variability throughout the day, low BOD_5/TN ratio and low alkalinity (302 ± 52 mgCaCO$_3$/L). For limiting membrane fouling, an innovative abrasive granular material has been proven in the Microdyn-Nadir membrane. Permeability ranged from 126 to 291 L/(h m^2 bar) during the operational period, achieving a maximum flux of 24 L/(m^2 h). A low BOD_5/TN ratio of the raw wastewater, led to insufficient denitrification, with an average nitrogen removal of 49%. This fact, in turn, caused a decrease in the pH due to the lack of alkalinity. This study underlined that wastewaters characterized by high variability throughout the day, low BOD_5/TN ratio and/or low alkalinity content require carefully design of the MBR systems. It was shown that a low pH in the HMBR led to a strong membrane fouling increasing cake resistances.

1. Introduction

Over the last century, conventional activated sludge systems (CAS) have been spread all over the world in municipal wastewater treatment plants (WWTP) because of its reliability and the long experience accumulated. In comparison with other newly developed biological technologies, such as membranes, aerobic granular sludge, or biofilm reactors (based on attached biomass), CAS facilities presented lower removal organic loading rates (OLR) [1].

Membrane technologies have become a well-acknowledged treatment process implemented worldwide for wastewater treatment [2]. A membrane bioreactor (MBR) can be defined as a modified conventional activated sludge (CAS) reactor with a membrane filtration process instead of the secondary settler [3]. MBR-related technologies offer many advantages over the CAS processes. The quality of the effluent is better, especially in terms of suspended solids and microbial indicators [4] in comparison with the CAS outputs. Moreover, the footprint requirements of MBR and the improved capacity of controlling the applied solids retention time (SRT) have made this technology very attractive. For instance, MBR systems are recommended when land scarcity is an issue or for treating sewage in areas with high environmental sensitivity.

The energy demand of MBR processes is still higher than that of CAS but similar to those facilities in which a tertiary post-treatment was implemented, and the overall energy requirements for treating sewage in such WWTPs could be as low as 0.65–0.70 kWh/m^3 [5]. Membrane fouling is one of the most important drawbacks of the MBR technology. This phenomenon has been defined as the deposition of inorganic and organic substances either on the membrane surface or in the pores of the membrane [6]. However, it has not been accurately described yet since the severe complexity and the interactions of the involved factors which impact in declining the capacity of the membrane. Both energy consumption and fouling are related, since an important share of the membrane aeration demands is driven to prevent the cake layer formation, increasing energy requirements [6,7]. Additionally, fouling has been associated with a detrimental hydraulic capacity of the MBR system.

In the last decades, biofilm processes have been launched as an integrated solution for increasing the capacity of the traditional CAS wastewater systems. These processes are based on the attachment of the microorganisms onto the surface of any support medium for the initiation of a microbial biofilm. Once the biofilm is developed, a self-regulated ecosystem is established [8,9]. Moreover, the microbial diversity in biofilms could be different to that found in suspension, in those systems in which biofilms and flocs coexist [10]. The use of small suspended biofilm carriers was successfully proven for enhancing

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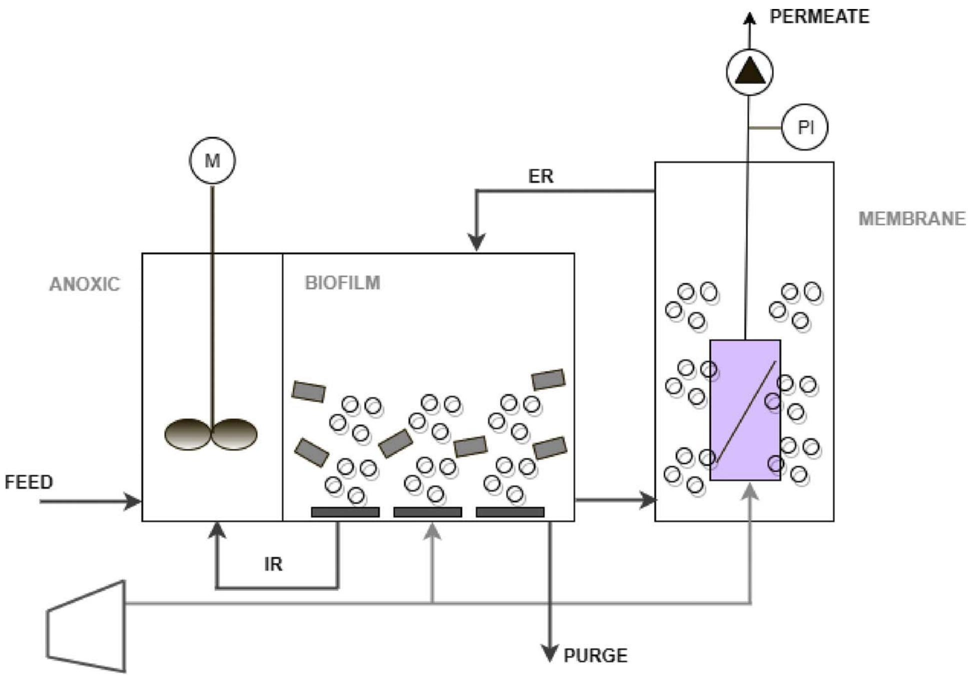

Fig. 1. Flowchart of the pilot plant HMBR. From the left to the right: anoxic (only suspended biomass), biofilms (with biofilm carriers & suspended biomass) and membrane (with suspended biomass) compartments.

organic matter and nutrients removal in conventional systems [11]. These alternatives based on the coexistence of both suspended and attached biomass, have been commonly known as hybrid systems. Thus, this approach should be always considered when studying the possibility of upgrading either urban or industrial WWTP based on CAS processes [12]. By adding these carriers and developing a biofilm onto their surface, the biomass concentration can be increased approximately an equivalent of 1.5–2.0 g/L of activated sludge [1]. As a consequence, it has been feasible to treat up to twice or three times higher organic and nitrogen loading rates, leading to a space demand much lower than in CAS systems.

In the 2000's, a new approach known as hybrid MBR (HMBR) was released [13]. As a result of MBR and biofilm combination, it was foreseen the empowerment of their benefits as treating higher loads of pollutants in less land and the reduction of drawbacks such as membrane fouling. This alternative has been especially appropriate when land scarcity or strict discharge limits are important requests.

A previous study with a lab scale HMBR, achieved nitrogen and organic loading rates of 1.8 kg N/m^3 d, and 6.5 kg COD/m^3 d, respectively. COD removal was 95% and ammonium was fully nitrified, treating industrial wastewaters from a tannery factory [14]. COD and TN of the incoming wastewater were 800–1300 mgCOD/L and 120–160 mgN/L. The reactor was operated at SRT comprehended between 1 and 10 days. In another study, a pilot-scale HMBR fed with fish-canning wasterwater, they were achieved an OLR of 4 kg COD/m^3 d and an NLR of 0.7 kg N/m^3 d. Up to 92% and 95% of COD and nitrogen removal were obtained, respectively [15]. Rodríguez-Hernández et al. [11] treated municipal wastewater in a HMBR of 1.8 m^3 volume (SRT up to 180 days and HRT 9–12 h), with COD and nitrogen removal rates up to 1.80 and 0.05 kg/m^3 d. The incoming COD and TKN were 372 and 24 mg/L, respectively. Other study with municipal wastewater also pointed out that the presence of both biofilms and suspended biomass in an HMBR improved nitrogen removal in comparison with a similar MBR containing only biomass in suspension [16]. In both studies, nitrogen denitrification was restricted to the inner parts of the biofilm.

The impacts of biofilm systems are not only limited to the capacity of upgrading CAS systems, also suspended carriers may influence the membrane performance. Thus, the carrier selection could either increase or decrease the membrane fouling. Kurita et al. [17] stated that carriers' material had a determinant impact on Fouling Rate (FR). In their work, when rope carriers where added, FR increased. In contrast, if either granular of sponge carriers were present FR diminished. Sánchez et al. [18] also found that the presence of biofilms diminished the FR, due to the significantly lower amount of colloids detected when biofilms were present in the MBR. Moreover, biofilms provided anoxic zones in their inner parts, promoting nitrogen removal through the denitrification process [17,19].

Despite the knowledge achieved in the last decades with regards to membrane technologies, the use of MBRs and especially HMBRs for treating low strength municipal wastewater still remains a challenge. This kind of municipal wastewater is commonly produced in cities with high pluviometry and/or when a combined sewerage collection network is available. Rain and underground water led to a dilution effect of the collected wastewater. Thus, a study on the HMBR applicability seemed to be an adequate option.

The main aim of this study is to present the results obtained in an HMBR operated in a municipal WWTP for the treatment of primary settled low strength and alkalinity municipal wastewater.

2. Materials and methods

2.1. Experimental set-up

The pilot plant used in this study was implemented in a WWTP located in Vigo, NW Spain. This WWTP has a design capacity of 400,000 equivalent inhabitants (Eq. in.). The treated water is discharged in an estuary containing bathing and aquaculture areas. The pilot plant (Fig. 1) was operated during four months fed with primary treated wastewater, pumped from one of the primary clarifiers of the facility. The feeding to the HMBR was led to a 1 mm rotary fine screen, in order to prevent the entrance of floating coarse solids and stored in a buffer tank.

The scheme of the HMBR is shown in Fig. 1. The HMBR, with a total capacity of 4.4 m^3, consisted of three compartments. In the first, a stirred anoxic reactor of 0.9 m^3 volume, named as anoxic compartment hereafter, only suspended biomass was used. The second, of 1.7 m^3 volume, contained both biofilms attached onto carriers and suspended biomass. Both, suspended biomass and biofilms were maintained in suspension by aeration. This compartment, named biofilm compartment hereafter, was filled with 40% v/v biofilm carriers (BioWater®,