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Pilot-scale membrane bioreactor for wastewater treatment using innovative encapsulated self-forming dynamic membrane

CASTROGIOVANNI F.[1], BOREA L.[1], HASAN S.W.[2], BELGIORNO V.[1] and NADDEO V.[1,*]

[1] Sanitary and Environmental Engineering Division (SEED), Department of Civil Engineering, University of Salerno, Fisciano 84084 (SA), Italy

[2] Department of Chemical Engineering, Khalifa University of Science and Technology, Masdar City Campus, PO Box, 54224, Abu Dhabi, United Arab Emirates.

*corresponding author:
e-mail: vnaddeo@unisa.it

Abstract The use of membrane bioreactors (MBR) is a promising technique for wastewater treatment that manages to respect the restrictive limits imposed by regulations.

However, during the filtration process membranes are subject to fouling which requires additional costs for cleaning and replacing the modules. This phenomenon severely limits the widespread of this technology on a real scale.

Thanks to many scientific studies, it has been possible to put into practice various fouling mitigation strategies which, at the same time, manage to increase the treatment efficiencies of the system, such as the application of electrochemical processes associated with MBR reactors (e-MBR).

The introduction of low-cost self-forming dynamic membranes (SFDM), to replace the conventional ones, has made MBR technology even more promising. However, the large size of the pores limits their application since the effluents obtained at the beginning of the process are not of good quality.

In the present study the performance of an innovative patented hybrid reactor, which combines encapsulated self-forming dynamic membranes (ESFDM) with an electro-MBR, was studied.

The experiment, conducted at a pilot scale using real wastewater from a full-scale wastewater treatment plant, evaluated the efficiency of pollutant removal and fouling formation as a function of the applied current density.

Keywords: Electrochemical processes, Current density, Membrane fouling, Dynamic membrane, Sustainable development

1. Introduction

In recent years, wastewater treatment using membrane bioreactors (MBR) has become increasingly frequent, thanks to the numerous advantages it can offer (Ensano et al., 2019; Millanar-Marfa et al., 2018).

Wastewater treated with an MBR reactor has an excellent quality, such that it can be reused for agricultural and/or industrial purposes. The volumetric load is higher and there is also a reduction in footprint and sludge production compared to conventional activated sludge systems (CAS) (Pervez et al., 2020).

Fouling of the membrane during the filtration phase represents the main obstacle for the full-scale application of this technology because it requires frequent cleaning of the membranes, and therefore high costs (Bagheri and Mirbagheri, 2018; Borea et al., 2019).

There are numerous studies by the scientific community that address the problem of fouling and confirm how difficult it is to undertake strategies for its mitigation. The factors that influence the membrane fouling can be grouped into four broad categories which are: the characteristics of the foulant (concentration, molecular size, solubility, diffusivity, hydrophobicity, charge, etc.), the properties of the membrane (hydrophobicity, surface roughness , pore size and PSD, surface charge and surface functional groups); the operating conditions (flow, solution temperature and flow rate), the characteristics of the feed water (chemistry of the solution, pH, ionic strength and presence of organic / inorganic matter) (Tijing et al., 2015).

Many authors have investigated the possibility of integrating electrochemical processes into MBR (e-MBR) (Bani-Melhem and Elektorowicz, 2010; Borea et al., 2019; Ensano et al., 2019).

Thanks to the mechanisms of electrocoagulation, electroosmosis and electrophoresis it is possible to have a good mitigation of fouling and, at the same time, to obtain greater treatment performance of the system (Borea et al., 2018; Ensano et al., 2016; Hasan et al., 2014).

An innovative MBR technology is based on the use of self-forming dynamic membranes (SFDM) to replace the conventional micro/ultra filtration modules used to separate the solids from the effluent (Ahmar Siddiqui et al., 2019; Sabaghian et al., 2018).

The main difference between an SFDM and a traditional membrane is the size of the pores; the self-forming dynamic membrane uses a material with coarse pores (10-200 microns) as a support for the formation of the dynamic membrane, which is formed during the first

stages of the process thanks to the deposit of the sludge present in the biological reactor (Mohan and Nagalakshmi, 2020).
The main advantages of SFDMs are the easy control of encrustations, the low costs of the membrane materials, the possibility of working with high permeate flows, the request for a low energy requirement and the possibility of obtaining an high treatment capacity, but only in the stable phase of the process. The large size of the pores in fact causes a poor quality permeate in the start-up phase. Furthermore, the SFDM is in contact with the aerated mixture which causes process instability (Ahmar Siddiqui et al., 2019; Pollice and Vergine, 2020).
The novelty of the research of this manuscript is the coupling and the transfer of the two technologies (eMBR and SFDM) to an encapsulated dynamic-forming membrane electro bioreactor (e-ESFDMBR), recently patented by the research group of the SEED laboratory of the University of Salerno (Italy) (Naddeo et al., 2020), on pilot scale fed with civil wastewater and subjected to the displacement of variables (temperature and nutrient load) that occur under standard operating conditions.

2. Materials and Methods

The e-ESDFMBR pilot plant was located in the municipal wastewater treatment plant of Battipaglia (Italy). The system consisted of a cylindrical plastic reactor with a working volume of 100 liters; the support material for the formation of the encapsulated self-forming dynamic membrane was dacron (Saati SpA), with a porosity of 30 μm, inserted in a suitably designed plexiglass support (Naddeo et al., 2020).
Two perforated cylindrical electrodes made of aluminum (anode) and stainless steel (cathode) were placed centrally on the membrane module and connected to a power supply (CPX400, TTi, 0-60 V, 0-20 A) with an intermittent operating mode.
Air was supplied through fine bubble air diffusers centered on the bottom of the reactor. The e-ESFDMBR was continuously replenished with municipal wastewater. The wastewater supplied in this study was subjected to varying temperatures and varying loads.
The removal efficiencies obtained by the system in terms of conventional contaminants were evaluated using standard methods (APAT and CNR-IRSA, 2003). Membrane fouling was evaluated in terms of fouling rate, precursors of membrane fouling such as EPS, SMP and TEP (Borea et al., 2019).

Figure 1 shows the experimental setup of the e-ESFDMBR system.

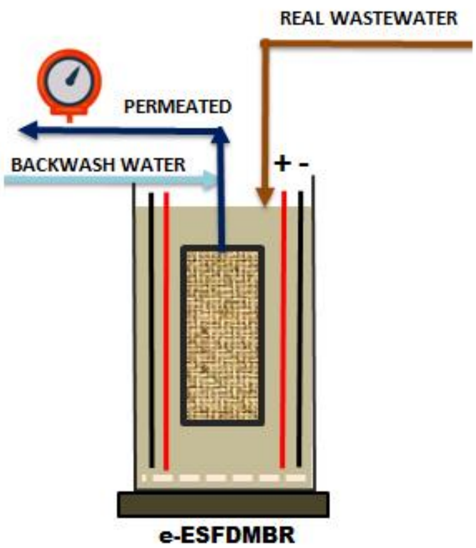

Figure 1. Experimental setup of the e-ESFDMBR at pilot scale

3. Results and Discussion

The application of electrochemical processes to encapsulated self-forming dynamic membranes (e-ESFDMBR) resulted in an increase in treatment performance, with high removals of organic and nutrient compounds, when the applied current intensity was increased.
With reference to the fouling of the encapsulated self-forming dynamic membrane, this study demonstrated how the application of an intermittent electric field in an ESFDMBR minimizes membrane dirt with a decrease in TMP over time.
Fouling of the membrane made it possible to clog the pores of the support material, which had a high porosity, and increase the purifying performance of the system.
Contaminant removal efficiencies were greater in reactors operating with electric field application compared to reactor operating without electric field application (ESFDMBR) due to the different electrochemical mechanisms developed within the e-ESFDMBR. COD removals ranging from about 95% to about 98% were achieved as the applied current density increased. As for ammonia nitrogen (NH_4-N) the removal efficiencies ranged from 97% to 99%.

The results obtained demonstrate how encapsulated self-forming dynamic membranes are able to obtain high purification efficiencies even using a real wastewater and operating in real climatic conditions.

4. Conclusion

This study has shown that the innovative e-ESFDMBR system is a potential tool to replace the traditional activated sludge treatment system and the use of traditional membranes, which still require high costs, with economical membranes that are able to encapsulate biomass and to increase the treatment performance with very low costs.

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