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Anaerobic dynamic membrane bioreactor for wastewater treatment at ambient temperature

Luca Alibardi [a], Nicoletta Bernava [b], Raffaello Cossu [a], Alessandro Spagni [c,*]

[a] *Department of Industrial Engineering, University of Padova, via Marzolo 9, 35131 Padova, Italy*
[b] *Department of Civil, Environmental and Architectural Engineering, University of Padova, via Marzolo 9, 35131 Padova, Italy*
[c] *Water Resources Management Laboratory, Italian National Agency for New Technology, Energy and Sustainable Economic Development (ENEA), via M.M. Sole 4, 40129 Bologna, Italy*

HIGHLIGHTS

- Anaerobic dynamic membranes can be developed at ambient temperature.
- Dynamic membrane over large pore size mesh can obtain efficient solid rejections.
- Biofilm forming the dynamic membrane significantly contributed to organics removal.
- Methane oversaturation occurred due to ambient temperature and low HRTs.

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ABSTRACT

A bench-scale dynamic membrane (DM) bioreactor was operated to evaluate the anaerobic treatment of a synthetic municipal wastewater at ambient temperature. The DM was developed over a large pore size (200 μm) mesh in order to improve sludge filterability and reduce energy consumption. The system achieved average organic removals higher than 80% and 90% for total COD and filtered COD, respectively. Results also demonstrated that the biofilm, which the DM is made of, played a significant part in obtaining the overall organic removal efficiency. The large pore size of the mesh allowed for high membrane fluxes (approximately 15–20 $\text{L m}^{-2}\text{ h}^{-1}$) applying low TMP (usually lower than 50–100 mbar). Fluxes higher than 20 $\text{L m}^{-2}\text{ h}^{-1}$ produced low solid removal efficiency indicating deterioration of the DM. COD mass balance suggests that the low hydraulic retention times applied to the system caused methane loss through the effluent due to oversaturation.

1. Introduction

Municipal wastewaters are, currently, mainly treated by the use of activated sludge systems which, although effective, require a great deal of energy [1]. As a result, anaerobic technologies have been widely investigated for the treatment of municipal wastewater. Their benefits are the production of biogas as a renewable energy source and reduced energy consumption if compared to conventional aerobic treatment [1–4]. The advantages of anaerobic treatments will also be emphasised in future water and wastewater management scenarios [5]. Anaerobic processes can in fact improve the recovery of energy, materials and water from concentrated and diversified wastewater streams both in centralised and decentralised systems [5].

Mesophilic conditions are the preferred option for anaerobic wastewater treatment. These conditions, however, make anaerobic processes of medium to low strength streams such as municipal wastewater non cost-effective. The low energy recovery per unit of volume is not in fact sufficient to satisfy the heat and power requirements of reactors [1,6]. Solutions allowing for the application of anaerobic processes at ambient or psychrophilic temperatures for low strength wastewater are, therefore, very attractive [6,7].

However, several aspects related to the application of psychrophilic conditions are still under investigation. For example psychrophilic conditions do not only reduce microbial kinetic rates but also increase gas solubility, thus leading to lower methane recovery and methane losses with the effluent [1,8].

Anaerobic processes under psychrophilic conditions have been successfully applied to municipal wastewater treatment by high rate systems such as the up-flow anaerobic sludge blanket (UASB) and expanded granular sludge bed (EGSB) reactors [6,7]. However, serious problems arise when treating low strength wastewater under psychrophilic conditions using these technologies. In fact, low biomass growth rates at low temperatures and high hydraulic

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* Corresponding author. Tel.: +39 051 6098779; fax: +39 051 6098309.
E-mail address: alessandro.spagni@enea.it (A. Spagni).

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loading rates increase sludge wash out. In addition, applications of UASB and EGSB reactors for municipal wastewater treatment are limited by the influent high concentrations of suspended solids and inert substances [6].

Over the last decade, several studies have investigated the application of membrane bioreactors (MBRs) in anaerobic conditions [2,9–12]. Microfiltration (MF) and ultrafiltration (UF) membranes, in fact, allow complete biomass retention so that a high concentration of slow-growing anaerobic bacteria in the reactor can be reached, even at low hydraulic retention time (HRT) [2,9,12]. Only a few studies have evaluated the performance of anaerobic MBR (AMBR) at psychrophilic or ambient temperature, although, very promising results have been obtained [2,12,13].

The first studies on sludge filterability in AMBRs [12,14] have showed, although not conclusively [10], more severe fouling phenomena under anaerobic rather than aerobic conditions. Consequently, mesh filtration has recently been proposed as an alternative to the use of MF/UF-MBRs in order to improve sludge filterability and reduce capital and management costs [15–19].

When mesh filtration is applied, a dynamic membrane (DM) develops on the support material (the mesh). DM is a cake layer or biofilm obtained through the deposition over the mesh of organic substances and bacteria present in the reactor. Once DM is formed, solids rejection is carried out by this regenerative biological layer while the mesh only acts as a support [17,20]. The layer can be formed and re-formed as a self-forming DM and the permeability can be affected by controlling its thickness while the support (mesh) can be characterised by large pores. The cake layer that develops on the mesh plays, thus, a central role during DM filtration [17] while it is considered the main drawback for the widely adopted conventional MF/UF-MBRs.

DMs cannot, it seems, achieve the high water quality obtained by MF and UF due to the different membrane cut-off. However, DMs could represent a worthwhile compromise between water quality and plant costs in anaerobic processes, since effluent post-treatments are usually considered prior to final water discharge (e.g. for nutrient removal).

DM technology can offer benefits over traditional filtration in biological treatments by precluding the need of costly membrane modules and by providing a low-cost, regenerative, self-forming filtration surface with adaptable permeability and high fluxes [16,17].

The link between mesh pore size and dynamic layer formation is still not clear. The use of large pore size mesh can reduce the overall filtration resistance and the cost of the filtration module; however, the maximum size allowing the development of a reliable dynamic filtration layer has not been defined yet. Experiments on DM development have been carried out with mesh opening between 30 and 90 μm [20–23]. Preliminary studies indicated that an effective cake layer does not develop over meshes with pore sizes larger than 60–70 μm [23]. On the contrary, Alibardi et al. [15] developed a DM on a large pore-sized mesh (200 μm) in mesophilic conditions by properly managing hydrodynamic conditions. Moreover, Kiso et al. [24] suggested that DMs not only act as filters but may also improve overall pollutant removal efficiency through the biochemical reactions that occur within the cake layer.

This study aimed to evaluate the application of an anaerobic dynamic membrane bioreactor (ADMBR) equipped with a coarse filtration mesh (200 μm) for the treatment of high-strength municipal wastewater at ambient temperature. A large pore size mesh was used in order to improve filterability and reduce energy consumption. The study also aimed to evaluate the contribution of the DM biofilm on the overall organic removal efficiency of the reactor.

2. Material and methods

2.1. Experimental setup

The study was performed by using a bench-scale ADMBR equipped with an external cross-flow filtration unit (Fig. 1).

The reactor had a total volume of 898 mL ($W \times H \times D$: $9.5 \times 10.5 \times 9$ cm) and a working volume of 684 mL. The level of the mixed liquor was kept constant by using a level sensor connected to the influent pump. The filtration support had an inner volume of 60 mL ($W \times H \times D$: $20 \times 1.5 \times 2$ cm). A monofilament woven mesh made of polyamide/nylon (SaatiMil PA 7, Saati s.p.a., Italy) with openings of 200 μm, thread diameter of 120 μm, mesh count of 31/cm and 39% opening area (data from the sup-

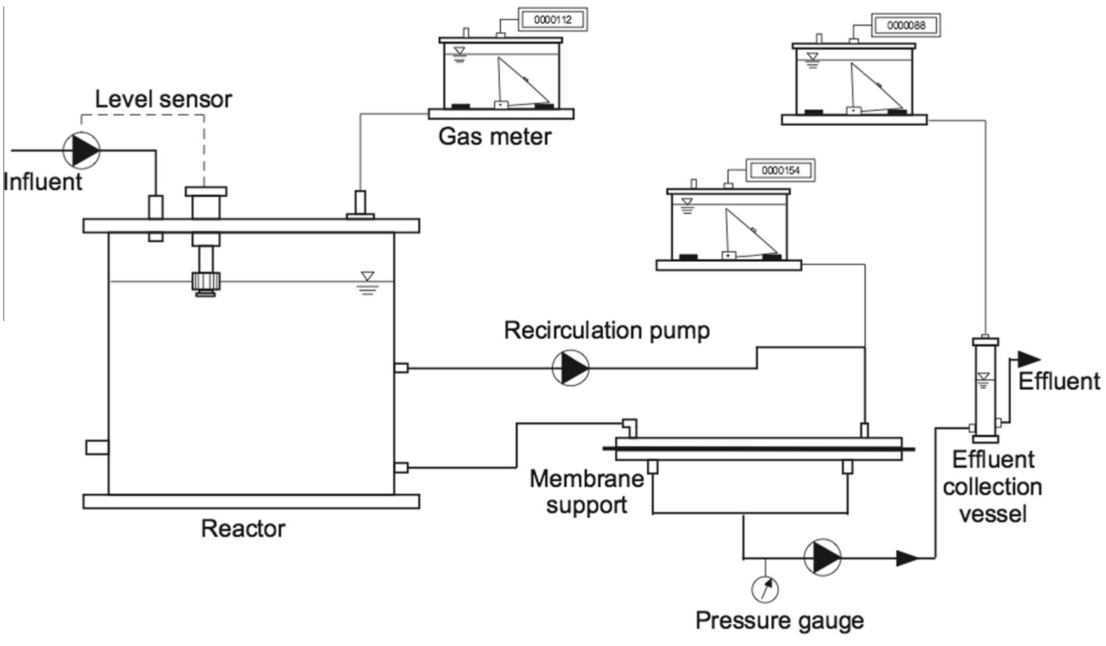

Fig. 1. Schematic diagram of the bench-scale ADMBR.