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Foaming in membrane bioreactors: Identification of the causes

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ABSTRACT

Membrane bioreactors (MBRs) represent by now a well established alternative for wastewater treatment. Their increasing development is undoubtedly related to the several advantages that such technology is able to guarantee. Nevertheless, this technology is not exempt from operational problems; among them the foaming still represents an "open challenge" of the MBR field, due to the high complexity of phenomenon. Unfortunately, very little work has been done on the foaming in MBRs and further studies are required. Actually, there is not a distinct difference between conventional activated system and MBR: the main difference is that the MBR plants can retain most Extracellular Polymeric Substances (EPSs) in the bioreactor. For these reason, unlike conventional activated sludge systems, MBRs have experienced foaming in the absence of foam-forming micro-organisms. Nevertheless, the actual mechanisms of EPS production and the role of bacteria in producing foam in activated sludge in MBRs are still unclear. In this paper, the authors investigated the roles of EPS and foam-forming filamentous bacteria by analyzing samples from different pilot plants using MBRs. In particular, in order to define the macroscopic features and the role of EPS and filamentous bacteria, a Modified Scum Index (MSI) test was applied and proposed. Based on the MSI and the foam power test, the causes of biological foaming were identified in terms of the potential for foaming, the quality and the quantity of the foam. The results indicated that the MBR foaming was influenced significantly by the concentration of bound EPSs in the sludge. In addition, the quantity and stability of MBR scum increased when both bound EPSs and foam-forming filamentous bacteria were present in the activated sludge.

1. Introduction

An Membrane BioReactocr (MBR) system replaces the gravitational sedimentation unit of the conventional activated sludge (CAS) process and provides complete solid–liquid separation by the use of a microfiltration or an ultrafiltration membrane (Judd and Judd, 2010). The membrane allows the retention of all solids that are larger than 0.01 (Ultrafiltration)-0.1 (Microfiltration) μm, so free swimming bacteria are retained. Unfortunately, there are some disadvantages, such as membrane fouling and biological foaming (Di Bella et al., 2010; Mannina and Di Bella, 2012). In fact, the tank in which the membrane module is submerged may become a "foam trap" and the recirculation of trapped foam make foaming worse (Wanner, 1994; Jenkins et al., 2004).

The ability of some micro-organisms to float and create foam is well known in general microbiology. In particular, the biological foaming by Nocardioform and *Microthrix parvicella* has been reported predominantly in nutrient removal plants that have different cultivation conditions compared with the conventional activated sludge plant (Wanner, 1994). In general, the periodic formation of foam, worries constantly the operators of wastewater treatment plant.

Although the phenomenon of foaming in CAS systems has been studied extensively, this is not the case for advanced wastewater treatment systems, such as membrane bioreactors (MBRs). Thus, the exact mechanism by which foam is formed and how to stabilise this process in MBRs has not been determined, and it may include several steps. Until this mechanism is determined, we will not be able to develop reliable control methods.

In general, foam results in the same adverse effects in both the CAS process and the MBR process, as described below:

- since significant quantities of mixed liquor suspended solids (MLSS) trapped inside the foam, it may be difficult to control the concentration of the sludge in the aeration tank;
- in warm climates, the foam decays rapidly, producing a foul odor;

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- if the production of foam is not curtailed, the foam can accumulate to such an extent that it can overflow the basin freeboard, covering walkways, handrails, surrounding areas, and creating hazardous or slippery conditions.

The investigation of foaming in the activated sludge process involves determining the propensity of mixed-liquor samples to foam and evaluating the various physico-chemical properties of the sludge that have been linked to CAS foaming in earlier studies (Fryer and Gray, 2012). In this context, the microscopic examination of activated sludge in many cases has shown that biological foams are generally enriched with gram-positive filamentous bacteria (Kragelund et al., 2007; Petrovski et al., 2011). Furthermore, the hydrophobic compounds that are synthesized and excreted by these bacteria increase the hydrophobicity of activated sludge, which is a key factor in controlling the formation of foam and stabilising the scum (Iwahori et al., 2001; Petrovski et al., 2011).

In the investigation of foaming in the activated sludge process, the usual approach is to conduct a series of foamability tests that simulate the aeration conditions in a plant and that provide an indication of the propensity of the sludge samples to generate foam. This approach is especially useful and important when new causes and effects must be identified, as is the case for the MBR process. Previously, simple foam tests were used to quantify the foam in CAS plants (Blackall et al., 1991; Constant, 1992; Pretorius and Laubscher, 1987). Similar foam tests have been used in recent years for MBR systems (Nakajima and Mishima, 2005; Di Bella et al., 2011). In particular, in order to define the quality, the quantity and the scum features, three main foam tests have been used: Scum Index (SI), Foam Rating (FR), Foam Power (FP). The SI quantifies the foam produced, in according with the selective flotation principle, proposed by Pretorius and Laubscher (1987), that provides a flotation of mixed liquor sample and a subsequent purification of separated scum from non-foam forming micro-organisms. The FR defines foam generation and stability in terms of foam volume, bubble size, foam speed formation and collapse time after aeration (Blackall et al., 1991).

The FP has been performed to evaluate the foam potential of MBR activated sludge, in according with protocol reported by Nakajima and Mishima (2005).

On the other hand, the surface areas covered by foam in different plants were determined for use in comparing the severity of foaming between plants (Hladikova et al., 2002), and, in some cases, foam coverage was found to correlate well with readings of foam potential (Torregrossa et al., 2005). Unfortunately, since the apparent degree of foam coverage on activated sludge tanks is likely to be influenced by the layout of the plant, the configuration of the process equipment, and operational parameters (e.g., trapping, recycling, and accumulation of foam in certain locations in the process), this variable must be used with extreme caution when compared on its own to other parameters, such as foam thickness and stability (Hug, 2006; Fryer and Gray, 2012).

Currently, none of the approaches reported in the international literature has presented a viable approach for quantifying the risk to MBR plants when foam forms the aeration surfaces. In fact, in the recent years, only a few experiments have been reported regarding the management and control of foaming in MBRs.

You and Sue (2009) investigated the role of certain micro-organisms in the formation of foam in MBRs. Their study was related to the metabolism of particular micro-organisms, some of which were already known as “foam-forming” micro-organisms in CAS plants. However, foaming in the MBR process has attracted the attention of many researchers because, contrary to what happens in CAS plants, foam has been observed in MBR plants even in the absence of foam-forming micro-organisms (Nakajima and Mishima, 2005; Di Bella et al., 2011). Under these circumstances, it has been reported that the quantity of foam formed is related to the concentrations of extracellular polymer substances (EPSs) (Di Bella et al., 2011).

In general, however, there is not a distinct difference between CAS and MBR in terms of form-forming mechanisms. Some surfactants produced by foam-forming bacteria, EPS released by bacteria, and some other factors may be responsible for the production of biological foams in most of biological wastewater treatment systems. The main difference is that the MBR plants can retain most of EPSs in the system.

Bearing in mind such considerations, in the research reported in this paper, we investigated the roles of EPSs and of the abundance of foam-forming, filamentous bacteria by analysing samples from several MBR pilot plants. In particular, in order to define the macroscopic features of foam in MBRs and the role of EPS and filamentous bacteria in the formation of foam in MBRs, some test results reported by Di Bella et al. (2011) were used. Specifically, in order to quantify the foam produced and to differentiate the effects of EPS and filamentous bacteria, a “modified” scum index (MSI) test was proposed and used.

2. Materials and methods

2.1. Experimental setup and operation

Samples of mixed liquor were collected from three different MBR pilot plants that had different configurations. The characteristics of the influent wastewater and the operating conditions of each MBR plant are summarised in Table 1. It is important to note that the values shown in the table are the average values that were measured during the experimental period (when the foam occurred in the pilot plant). Further, the plants have not been

Table 1
Wastewater characteristics and operating condition of investigated MBRs.

Wastewater characteristics				Operating condition			
	MBR1	MBR2	MBR3		MBR1	MBR2	MBR3
COD_{TOT} (mg/L)	451	326.6	511.6	Experimentation length (days)	60	165	70
COD_{SOL} (mg/L)	204	104	210	Recirculation ratio/feed rate	5:1	6:1	6:1
BOD_5 (mg/L)	240	175.9	265	Permeate flux (L/m^2h)	45	21	21
NH_4–N (mg/L)	40.4	15.9	32.4	HRT (h)	13	18	18
NO_x–N (mg/L)	0.02	1.8	3.5	SRT (days)	∞	36	∞
TKN (mg/L)	–	91.3	102.3	F/M (kg_{COD}/kg_{MLSS} day)	0.07–0.2	0.06–0.19	0.07–0.2
PO_4–P (mg/L)	1.4	1.5	2.1	DO aerobic tank (mg/L)	3.9	3.9	3.1
P_{TOT} (mg/L)	–	3.8	6.4	Returned MLSS flow (L/h)	90	120	120
TSS (mg/L)	290	282.5	295	Returned NO_3 flow (L/h)	225	240	240
VSS (mg/L)	182	177.3	188	MLSS (g/L)	5.5–10.5	5	6–8.2
T (°C)	19.8	20.8	23.6	MLSSV (g/L)	3.5–7.5	3.5	4.5–6.1
pH	7.5	7.6	7.7	Y_{obs} (g_{COD}/g_{VSS}rem)	0.18	0.07	0.12