Separation and Purification Technology 95 (2012) 49–57

Contents lists available at SciVerse ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

Screening of novel MBR fouling reducers: Benchmarking with known fouling reducers and evaluation of their mechanism of action

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ARTICLE INFO

Article history:
Received 20 February 2012
Received in revised form 19 April 2012
Accepted 19 April 2012
Available online 26 April 2012

Keywords:
Membrane bioreactor
Fouling
Additive
MBR-VFM
Flocculant

ABSTRACT

A novel fouling characterization method was applied for a first screening of two novel synthetic flocculants developed by BASF (BASF-1 and BASF-2) and benchmarking with six well-known products. Results showed that this MBR-VITO Fouling Measurement (VFM) was able to identify beneficial and adverse effects of different additives on the mixed liquor's reversible and irreversible fouling and, in combination with supporting mixed liquor analyses, allowed to identify the additive's main working mechanism. The first screening tests indicated that BASF-1 and BASF-2 reduced reversible and irreversible fouling to a similar extent as the known synthetic flocculants due to a charge neutralization mechanism, resulting in enhanced flocculation and SMP removal. Further testing at different additive concentrations provided a first indication of the optimal dosage and revealed a considerable risk of overdosing for BASF-2, rendering it less suited for fouling control. In contrast, such adverse effects were not observed for BASF-1. BASF-1 induced similar beneficial effects as the known MPE50 polymer at lower dosage and was therefore considered promising for application in MBRs.

1. Introduction

Although membrane bioreactors (MBR) are increasingly used for the treatment of both municipal and industrial wastewaters, membrane fouling remains a major drawback influencing the operational performance, stability and cost. Traditional methods to limit fouling are low flux operation, crossflow filtration (membrane aeration) and physical (relaxation, backwash) and chemical cleanings. An alternative method is the addition of certain chemicals which modify the mixed liquor through mechanisms like adsorption, coagulation and/or flocculation. Such 'fouling reducers' alter the sludge flocs as well as the mixed liquor supernatant. Especially the latter seems of great importance since many recent studies have clearly pointed out the impact of both the quantity and quality of various soluble microbial product (SMP) fractions for MBR filtration performance.

Many researchers have already examined the effects of fouling reducers on MBR performance (Table 1). A good example is the very elaborate study performed by Iversen [14], examining the effects of a large number of additives on the characteristics and fouling propensity of municipal MBR mixed liquors. No less than 30 different additives were screened with shaker and jar tests, including activated carbons, metal salts, resins, natural and synthetic flocculants and special enzymes, and some of them showed a great potential for filterability improvement. However, Iversen et al. [3] also observed that dewaterability measurements and short-term filtration tests sometimes overestimated or even wrongly predicted the effects of fouling reducers in real MBR operation. The synthetic polymers, MPE50 and Adifloc KD452, for example, showed similar, but much smaller effects in pilot trials as compared to batch tests. Another more striking example is starch. This natural polymer showed a very high improvement of dewaterability and short-term filterability in batch experiments, while a detrimental effect on the permeability trend was found during longer-term pilot trials. Despite their obvious benefits, such pilot trials require a lot of time and resources. More practical and

Abbreviations: CST, capillary suction time; DOC, dissolved organic carbon; MBR, membrane bioreactor; MBR-VFM, membrane bioreactor-VITO fouling measurement; MLSS, mixed liquor suspended solids; PSD, particle size distribution; SMP, soluble microbial products; SMP_c, carbohydrate fraction of soluble microbial products; SMP_p, protein fraction of soluble microbial products; SMP_{UV}, UV absorbance of soluble microbial products; TMP, transmembrane pressure; TOC, total organic carbon; TTF, time-to-filter; VFMrev, reversible fouling potential measured by MBR-VFM; VFMirrev, irreversible fouling potential measured by MBR-VFM.

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http://dx.doi.org/10.1016/j.seppur.2012.04.024

Table 1
Literature review: effects of additive dosing on fouling and mixed liquor characteristics.

	Reference	Additive and dosage	Wastewater	Effect on fouling	Mechanism of action
Adsorbent	[1]	PAC, 750–1500 mg l^{-1}	Municipal	Organic fouling ↓, surface fouling ↓, concentration polarization ↓, cake layer ↓, adsorption fouling ↓, But: pore blocking by PAC at high dosage	EPS deposition ↓
	[2]	PAC, 500 mg l^{-1}	Municipal	Fouling ↓	Floc strength ↑ (floc shear resistance ↑ and release of foulants in vicinity of membrane ↓)
	[3]	PAC, 20–7000 mg l^{-}	Municipal	Dewaterability ↓	SMP ↓, altered floc structure (incorporation PAC)
	[4]	PAC, 450 mg l^{-1}	Municipal	Dewaterability ↓	No effect volume-based particle size, fine particles ↓
	[5]	PAC, 1000 mg l^{-1}	Industrial	Fouling ↓, surface fouling ↓, concentration polarization ↓, cake layer ↓	Scouring effect, EPS deposition ↓, PAC pre-filter
	[6]	PAC, 2000 mg l^{-1}	Industrial	Settleability ↑	No effect particle size, no effect total SMP and EPS, but protein/carbohydrate ratio ↑
Coagulant	[7]	$FeCl_3$, 0–1.6 mM	Synthetic	Fouling ↓, chemical cleaning frequency ↓But: $Fe(OH)_3$ colloids deposition	SMP ↓, colloids ↓, floc size ↑
	[8]	$FeCl_3$, 42 mg l^{-1} wastewater	Synthetic	Fouling ↓, critical flux ↑But: inhibition nitrification, sludge production ↑	SMP ↓, floc size ↑, fine particles ↓
	[9]	$FeCl_3$, 0–3 mM as Fe	Municipal	Specific resistance sludge ↓	Floc size ↑, supernatant TOC ↓
	[10]	$FeCl_3$, 85 mg l^{-1}	Municipal	Fouling ↓	SMP ↓
Flocculant	[8]	Chitosan, 42 mg l wastewater^{-1}	Synthetic	Fouling ↓, critical flux ↑	SMP ↓, floc size ↑, fine particles ↓, chelation
	[11]	Chitosan, 20 mg l^{-1}	Synthetic	Fouling ↓, pore blocking ↓, gel layer ↓, cake layer ↓	SMP ↓, floc size ↑, looser floc structure, little effect surface charge, bound EPS and zeta potential
	[12]	MPE50, 400 mg l^{-1}	Municipal	Fouling ↓ (even at peak flows), critical flux ↑, foam ↓	SMP ↓
	[3]	Starch, 1500 mg l^{-1}	Municipal	Reversible fouling ↑, dewaterability ↑	No effect SMP, floc size ↑
		Adifloc KD452, 70 mg l^{-1}	Municipal	Fouling ↓, critical flux ↑, little effect dewaterability	SMP ↓, bound EPS ↑, no effect biopolymers, floc size ↑
		MPE50, 500 mg l^{-1}	Municipal	Fouling ↓, critical flux ↑, chemical cleaning efficiency ↑, dewaterability ↑	SMP and biopolymers ↓, floc size ↑
	[13]	MPE50, 200–600 mg l^{-1}	Industrial	Permeability ↑, chemical cleaning frequency ↓, foam ↓	Fine particles ↓

economical would be to implement a quick, but representative test method for a first screening of a large number of additives, followed by longer-term pilot experiments for a further examination of the most promising products.

The MBR-VITO Fouling Measurement (VFM), a novel fouling characterization method, might be a suitable method for such a first selection. Thanks to the combination of a small-scale filtration set-up and a specific well-defined measurement protocol, this fouling sensor makes it possible to evaluate the fouling potential of MBR mixed liquor in a short-term and in an accurate and reproducible way. Moreover, it allows distinguishing between the reversible and irreversible fouling potential. Furthermore, pilot-scale validation tests have indicated that the fouling data derived from the MBR-VFM can also capture longer-term fouling effects due to the applied 'accelerated fouling' principle. More information on the development and validation of the MBR-VFM can be found in [15–17].

In the study elaborated in this paper, the MBR-VFM was used to compare the effects of two novel MBR additives provided by BASF with those of six well-known products, which have already been evaluated in literature. The measurements on the known additives allowed to assess whether the MBR-VFM could effectively capture additive effects on reversible and irreversible fouling phenomena and thus served as a validation of the MBR-VFM as a screening tool for potential fouling reducers. This tool was then applied to benchmark the novel products. Supporting analyses of mixed liquor characteristics were performed in order to reveal the mechanisms of action of the different additives. In a later stage, the optimal dosage of the novel additives was determined for a municipal and an industrial mixed liquor and compared to a known fouling reducer with a similar working mechanism to ensure an objective comparison.

2. Experimental

2.1. Experimental set-up

The experiment consisted of two test series, with each test performed in duplo. In the first screening tests, MBR-VFM measurements were performed on mixed liquor samples without and with a certain dosage of additive to select the most promising products. The applied dosages (Table 2) were the optimal dosages obtained from supplier specifications (synthetic flocculants) or literature [7,14] for mixed liquor suspended solids (MLSS) concentrations of 10 g l^{-1}. Afterwards, a smaller selection of additives was tested further at different concentrations in order to determine the optimal concentration and assess possible risks of under- or overdosing. The dosages applied in these tests were the recommended dosage (as applied in the screening tests), half and double of this dosage. The different concentrations were measured two by two, in a random order. Due to time limitations, additives were tested on a different day and thus on a different reference mixed liquor.

The mixed liquor samples for both series of tests were collected from a full-scale MBR for municipal wastewater treatment