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Clogging vs. fouling in immersed membrane bioreactors

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ABSTRACT

Whilst the fouling of MBR membrane surfaces has been very extensively explored by the academic community, there is an increasingly widespread recognition by practitioners of the issue of clogging of membrane channels with sludge solids, sometimes termed "sludging". The study undertaken has quantified this phenomenon using a bespoke test cell allowing a flat sheet membrane channel to be viewed directly during operation and the accumulated solids determined by digital image processing. Sludging behaviour has then been correlated both with the sludge properties, from sludge samples taken from both an industrial and municipal MBR, and the permeability decline rate data.

The work has revealed the expected trends in fouling propensity, as quantified by the exponent n of the $\Delta p/\Delta t = m.\exp(nJ)$ correlation from classical flux-step tests. With zero membrane aeration the industrial samples exhibited sludging, the filling of the complete thickness of the membrane channel with sludge solids, whereas for municipal sludge the solids formed a cake layer which did not fill the channel. In the absence of sludging the permeability decline followed the expected pattern of increasing at the elevated soluble COD and capillary suction time values of the industrial sludge, compared with municipal sludge at the same solids concentration range (8–12 $g.L^{-1}$). However, there was no evident correlation between fouling (permeability decline without sludging) and sludging: incipient sludging did not appear to influence permeability, though can be assumed to negatively impact on long-term operation, or relate to the sCOD concentration. Sludging instead appeared to depend on the sludge physical properties, and primarily the viscosity: sludge samples at high viscosities were found to exhibit a different air-scour pattern to that at normal MLSS concentrations.

Outcomes suggest that sludging is caused by rheological conditions promoting bubble coalescence and bubble stream constriction, reducing the exposure of the membrane surface to scouring air.

1. Introduction

Membrane bioreactor (MBR) technology is known to be constrained by the tendency for the membrane permeability to decrease during the filtration cycle. This demands periodic physical and chemical cleaning, which then increases operating costs due to the downtime incurred. The reduction in the operating flux also increases the membrane area demanded, impacting on capital costs.

Permeability reduction has almost exclusively been attributed to membrane surface fouling by the scientific community, with regular reviews on fouling characterisation and mitigation published in learned journals (Le Clech et al., 2006; Drews, 2010; Lin et al., 2014), including three in 2017 alone (Aslam et al., 2017; Krzeminski et al., 2017; Meng et al., 2017). However, within the practitioner community the impact of membrane channel clogging or "sludging" (or, sometimes, "localised dewatering", Stone and Livingston, 2008), the filling of the membrane interstices with sludge solids, is widely recognised as being as problematic as fouling (Stone and Livingston, 2008; Mason et al., 2010, Gabarrón et al., 2013, 2014; The MBR Site, 2015; Wang et al., 2014) for both hollow fibre (HF) and flat sheet (FS) membranes. Whilst fouling is generally effectively ameliorated through cleaning physically (Aslam et al., 2017) and chemically (Wang et al., 2014), in practice these strategies have little or no impact on clogging. Clogging - including "ragging" or braiding of short filaments to form long rag-like particles (Stefanski et al., 2011) - usually demands manual intervention to clear out the solids (Mason et al., 2010; Stefanski et al., 2011; Gabarrón et al., 2013). Such intervention is time-consuming, labour-intensive and potentially damaging to the membranes, all factors significantly impacting on costs to a greater

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extent than adjustment of the chemical cleaning protocol to mitigate surface fouling.

It has been assumed by practitioners that problems associated with clogging are only effectively ameliorated through both:

a) fine screening of the feed to remove the inlet gross solids (Frechen et al., 2008; Impero, 2015), incurring additional costs associated with screenings management, and
b) appropriately limiting the MLSS (mixed liquor suspended solids) concentration in the membrane tank (Zsirai et al., 2014).

However, there has been very limited research on clogging/sludging, to substantiate these rules of thumb. Despite its practical significance, only a few isolated studies (Buzatu et et al, 2012, Zsirai et al., 2014) have sought to quantify sludging gravimetrically. Specifically, the key MLSS characteristics to which sludging may be attributed have not been identified, such that the efficacy of any remedial measures taken to address it cannot be established. This is in stark contrast with corresponding research into membrane surface fouling, apparently comprising 25–30% of all published research into MBR technology in the past 15 years (Judd, 2017).

This paper aims to provide further insight into sludging phenomena in iMBRs through experimental study of MLSS samples extracted from full-scale operating MBRs. The work, only the third study quantifying sludging in MBRs, made use of a bespoke bench-scale test cell which allowed the filterability of MLSS samples to be directly measured along with the sludging rate, through accelerated testing. The filterability measurements were supplemented by measurement of commonly recorded sludge bulk characteristics, namely the capillary suction time (CST) and sludge volume index (SVI), along with rheological characterisation.

2. Materials and methods

2.1. Plant description and monitoring

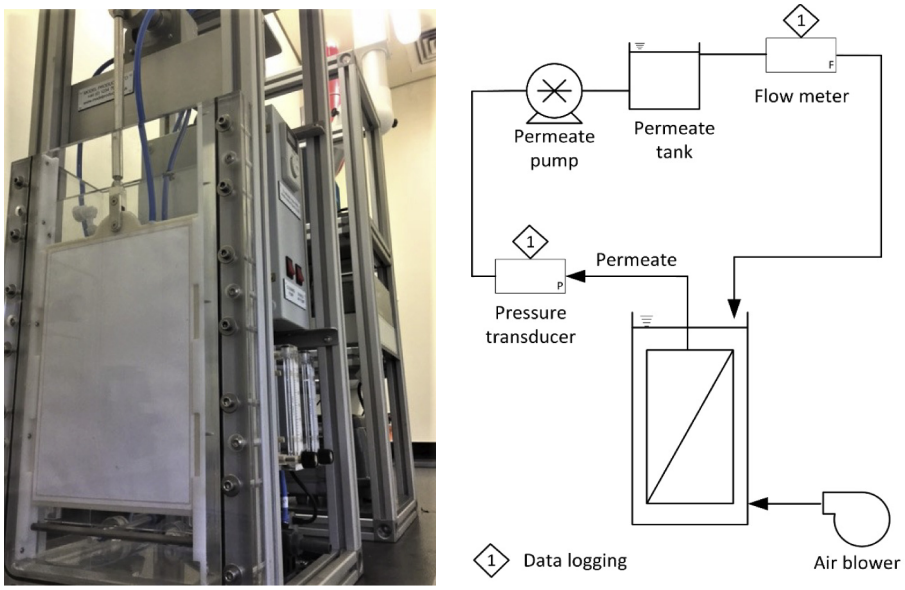
The iMBR test cell (Fig. 1) consisted of a single *A4*-sized, 6 mm-thick flat sheet (FS) membrane panel (*Kubota Membranes Europe*, London) housed in a ~500 mm-tall rectangular acrylic tank (130 mm width, 245 mm length). The membrane was placed between the tank wall and an acrylic baffle spaced at a distance of 6 mm from the membrane surface, this channel thickness being equal on both sides of the membrane panel to avoid imbalance of flows. The acrylic construction allowed the membrane surface to be directly viewed to observe sludging in the form of agglomerated solids within the channel. The non-visible side of the membrane was sealed, such that flow through the membrane was limited to the viewable side. A fine-bubble aerator was placed in the process tank to mix the MLSS flocs and provide dissolved oxygen to the biomass.

The permeate was removed under suction using a peristaltic pump able to achieve a flow of up to 500 mL/min. It was then fed to a de-aerator, a simple open 2L cylindrical tank, and the overflow from this tank allowed to flow through a digital flowmeter. The permeate line was also fitted with a digital pressure sensor operating within the range of −0.6 to +0.6 bar.

2.2. Physical and rheological characterisation

Sludge samples were collected on alternate weeks from the membrane tanks of two nearby full-scale MBR installations, one being a 32,000 m^3/day capacity municipal wastewater treatment plant (WwTP) and the other a 50 m^3/day plant treating petroleum industrial effluent. All samples were physically and chemically characterised immediately after being brought to the University laboratories. The physical characteristics of the sludge were assessed with reference to the MLSS, particle size (using a Mastersizer, 2000; Malvern Instruments Ltd., UK), capillary suction time (CST), and sludge volume index (SVI), all according to standard methods (APHA, 2012). Chemical characterisation was limited to the filtered (or soluble) COD, conductivity, NaCl concentration and pH.

Rheological characterisation was based on the determination the evolution of viscosity over time using a controlled stress and strain rheometer (Anton Paar Model *MCR 302*, Austria) with a cup and bob configuration (DIN coaxial cylinder). The temperature was set at 20 °C and a new sample (approximately 20 mL volume) used for each applied shear rate. Measurements were performed under



(a) (b)

Fig. 1. The MBR test cell, (a) membrane and channel, and (b) schematic.