WATER RESEARCH 47 (2013) 6719–6730

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

Filtration properties of activated sludge in municipal MBR wastewater treatment plants are related to microbial community structure

Thomas V. Bugge [a], Poul Larsen [a], Aaron. M. Saunders [a], Caroline Kragelund [a,b], Lisbeth Wybrandt [a], Kristian Keiding [a,c], Morten L. Christensen [a], Per H. Nielsen [a,*]

[a] Department of Biotechnology, Chemistry and Environmental Engineering, Aalborg University, Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark

[b] Danish Technological Institute, Chemistry and Biotechnology, Kongsvang Allé 29, DK-8000 Aarhus, Denmark

[c] Grundfos Holding, Poul Due Jensens vej 7, DK-8850 Bjerringbro, Denmark

A R T I C L E I N F O

Article history:
Received 6 April 2013
Received in revised form
29 August 2013
Accepted 2 September 2013
Available online 12 September 2013

Keywords:
Membrane bioreactors
Filterability
Extracellular polymeric substances
FISH
Microbial community structure

A B S T R A C T

In the conventional activated sludge process, a number of important parameters determining the efficiency of settling and dewatering are often linked to specific groups of bacteria in the sludge – namely floc size, residual turbidity, shear sensitivity and composition of extracellular polymeric substances (EPS). In membrane bioreactors (MBRs) the nature of solids separation at the membrane has much in common with sludge dewaterability but less is known about the effect of specific microbial groups on the sludge characteristics that affect this process.

In this study, six full-scale MBR plants were investigated to identify correlations between sludge filterability, sludge characteristics, and microbial community structure. The microbial community structure was described by quantitative fluorescence in situ hybridization and sludge filterability by a low-pressure filtration method. A strong correlation between the degree of flocculation (ratio between floc size and residual turbidity) and sludge filterability at low pressure was found. A good balance between EPS and cations in the sludge correlated with good flocculation, relatively large sludge flocs, and low amounts of small particles and single cells in the bulk phase (measured as residual turbidity), all leading to a good filterability. Floc properties could also be linked to the microbial community structure. Bacterial species forming strong microcolonies such as *Nitrospira* and *Accumulibacter* were present in plants with good flocculation and filtration properties, while few strong microcolonies and many filamentous bacteria in the plants correlated with poor flocculation and filtration problems. In conclusion this study extends the hitherto accepted perception that plant operation affects floc properties which affects fouling. Additionally, plant operation also affects species composition, which affects floc properties and in the end fouling propensity.

* *Corresponding author*. Tel.: +45 9940 8503; fax: +45 9814 1808.
E-mail address: phn@bio.aau.dk (P.H. Nielsen).

http://dx.doi.org/10.1016/j.watres.2013.09.009

List of symbols

k	Rate constant describing shear sensitivity (min^{-1})
P	Pressure difference across the filter cake (Pa)
P_a	Characteristic pressure (Pa)
V_d	Drainage velocity (m/s)
V_s	Sedimentation velocity (m/s)

Greek symbols

α_{av}	Average specific resistance to filtration (m/kg)
α_0	Average specific resistance of a theoretically non-compressible cake (m/kg)
τ_{inf}	Infinite turbidity (–)
τ_0	Initial turbidity (–)

1. Introduction

Membrane bioreactor (MBR) technology has improved significantly during the last decade with respect to energy efficiency and is becoming a competitive alternative to the conventional activated sludge (CAS) process for municipal wastewater treatment (Drews, 2010; Judd, 2008; Meng et al., 2009). However, membrane fouling is still the main operational issue, which needs to be addressed, and much research is targeted towards the most important factors for improved fouling control.

So far, there is a progressive consensus that extracellular polymeric substances (EPS), and most significantly, soluble microbial products (SMP) have significant impact on the fouling propensity and should be limited to avoid severe fouling of the membranes (Arabi and Nakhla, 2010; Drews, 2010; Liang et al., 2007; Meng et al., 2009; Trussell et al., 2006; Ahmed et al., 2007). Also bulk sludge properties such as the mixed liquid suspended solids (MLSS) levels (Lousada-Ferreira et al., 2010), floc size (Wisniewski and Grasmick, 1998), number of filamentous bacteria (Meng et al., 2006) and concentration of cations (Arabi and Nakhla, 2009; van den Broeck et al., 2011) are important for the performance of MBRs. This is very similar to the important parameters in the solid–liquid separation process of the CAS process (Bruus et al., 1992; Jin et al., 2003).

In CAS systems, it has been demonstrated that some physico-chemical floc properties are determined by microbiological activity (e.g. Wilén et al., 2000) and species composition (e.g. Klausen et al., 2004; Larsen et al., 2006, 2008a). This is, at least in part, due to the production of different EPS components by the different species (Dominiak et al., 2011b; Larsen et al., 2008b). A few similar links between physico-chemical floc properties and microbial community composition have been identified in MBR systems, where especially the presence of filamentous bacteria have been associated with poor floc properties and increased fouling propensity (Gil et al., 2011; Kim and Jang, 2006; Meng et al., 2006, 2007; Su et al., 2011; Tian et al., 2011). However, other studies have found negligible or even positive effect of filamentous bacteria on membrane filtration (Al-Halbouni et al., 2008; Li et al., 2008; Parada-Albarracín et al., 2012). Improved membrane filtration were caused by certain species of filamentous bacteria that degrade dissolved EPS, which otherwise would increase fouling propensity (Miura et al., 2007a, b; Wang et al., 2012). Other bacterial groups have also been associated with membrane fouling, e.g. nitrifiers (Drews et al., 2007).

Such studies indicate that there is a link between the presence of specific microorganisms, the filtration properties and fouling propensity. A prerequisite for investigating this in greater detail is that there is manageable number of species to investigate and fortunately, recent research has shown this is the case. In 25 Danish full-scale CAS plants with biological nitrogen and phosphorus removal, 60–90% of the total bacterial biovolume is comprised by a common core of only 30–40 species/genera (Nielsen et al., 2010, 2012), and the microbial composition in each plant is very stable over time (Mielczarek et al., 2012, 2013). Furthermore, information on several abundant bacterial groups and their floc-properties exists (Dominiak et al., 2011b; Larsen et al., 2008b) and as many of the same microorganisms are present in many full-scale MBR systems with similar operation (Saunders et al., 2013; Silva et al., 2012), the correlation between the presence of specific microorganisms and filtration properties relevant to MBRs can be investigated.

The aim of this study was to investigate activated sludge at six full-scale municipal WWTP MBRs to identify correlations between sludge filterability at low pressure, sludge characteristics and microbial community structure. Sites with varying operational designs and wastewater characteristics were chosen as a first attempt to identify potential correlations for further in-depth studies.

2. Materials and methods

2.1. Wastewater treatment plants

Six municipal wastewater treatment plants operated with submerged membrane bioreactors were included in the study. Activated sludges from two sites in UK (Westbury and Swanage), two in France (Deauville and Avranches) and two in Germany (Nordkanal and Hünxe) were analyzed (Table 1). All plants have N-removal and the two French sites also enhanced biological phosphorus removal (EBPR). In Westbury, the treated wastewater was partly industrial whereas the other sites treated only municipal wastewater. The sites varied in size with Hünxe treating 8800 person equivalents (PE) to Deauville treating 115,000 PE, and also the operational design and type of membrane modules varied from site to site.

2.2. On-site analysis and sampling

Conductivity, pH, total suspended solids (TSS), diluted sludge volume index (DSVI), shear sensitivity and sludge filterability were all analyzed on-site within two days at each site. In addition, the following samples were taken for further analysis. A 500 mL sludge sample in a 1 L bottle was used for analysis of particle size distribution, EPS extraction and FISH.