Water Research 102 (2016) 252–262

Contents lists available at ScienceDirect

Water Research

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

Review

A review of practical tools for rapid monitoring of membrane bioreactors

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ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form
17 May 2016
Accepted 13 June 2016
Available online 16 June 2016

Keywords:
MBR
Activated sludge
Process monitoring
CST
TOC/TNb
ATP

ABSTRACT

The production of high quality effluent from membrane bioreactors (MBRs) arguably requires less supervision than conventional activated sludge (CAS) processes. Nevertheless, the use of membranes brings additional issues of activated sludge filterability, cake layer formation and membrane fouling. From a practical standpoint, process engineers and operators require simple tools which offer timely information about the biological health and filterability of the mixed liquor as well as risks of membrane fouling. To this end, a range of analytical tools and biological assays are critically reviewed from this perspective. This review recommends that Capillary Suction Time (CST) analysis along with Total Suspended and Volatile Solids (TSS/VSS) analysis is used daily. For broad characterisation, total carbon and nitrogen analysis offer significant advantages over the commonly used chemical and biological oxygen demand (COD/BOD) analyses. Of the technologies for determining the vitality of the microbial biomass the most robust and reproducible, are the second generation adenosine-5′-triphosphate (ATP) test kits. Extracellular polymer concentrations are best monitored by measurement of turbidity after centrifugation. Taken collectively these tools can be used routinely to ensure timely intervention and smoother operation of MBR systems.

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http://dx.doi.org/10.1016/j.watres.2016.06.031
0043-1354/

1. Introduction

According to the Food and Agriculture Organisation of the United Nations (FAO) the volume of wastewater produced globally is unknown, largely due to a lack of data in many countries (FAO, 2012). It is known however, that many hundreds of cubic kilometres of wastewater are produced. This immense volume of wastewater represents both a potential hazard, and a vital resource for humanity and the environment. In developed countries the bulk of this wastewater is treated in centralised plants where pathogen and nutrient content are reduced before it is either released into the environment or disinfected for reuse.

For over one hundred years the conventional activated sludge (CAS) process has been used to treat both domestic and industrial wastewaters (Lofrano and Brown, 2010; Tilley, 2011). This likely represents the largest use of industrial bioprocesses worldwide (Seviour and Nielsen, 2010). Many permeations of the CAS process have been implemented to suit varying wastewater streams and local environmental conditions (Metcalf and Eddy, 2003). CAS processes can suffer from biological phenomena such as bulking and reduced settling in clarifiers which result in poor quality effluent which contains suspended biomass (Jenkins et al., 2004).

The rise of membrane bioreactors (MBRs) over the last 15 years has been driven by the desire for smaller plant footprints, higher quality effluent, the necessity of water reuse and advances in membrane technology (Judd and Judd, 2011a,b). Although an aerobic MBR contains an activated sludge process, effluent suspended solids issues are mitigated by membrane separation. MBRs are an established technology now approaching maturity with ‘fifth generation’ plants currently being built (Kraemer et al., 2012). MBRs can however fail to process the desired volume of wastewater if extreme caking, fouling or low biomass filterability occurs (Judd and Judd, 2011a,b). Additionally due to the necessity of constant membrane agitation, and chemical cleaning for removal of fouling, the capital and operational costs of ownership of MBRs is higher than for CAS processes (Le-Clech, 2010; Kraemer et al., 2012; Li et al., 2012).

Membrane fouling is typically categorised as either inorganic or organic, with the latter being less well understood. A large proportion of the literature regarding MBRs concerns mixed liquor properties and fouling propensity (Chang and Lee, 1998; Rosenberger and Kraume, 2002; Ng and Hermanowicz, 2005; Pollice et al., 2005; Rosenberger et al., 2005; Choi et al., 2006; Le-Clech et al., 2006; Lebegue et al., 2008; Pan et al., 2010; Tian et al., 2011; Ma et al., 2013). Research evidence strongly indicates that higher concentrations of extracellular polymers (ECPs) and/or soluble microbial polymers (SMP) are the keys to explaining low biomass filterability and a consequent high fouling tendency (Sheng et al., 2010). The literature is complex and marred by the variation in extraction methods and analytical techniques.

Given the uncertainties over operational issues affecting biomass filterability and the opex costs of MBR ownership, the question of how to best monitor the operation of an MBR and its biomass becomes more urgent. This review critically examines the range of analytical techniques (tools) now available for engineers and operators to monitor the biomass and treatment efficiency of an MBR. The techniques evaluated (Table 1 below) include both current analytical techniques as well as a range of newer techniques. In this review we have considered process chemistry methods for ion and sum parameter analysis and methods for the bulk assessment of solids. A particular focus is placed on the determination of extracellular polymers and viability and vitality by respiration indicators, dehydrogenase quantification and ATP measurement. Lastly, methods for microbial ecology are reviewed, with discussion limited to the number of techniques currently able to provide timely feedback.

The analytical tools identified in Table 1 have been evaluated from a practical standpoint, and scored according to equipment and reagent cost, ability for point of testing use, ease of use and repeatability and timeliness allowing for rapid (same day) management responses. See Table 2 below for the scoring criteria and Table 3 for the results themselves. Although this review is largely focused on MBR operation, many techniques are transferrable to the operation of CAS plants.

Having placed a focus on the use of analytical tools in everyday plant operation, the review does not include the time consuming methods typically employed by researchers. For a review of molecular techniques in use for wastewater treatment the reader is directed to (Sanz and Köchling, 2007; Seviour and Nielsen, 2010). For the use of flow cytometery (Díaz et al., 2010; Davey, 2011) and for advanced image analysis of biomass (Costa et al., 2013). Moreover, this review does not cover the use of conventional on-line membrane engineering parameters such as monitoring of flux, permeability and trans-membrane pressure. For information on these see either the MBR Book or WEF Manual of Practice No 36 (Judd and Judd, 2011a,b; Water Environment Federation, 2012). This review also omits the basic measurements of pH, conductivity and temperature, as they are assumed to be ubiquitous in all water labs.

1.1. Notes on the criteria for evaluation

Tools are evaluated under six categories, detailed in Table 2. Each category is rated 1 to 5 with 5 being the best.