International Biodeterioration & Biodegradation 119 (2017) 528–537

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

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

Assessing the performance of an MBR operated at high biomass concentrations

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ARTICLE INFO

Article history:
Received 3 July 2016
Received in revised form
2 October 2016
Accepted 4 October 2016
Available online 15 October 2016

Keywords:
Membrane bioreactor (MBR)
Oxygen transfer
High MLSS
Oxygen uptake rate (OUR)
Filterability
Emergency sanitation

ABSTRACT

Reducing the footprint requirements of membrane bioreactors (MBR)s can both decrease the surface area needs for new wastewater treatment plants (WWTP)s, and increase the treatment capacities of existing WWTPs at a given surface area. In addition, it may promote the development of movable/portable containerized MBRs for a diverse range of wastewater treatment applications. Applications may include the provision of municipal/industrial wastewater treatment in remote areas without sewerage, and the provision of sanitation services under challenging site-specific conditions such as after the occurrence of a human-made or a natural disaster. The reduction of the footprint requirements of MBRs is constrained by the maximum amount of biomass that can be accommodated in the aerobic basin. The biomass concentration is mainly limited by the extremely low oxygen transfer efficiency (OTE) experienced by conventional aeration bubble diffuser systems at mixed liquor total suspended solids (MLSS) concentrations higher than 20 g L^{-1}. Another potential limitation for the operation of MBRs at such high MLSS concentrations is the reduction on the membrane permeability due to excessive fouling. A pilot MBR with a treatment capacity of one m^3 d^{-1} was installed at the research hall facilities at the Harnaschpolder wastewater treatment plant in Delft, The Netherlands. The MBR was operated at MLSS concentrations of up to 28 g L^{-1} at sludge retention times (SRT)s ranging from 30 to 35 days. The MBR was provided with a Speece cone concentrated oxygen delivery system to overcome the oxygen transfer limitations of conventional bubble diffuser aeration systems at high MLSS concentrations. The MBR performance was evaluated by monitoring the influent and effluent water quality, the membrane permeability, the sludge filterability, the dissolved oxygen (DO) concentration, and the oxygen uptake rate (OUR). The Speece cone proved to be effective in delivering enough oxygen to maintain DO concentrations in the MBR of approximately 2 mg L^{-1} at MLSS concentrations of up to 22 g L^{-1}. OUR values above 200 mg L^{-1} h^{-1} were observed at 14 g L^{-1} MLSS and higher than 300 mg L^{-1} h^{-1} at 22 g L^{-1} MLSS. The MBR exhibited chemical oxygen demand (COD) removal efficiencies of up to 99% even at a hydraulic retention time (HRT) as low as 3.7 h. A reduction in permeability from 33 to 11 lmh bar^{-1} was observed when the MLSS concentrations increased from 18.7 to 27.8 g L^{-1}. Sludge filterability values expressed as the added resistance (ΔR_{20}) fell in the range of "poor filterability" for all the evaluated operational conditions; however, a lower filtration resistance in the range of "moderate filterability" at approximately 23 g L^{-1} MLSS was noticed. The experimental results suggest that at the evaluated experimental conditions the existent limitations on poor oxygen transfer and low permeability when operating a MBR at high MLSS concentrations can be overcome; therefore, the footprint requirements of MBR systems may be further reduced.

1. Introduction

Considering all the existent alternatives for the provision of wastewater treatment, MBRs present some additional advantages including the production of a high quality effluent suitable for

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http://dx.doi.org/10.1016/j.ibiod.2016.10.006
0964-8305/

water reuse, (Arceivala, 2008; Hai and Yamamoto, 2011; Henze et al., 2008; Judd, 2008, 2010; Melin et al., 2006; Stephenson, 2000), the reliability of the technology, the potential production of small amounts of already stabilized sludge, and the operational flexibility to adjust to changes in the organic loads, among others. The reduction of the footprint requirements of membrane bioreactors MBRs can allow both the reduction of the surface area needs when constructing new WWTPs, and the increase of the treatment capacities of existing WWTPs at a given surface area. In addition, the achievement of an additional footprint reduction on MBRs may promote the development of movable/portable containerized MBRs for a diverse range of applications including the provision of municipal/industrial wastewater treatment in remote areas without sewerage and the provision of sanitation services under challenging site-specific conditions such as after the occurrence of a human-made or a natural disaster. However, the reduction of the footprint requirements of MBRs is constrained by the maximum amount of biomass that can be accommodated in the aerobic basin.

The maximum biomass concentration that can be achieved in a MBR is mainly limited by the extremely low OTE experienced by conventional aeration systems such as fine and coarse bubble diffusers at MLSS concentrations higher than 20 g L^{-1} (Germain et al., 2007). Another limitation for the operation of MBRs at such high MLSS concentrations is the reduction on the membrane permeability observed due to excessive fouling. This drastic decrease in permeability is caused mainly by the accumulation of fouling substances and the increased mixed liquor viscosity (Trussell et al., 2007). The relation between the potential benefits of operating a high MLSS MBR and the negative impact on the system permeability has been addressed in the literature as the "*Capex-Opex dichotomy*" (Judd, 2008). Therefore, and in order to avoid these adverse conditions, conventional MBR systems are currently designed to operate at MLSS concentrations of approximately 10 g L^{-1} setting the footprint requirements of this technology.

Oxygen transfer in aerobic wastewater treatment processes has been extensively addressed in the past decades. Several studies demonstrated that both the suspended solids as well as the mixed liquor viscosity negatively affect the oxygen transfer process (Cornel et al., 2003; Germain et al., 2007; Germain and Stephenson, 2005; Moreau et al., 2009; Trussell et al., 2007; Wu et al., 2007). Krampe and Krauth (2003) reported a decrease on the OTE as the biomass concentration increased. The evaluation was conducted on a biological system provided with a conventional fine bubble diffuser up to biomass concentrations of approximately 28 g L^{-1}. Alpha factors as low as 0.1 were reported at a 20 g L^{-1} MLSS concentration demonstrating an extremely low OTE at the evaluated conditions. A study conducted by Henkel et al. (2009) investigated the OTE of fine and coarse bubble diffusers at MLSS concentrations ranging from 4.7 to 19.5 g L^{-1} under different air flow conditions and operating the biological systems at high SRTs. A decrease on the alpha factor was reported as the biomass concentrations (expressed as MLSS) increased. In addition, a more direct correlation was noticed between the decrease of the alpha factor and the increase of the mixed liquor volatile suspended solids (VSS). The authors concluded that the mixed liquor VSS concentration in the reactor is the main factor impacting on the oxygen transfer process. At mixed liquor VSS concentrations higher than 20 g L^{-1} negligible alpha factors were reported; therefore, very little DO at a very low OTE could be supplied at the evaluated experimental conditions. The rheological and physiological properties of MBRs were investigated by Wu et al. (2007); the authors demonstrated that the MLSS concentration has a direct impact on the mixed liquor apparent viscosity, which consequently affects the oxygen diffusion process. The effect of the high MLSS concentration on the apparent viscosity was also demonstrated by Trussell et al. (2007). The negative impact of the apparent viscosity on the oxygen transfer process was reported in a more recent publication by Durán et al. (2016) for fine bubble diffuser aeration. In a comparative study carried out by Krampe and Krauth (2003), different bubble diffuser aeration systems were evaluated at MLSS concentrations of up to approximately 20 g L^{-1}. In accordance with previously reported studies, the authors concluded that the alpha factor decreases exponentially with increasing MLSS concentrations. In addition, an increase on the viscosity was observed as the MLSS concentration increased. The authors proposed that the increased viscosity of the mixed liquor could promote the formation of large bubbles via coalescence resulting in a reduced available interfacial gas-liquid area negatively impacting the oxygen transfer process. Even though several studies were carried out evaluating the OTE on biological systems at different MLSS conditions, there is still a need and a clear interest for advancing on alternative oxygen delivery systems for efficiently supplying DO; particularly, when designing biological systems to operate at higher than usual MLSS concentrations.

Alternative aeration systems are needed to cope with the high oxygen demands and low OTEs commonly observed on MBRs operated at high MLSS concentrations. The oxygen transfer rates and OTEs of innovative concentrated oxygen delivery systems such as the super saturated dissolved oxygenation system – (SDOX) were recently evaluated by Kim et al. (2015). The SDOX system recirculates activated sludge through a chamber that is pressurized with pure oxygen. The activated sludge is introduced into the chamber through a nozzle generating a mist enhancing the gas-liquid interaction; consequently, the oxygen mass transfer between the pure oxygen gas phase and the mixed liquor solution is maximized. The authors reported similar alpha factors compared to conventional bubble diffuser systems; however, the SDOX system exhibited nearly 100% OTEs when working at MLSS concentrations of up to 40 g L^{-1}. That is, nearly all of the oxygen supplied to the pressurized chamber ended up as DO in the biological reactor. In addition, such aeration systems are not subject to clogging or scaling as it is the case for membrane fine bubble diffusers. The clogging or scaling of the diffuser reduces the OTE even further causing an increased backpressure in the air distribution line (Garrido-Baserba et al., 2016). Another concentrated oxygen delivery technology, the Speece cone system, may present a feasible alternative for providing the required DO in biological systems working at high MLSS concentrations. The Speece cone system has been commonly used in the past for hypolimnetic aeration applications mainly for bioremediation of lakes and other water courses (Ashley et al., 2008). The Speece cone system recirculates the mixed liquor from the aerobic basin of the reactor through a pressurized inverted cone structure. Pure oxygen gas is directly supplied at the top of the cone and is dissolved into the mixed liquor, which is introduced into the top of the pressurized inverted cone without the use of any nozzle, as compared to the situation previously described for the SDOX system. For this reason, the Speece cone system minimizes the head losses of the system allowing to process large volumes of mixed liquor without large energy expenditures (McGinnis and Little, 1998). The improvement on the oxygen mass transfer observed at the Speece cone is based on both the high pure oxygen pressure conditions inside the cone, and on the specially designed cone geometry. That is, based on the geometry of the inverted cone and on the selected mixed liquor flow rate through it, a particular downward velocity can be set for the mixed liquor. The mixed liquor velocity at the top of the cone is higher than the pure oxygen bubbles buoyancy due to the small cross sectional area. Therefore, the oxygen bubbles are forced down inside the cone to be in contact with the mixed liquor. As the oxygen bubbles and mixed liquor travel down, the cross sectional area of the inverted