Journal of Membrane Science 476 (2015) 68–75

Contents lists available at ScienceDirect

Journal of Membrane Science

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

Impact of suspended solids concentration on sludge filterability in full-scale membrane bioreactors

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ARTICLE INFO

Article history:
Received 20 August 2014
Received in revised form
22 October 2014
Accepted 8 November 2014
Available online 18 November 2014

Keywords:
Membrane bioreactors
Filterability
Mixed liquor suspended solids concentration

ABSTRACT

The relation between activated sludge filterability and mixed liquor suspended solids (MLSS) concentration in membrane bioreactors (MBRs) is framed in a single hypothesis, explaining results seemingly contradictory. A total of 44 activated sludge samples were collected and analyzed on a variety of parameters, i.e. filterability, MLSS concentration, soluble microbial products (SMP) concentrations and particle size distribution in the range of 2–100 µm and of 0.4–5.0 µm. The sludge filterability was assessed by using the Delft Filtration Characterization method (DFCm). In order to investigate the impact of MLSS concentration, identical samples were diluted with permeate. Results showed that dilution of the samples led to an increased activated sludge filterability, but only when the starting MLSS concentration was below the apparent critical value of 10.5 g/L. As opposed, the filterability of sludge with MLSS concentrations above 10.5 g/L, and which was characterized by a moderate to good filtration quality, i.e. $\Delta R_{20} < 1$ [$\times 10^{12}$ m^{-1}], worsened when diluted. The specific resistance times the particle concentration of a cake layer obtained when filtrating sludge of moderate to good filterability and MLSS concentration above the apparent critical value was 5.5 times smaller compared to the cake layer of sludge with MLSS concentration below the critical value. Results from SMP assessment and particle counting in the range 2–100 µm showed that reduction in sludge mass and de-flocculation occurred, upon dilution of all samples. However, when diluting sludge samples with MLSS concentrations exceeding 10.5 g/L and which were characterized by a moderate to good filtration characteristics, there was also release of particles below 0.4 µm, opposite to dilutions of samples with MLSS concentrations below 10.5 g/L. We postulate that sludge, which is characterized by a moderate to good filterability, having an MLSS concentration above the apparent critical value of 10.5 g/L, is likely to retain particles smaller than 0.4 µm in its mass, as opposed to sludge with MLSS concentration below the apparent critical value. Our work indicates that there are optimal MLSS concentration ranges in MBR technology, to promote good filterable sludge quality in order to avoid fouling.

1. Introduction

One of the main advantages of membrane bioreactor (MBR) technology is the possibility to work at high mixed liquor suspended solids (MLSS) concentrations [12]. However, one of the main constraints is the need to control membrane fouling [12]. Membrane fouling can be defined as the sum of processes leading to flux deterioration due to surface or internal pore blockage of the membranes [11]. In the early stages of MBR technology, MLSS concentration was considered one of the possible fouling parameters [30]. Nowadays, it is generally accepted that MLSS concentration alone is a poor indicator of biomass fouling propensity [10]. However, it is also generally understood that biological flocs, i.e. the suspended fraction of the activated sludge, play a key role in the fouling layers built up [15]. In short, MLSS concentration alone is considered to be a poor indicator of fouling propensity, but the suspended fraction of the sludge does play a role in the build-up of the cake layer.

Literature reports on the effect of MLSS concentration on membrane filtration provide apparently contradictory results. Meng et al. [24] observed that membrane fouling increased exponentially with increasing MLSS concentrations. Le-Clech et al. [16] saw no effect on fouling for a shift from 4 to 8 g/L in MLSS concentration, but a significant increase in critical flux occurred for MLSS concentrations of 12 g/L. The relation between the fouling propensity and MLSS concentration is therefore not clarified. In practice, in membrane tanks of full-scale MBRs, MLSS

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http://dx.doi.org/10.1016/j.memsci.2014.11.012
0376-7388/

concentrations are mainly determined by the membranes manufacturers. Optimal MLSS concentrations for MBR activated sludge, aiming at an optimal sludge filtration quality, are not defined.

The Delft Filtration Characterization method (DFCm) was defined to characterize the sludge fouling potential, by measuring sludge filterability through a pre-defined procedure [4]. The DFCm was applied in several MBR installations scattered around Europe [25,18,13]. The boundaries of the DFCm were clarified, namely on data processing, accuracy, reproducibility, reliability and applicability, leading to the conclusion that the DFCm was a convenient tool to research how filterability can be influenced by activated sludge characteristics such as MLSS concentrations [20]. In our previous work, the membrane tank sludge filterability and MLSS concentrations were measured at four full-scale MBRs scattered around Europe, during weekly campaigns at summer and winter seasons [21]. The filterability was measured according to the DFCm, which provides ΔR_{20} results. The ΔR_{20} presents the cake layer resistance obtained after extracting 20 L of permeate per membrane area. Further information on the DFCm is provided in Section 2. A classification linking the assessed ΔR_{20} and activated sludge filterability was defined, showing that for values of $\Delta R_{20} < 0.1$ [$\times 10^{12}$ m^{-1}] sludge filterability is good [6]. Fig. 1 presents the results obtained at the 4 full-scale European MBRs, with sludge collected at the membranes tanks and measured immediately after collection.

Fig. 1 shows that the sludge filterability can be good, i.e. filterability assessed by the DFCm with a ΔR_{20} value below 0.1 [$\times$ 10 m^{-1}], at MLSS concentrations around 15 g/L. The lower range is insufficiently captured by the data; however for higher ranges there is a clear improvement of filterability with increasing MLSS concentrations. Nevertheless, Chang and Kim [2] measured an increased cake resistance with an MLSS concentration shift from 0.09 to 3.7 g/L, Fang and Shi [5] measured an increase in total resistance with a shift from 2.4 to 9.6 g/L and Psoch and Schiewer [26] measured an increased fouling potential with a shift from 3 to 10 g/L in MLSS concentration. Therefore, it seems logical to assume that good sludge filterability might also be possible in sludge with low MLSS concentrations. The above results lead us to the following hypothesis.

In our present research, we hypothesize that the relation between filterability and MLSS concentration can be explained by the characteristics of the activated sludge mass. In sludge with an MLSS content below an apparent critical concentration, fouling particles are available in the free water of the activated sludge bulk. As opposed, in activated sludge with a high MLSS content, i.e. above a *critical* concentration, and moderate to good filterability, fouling particles become entrapped in the sludge matrix. The critical MLSS concentration is understood as the MLSS concentration above which the entrapment of particles results in a filterability improvement.

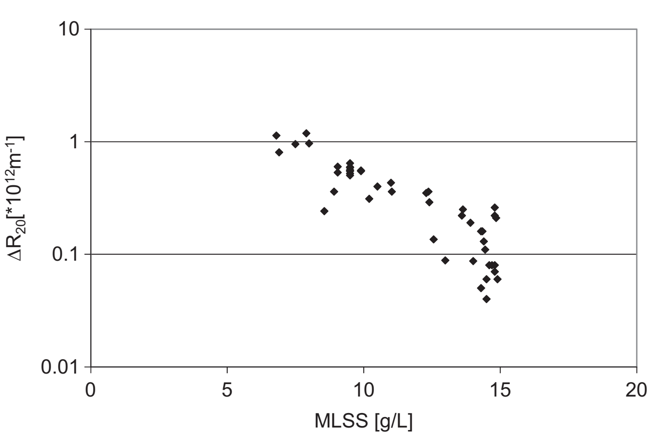

Fig. 1. Filterability and MLSS concentration at full-scale MBRs.

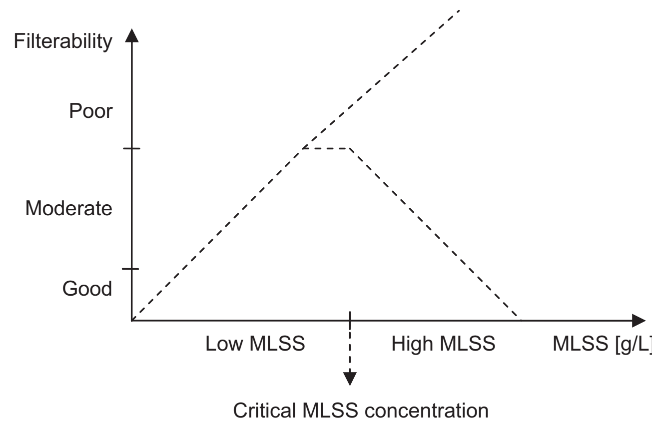

Fig. 2. Schematics of concepts [18].

Fig. 2 clarifies the definitions used in the above hypothesis and henceforth in this research.

In Fig. 2 two MLSS concentration ranges are defined, namely, “Low MLSS” and “High MLSS” as below and above the critical MLSS concentration. According to the hypothesis, increasing the MLSS concentration of sludge with “High MLSS” and moderate to good filtration quality lead to a filterability improvement because more fouling particles remain entrapped in the activated sludge mass. As opposed, sludge in the “Low MLSS” range improves its filterability when the MLSS concentration is reduced because the amount of fouling particles will also be reduced. To test the aforementioned hypothesis, sludge with different MLSS concentrations was collected at full-scale MBRs and further diluted to obtain sludge with lower MLSS concentrations. If our hypothesis is proven true then there are optimal MLSS concentrations in MBR systems to promote good filterable sludge quality in order to avoid fouling.

2. Methodology

In this research, 44 activated sludge samples, further referred to as non-diluted samples, were collected from the membrane tanks of full-scale MBRs and submitted to the following measurements: filterability, MLSS concentration, soluble microbial products (SMP) concentrations and particle size distribution in the range of 2–100 μm and of 0.4–5.0 μm. Identical samples were diluted with permeate, in a fast procedure of about 30 minutes, to obtain sludge with different MLSS concentrations, further referred to as dilution samples. The dilution samples were then submitted to the same analyses as the original, non-diluted, samples.

The experiments were organized in sets, namely 44 sets of experiments. For each set, a minimum of three filtration measurements were performed, followed by the abovementioned physical–chemical analyses. One filtration measurement was performed with the original non-diluted sample and the other two with diluted samples. The diluted samples were prepared according to the methodology described in Lousada-Ferreira et al. [19]. The experiments were performed with the following goals: (i) sets 1–22 to characterize the MBR activated sludge; (ii) sets 23–28 to compare sludge from membrane and aeration tanks, within one full-scale MBR installation; (iii) sets 29–32 to compare sludge from different MBRs.

The sludge samples were collected at four full-scale installations further referred to as MBR A to MBR D. Details of the MBR installations are provided in Table 1. In this research, 88% of the sludge samples were collected at MBR A. All samples were collected at the upper-decks of the MBR membrane tanks, in central areas, with the following exception. MBR A has two separate membrane tanks plus 6 other tanks, intended for carbonaceous and nutrient