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Particle counting as surrogate measurement of membrane integrity loss and assessment tool for particle growth and regrowth in the permeate of membrane bioreactors

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ABSTRACT

Wastewater is increasingly used as a viable water source. Reclamation schemes rely on membranes technologies, such as Membrane Bioreactors (MBR) and subsequent membrane filtration steps to achieve the discharge or reuse limits. However, membrane technology is only effective if the membranes are intact. Moreover, growth or regrowth of particles between membrane filtration steps should be restricted, to guarantee a stable water production. Membrane integrity tools are being developed for the drinking water industry with high sensitivity and accuracy. However, such standards are not required for MBRs, where the produced permeate is not used for consumption without further treatment. In this research, we focused on permeate quality and particle counting measurements in the range 2–100 μm. A total of 433 samples of permeate and process water were measured at 8 full-scale and pilot-scale MBR locations, which were compared with 43 de-mineralized water samples measured at TU Delft. Only at one full-scale MBR the membrane integrity was compromised, which was successfully assessed by counts and shapes of the permeate particle counting distributions. All permeate samples had particles about a 100 times larger than the membrane pore size. Our results allowed us to define the relevant steps of a methodology to assess membrane integrity, particle or biomass growth and aggregation in MBR permeate. The latter two are of particular interest to determine whether growth in permeate lines is still acceptable or whether a cleaning action of the permeate collection system is required.

1. Introduction

According to the World Health Organization [1], by 2025 half of the world's population will be living in fresh water stressed areas. To minimize the problem, unconventional water sources, such as wastewater, are being increasingly considered as water source. Water reclamation mainly relies on membrane technology to assure compliance with the reuse criteria. Membrane bioreactor (MBR) technology is usually applied in wastewater reclamation followed by reversed osmosis (RO) [2,3]. It is overall accepted that MBR technology removes protozoan cysts, oocysts, helminthes ova, bacteria and viruses [4]. However, removal of microorganisms is only effective if the membranes are intact [5]. Membrane leakages have been reported in MBR systems, with coliform breakthrough leading to RO flux decline [6]. In drinking water treatment, water reuse motivated a growing interest on membrane integrity tools [7–10]. Therefore, with the increasingly applied reuse of treated water it is logical to assume that membrane integrity tools, adapted to wastewater characteristics and treatment specificities, must be developed and evaluated.

Membrane integrity maybe tested by direct and indirect measurements. Direct tests measure a change in the integrity of the membranes and are performed when the membranes are off-line [5]. Direct tests usually measure changes in pressure, air flow or sound whose magnitude is a direct function of membrane breaches [11]. Indirect methods rely on water quality parameters and measure the result of a membrane breach [5]. Recently, several new integrity methods have been reported, either based on direct [7–9], or indirect measurements [10]. The new methods mainly arise from the water industry and aim to validate the removal of microorganisms in membrane systems, which are increasingly applied. Removal of microorganisms is crucial when producing water of drinking water quality, therefore the new methods aim to a very high sensitivity and detection of membrane breaches.

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In wastewater treatment, in-situ testing, i.e. direct measurements tests, are not feasible [12] because they require downtime, which might not be hydraulically or economically possible. Laser-induced breakdown detection was proposed as a suitable indirect method of membrane integrity in drinking water and other treatment systems [10]. However, the technology requires the definition of a baseline, i.e. to be applied to known particles, which might not be the case in wastewater effluents. Phattaranawik et al. [13] proposed a membrane-based sensor for on-line integrity measurements and tested MBR effluent, also designated as permeate. The membrane sensor mimics the principle of a full-scale MBR, i.e. the permeate is submitted to membrane filtration which is monitored through trans-membrane pressure. Since the sensor is placed downstream an MBR system, it can monitor not only the membrane integrity of the MBR membranes, but also quantify the membrane fouling in the subsequent membrane filtration steps such as RO or nano-filtration (NF). The latter double feature is especially important in water reclamation systems, because MBR technology is seldom applied as a single membrane barrier. Nevertheless, to our knowledge, at this moment none of the abovementioned technologies is commercially available.

Within the indirect methods, turbidity and particle counts, analyzed in the product water, are commonly applied in water treatment plants [11]. The primary means of determining membrane integrity in an MBR is by measuring permeate turbidity [12]. Turbidity monitoring is less expensive than particle counting but offers lower sensitivity [5,14]. The sensitivity of turbidity and particle counting was reported as below 1 and 3.5 log microorganisms removal [5], respectively, being sensitivity as the maximum log removal value (LRV) that can be reliably verified by the integrity test. Permeate with a turbidity of 0.1 NTU can have significant bacterial contamination [11]. Turbidity measurements become unreliable for high quality treated waters and the values cannot be interpreted in terms of particle concentrations or particle size [15], which could be directly compared with the membrane pore size. Particle counting instruments do count and size particles in specific size ranges. The technology is widely applied in water industry and is considering convenient for routine qualitative monitoring [11]. Nevertheless, in drinking water treatment particle counting is considered to have a low sensitivity, namely below a 4 LRV. However, previous research indicated that particle counting had the required sensitivity to test membrane integrity, able to detect one compromised membrane fiber out of 40,000 fibers [14,16]. Applying particle counting in on-line continuous operation does have certain requirements, namely a determined number of particle counters per membrane area and the need for an installation with suitable hydraulics, capable to prevent entrapment and sizing of air bubbles and flow variations during measurements [5,11]. However, particle counting can be applied off-line, in batch mode, allowing tighter control on flow variations and eventual entrapment of air bubbles. Nevertheless, regulations on drinking water supply are becoming increasingly stringent, justifying the development of membrane integrity techniques with high detection levels.

However, in sewage water reclamation, where MBR technology is usually followed by a subsequent membrane filtration step of smaller pore size or higher molecular cut-off, the produced permeate has a lower quality than drinking water. Moreover, after the subsequent filtration step, usually RO or NF, the produced water will not be used for human consumption without further treatment. Therefore, it seems to be logical to allow less stringent membrane integrity requirements to MBR permeate, and consequently to MBR technology, compared to membrane applications in drinking water production. In wastewater treatment, particle counting was already applied to evaluate the systems performance [17,18]. In this research, we postulate that particle counting can be used in MBR technology, not only to detect membrane integrity failure but also to determine whether the permeate collection system should be cleaned, in order to avoid growth or regrowth of permeate particles. To evaluate the hypothesis, samples of permeate and process water, i.e. water used in the WWTP for local tasks such as cleaning floors or cleaning system components, were submitted to particle counting measurements in the range 2–100 μm in 4 full-scale and 4 pilot-scale MBR installations.

2. Methodology

A particle counter set-up was transported to 8 European MBR installations, characterized in Table 1. The particle counting measurements were done at the locations, with permeate grab samples, measured directly after collection. A total of 255 permeate samples were measured and analyzed. Permeate was collected in the first outlet available of the permeate collection system, preferably in the permeate outlets of each membrane module.

To evaluate the reliability of the particle counter and allow comparison with the permeate samples results, 43 de-mineralized water samples, 178 process water samples and 4 conventional activated sludge (CAS) samples were also measured using the same methodology. The process water is used inside the WWTP in local tasks that do not necessarily require water with drinking water standards. The source of the process water within each WWTP, varies according to the location. With the exception of de-mineralized water measured at the TU Delft water lab, all remaining samples were measured at the locations using local sources. The sources of the process water were drinking water, an on-site well and permeate.

2.1. Particle counting

In a particle counter an electric signal is created when the particles pass through a sensing zone. Afterwards, the signal is mathematically interpreted and particles are sized and counted. The sizing is done in increments, i.e. all signals within a certain range are counted as equal, resulting in a discrete, rather than

Table 1
MBR installations characteristics.

Location	Pop. Equi.	WWTP	Membrane configuration	Membrane pore size (μm)	Cleaning
A	28,000	CAS + MBR	HF[b]	0.04	Mechanical and chemical (once a week)
B	9700	MBR	HF	0.04	Mechanical and chemical (twice a year)
C	80,000	MBR	HF	0.04	Mechanical and chemical (once a week)
D	13,000	CAS + MBR	FS[c]	0.08	Mechanical and chemical (twice a year)
E	250	MBR	FS	0.2	Mechanical and chemical (frequency determined by need)
F	8	MBBR[a]	HF	0.04	Mechanical and chemical (frequency determined by need)
G	200	MBR	2 HF	0.04; 0.1	Mechanical and chemical (frequency determined by need)
H	100	MBR	2HF 1FS	0.04; 0.04; 0.4	Mechanical and chemical (frequency determined by need)

[a] MBBR – Moving Bed Biofilm Reactor.
[b] HF – Hollow Fiber.
[c] FS – Flat sheet.