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Physical properties of activated sludge in a submerged membrane bioreactor and relation with membrane fouling

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Abstract

The objective of this study is to establish some relations between the physical properties of the sludge (i.e., specific resistance to filtration, capillary suction time . . .) and membrane fouling in a submerged membrane bioreactor, for high solid retention time (SRT) conditions. The analysis of the membrane performances, carried out with an analysis of the depollution performances and of the activated sludge physical properties, is proposed in an experimental membrane bioreactor (MBR) unit working with complete biomass retention. It is first confirmed that high-SRT conditions involve a high degree of organic degradation, with low sludge yield. A continuous increase of the viscosity can be observed during time but the sludge dewatering behaviour can be considered as constant, despite the total suspended solids (TSS) increase. No direct correlation is established between the transmembrane pressure (TMP) evolution and the conventional parameters used to describe sludge dewaterability but it can be assumed that the sludge filtration is not possible when TSS and viscosity reach "critical" values. Soluble microbial substances and mean floc size diameter evolutions cannot explain the decrease of membrane permeability, although these compounds may enhance fouling. The characterisation of the bulk suspension seems to not provide enough informations to anticipate the evolution of the membrane fouling and some complementary methodologies, allowing the characterisation of the environment close to the membrane, have to be developed.

Keywords: Membrane bioreactor; Sludge physical properties; Dewaterability; Filterability; Membrane fouling

1. Introduction

Nowadays, the membrane bioreactor (MBR) technology is one of the cost-effective and sustainable solutions for new and efficient advanced municipal wastewater treatments. In comparison with the conventional activated sludge (CAS) process, this technology presents several advantages: (i) the space requirement is greatly reduced due to the absence of settlement tanks and to high biomass concentration (two to five times higher than the one observed with CAS), (ii) the effluent quality is significantly better as the suspended and colloidal materials are removed as well as all the associated pollutants, such as heavy metals, micro-pollutants, bacteria, viruses and colour, and (iii) a flexible and phased extension of existing wastewater treatment plants is possible. However, the membrane fouling, which leads to permeability decline and increase of operating cost, is a major obstacle for an extensive development of this system for wastewater treatment and reuse.

This membrane fouling is dependant on various parameters concerning the membrane characteristics, the operational conditions and the activated sludge characteristics (Fig. 1).

Three families of compounds (particular, colloidal and soluble compounds) take part in permeability decline but the impact of these different fractions on membrane fouling is discussed controversially in the literature. Some authors state that the solid fraction has the most significant impact on fouling [1]. Other authors found that the non-settleable organic fraction of the suspension has a great importance and demonstrated that some of the liquid phase substances, often assigned to soluble microbial products (SMP), have generally a negative effect on membrane fouling [2–4]. The results given in the literature are difficult to

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Nomenclature

CAS	conventional activated sludge
C_m	mass loading (T^{-1})
COD_S	soluble chemical oxygen demand ($M\,L^{-3}$)
COD_T	total chemical oxygen demand ($M\,L^{-3}$)
CST	capillary suction time (T)
Dm	floc size (L)
HRT	hydraulic retention time (T)
r_s	organic removal rate ($M\,L^{-3}\,T^{-1}$)
r_x	biomass growth rate ($M\,L^{-3}\,T^{-1}$)
s	compressibility coefficient
S_L	dryness limit
SMP	soluble microbial products ($M\,L^{-3}$)
SRF	specific resistance to filtration ($L\,M^{-1}$)
SRT	solid retention time (T)
SVI	sludge volume index ($L\,M^{-1}$)
TMP	transmembrane pressure ($M\,L^{-1}\,T^{-2}$)
TSS	total suspended solids ($M\,L^{-3}$)
VSS	volatile suspended solids ($M\,L^{-3}$)
Y_{obs}	biomass conversion
μ_∞	limit dynamic viscosity ($M\,L^{-1}\,T^{-1}$)

compare as they depend very much on the operating conditions of the investigated MBR, e.g. hydrodynamic conditions (shear stress, backwash, or relaxation period, ...) or solid residence time.

In the present study, high-SRT conditions are chosen in order to minimize the sludge production [5–7]. In these specific conditions, the aim of this work is to investigate the performance of submerged membrane modules during a long-term MBR operation with complete biomass retention. The analysis of the MBR membrane fouling is carried out with an investigation of the overall MBR performance and an analysis of the activated sludge physical properties, focused on the conventional used to describe sludge dewaterability. The objective of these simultaneous analyses is to establish some relations between the physical properties of the sludge and membrane fouling for high-SRT conditions.

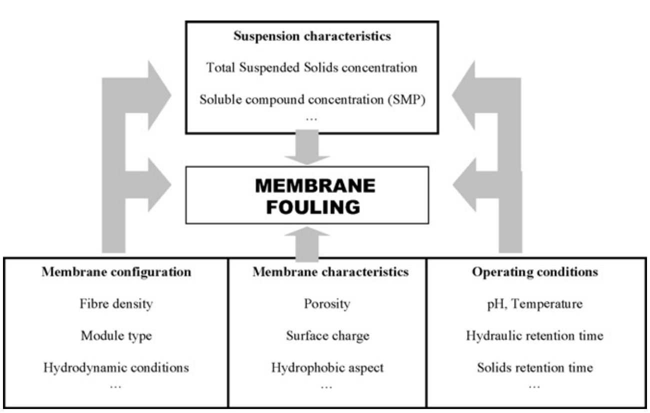

Fig. 1. Key parameters in membrane fouling.

2. Materials and methods

2.1. Experimental set-up and operating conditions

2.1.1. Plant configuration

The experiments are performed in a submerged membrane bioreactor with a working volume of 50 L. The suspension is continuously stirred using a rotating mixer to ensure a perfect mixing of the bulk suspension in the reactor. The pilot plant configuration is shown in Fig. 2.

Polysulphone hollow fibre membranes with a pore size of 0.08 μm are used (Polymem, France). The total filtration area is 0.2 m^2 (two modules, each of 0.1 m^2). Filtration is performed in a continue mode, without relaxation or back-wash, in an outside to inside mode at a constant permeate flux equal to 4.8 $L\,m^{-2}\,h^{-1}$ maintained by peristaltic pumps. Critical flux was quantified in preliminary experiments and the chosen flux allows working in subcritical conditions [8,9]. Aeration is imposed at the bottom of the membrane modules to create shear stresses close to the membrane surface in order to limit deposit and reversible fouling. The aeration flow rate per filtration area is equal to $1.2 \times 10^4\,L\,m^{-2}\,h^{-1}$ and provides also oxygen for the biological process needs.

2.1.2. Operating conditions

The operating conditions are given in Table 1. The synthetic substrate is composed of acetate and meat extract (Viandox®) and is representative of a complex influent. During the whole period of the experiment (140 days), no sludge is removed from the pilot plant except for sampling. Due to the complete retention of sludge in the system, the solid retention time (SRT) can be considered equivalent to the operation time.

2.2. Analysis and measurements

The performances of the membrane bioreactor are studied by (i) following the organic matter removal and the evolution of the biomass concentration and characteristics in the system, and (ii) following the membrane fouling characterised by the transmembrane pressure (TMP) evolution.

Conventional parameters (COD, TSS, VSS) are investigated on the influent, the permeate, the bulk suspension and the soluble fraction of the bulk suspension. The soluble fraction is obtained after a centrifugation (10,000*g*, 20 min), following by a filtration of the supernatant through a 0.45 μm filter. Proteins and polysaccharides, mainly soluble microbial products, are quantified in the soluble fraction of the bulk suspension.

The dewaterabilty and the filterability of the sludge are evaluated using the specific resistance to filtration (SRF), the compressibility coefficient (s), the dryness limit (S_L), the sludge volume index (SVI) and the capillary suction time (CST). Measurements were performed according to the conventional methodologies [10–12].

Mean particle size and dynamic viscosity are analysed to complete the sludge characterisation. Conventional activated sludge are well-known to be non-Newtonian fluids: the apparent viscosity depends on the shear rate. In our experiments,