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Physical characteristics of the sludge in a complete retention membrane bioreactor

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ABSTRACT

Sludge physical characteristics play an important role in the operation of membrane bioreactors (MBR) due to their influence on filtration and their effects on handling of excess sludge. These systems are designed to maintain high solid concentrations, thus limiting sludge production and the related operational costs of the process. In this study, the sludge from a bench scale MBR operated for about 1 year with complete solid retention was investigated to assess its physical and rheological properties. Concentrations of mixed liquor suspended solids (MLSS) up to 24 g TSS L^{-1} affected the diluted sludge volume index (DSVI), the capillary suction time (CST), the specific resistance to filtration (SRF) and the compressibility (s). The MBR sludge displayed similar dewatering properties of conventional waste activated sludge, suggesting that the upgrade of wastewater treatment plants with the MBR technology would not affect the behaviour of the dewatering equipment.

The apparent viscosity was expressed as a function of the MLSS and the experimental data were interpreted by comparing different models. Ostwald model was chosen, and two equations for viscosity were proposed. The thixotropy of MBR sludge was also evaluated by measuring the reduced hysteresis area (rHa) and relating this parameter to the characteristics of the sludge. The evaluation of energy consumption for mixing evidenced that, under the tested conditions, the increase of solid concentration from 3 to 30 g TSS L^{-1} resulted in a limited increase of energy requirements (25–30%).

1. Introduction

In the last decades, the wide exploitation of limited water resources and the need for preservation of primary sources for drinkable uses has increased the interest in reuse of treated wastewater. As a result, a strong demand towards sustainable technologies aimed at obtaining high-quality effluents has developed. In this framework, membrane bioreactors (MBR) offer a possible solution for wastewater reclamation.

The MBR technology integrates biological degradation of wastewater pollutants with membrane filtration, ensuring effective removal of organic and inorganic contaminants and biological material from municipal and/or industrial wastewaters (Cicek et al., 1998). Limitations inherent to MBR processes are the cost of membranes and the loss of membrane filtration capacity due to fouling. However, the advantages of MBR with respect to traditional treatment techniques include smaller footprint, high loading rate capabilities, and modularity (Stephenson et al., 2000; Visvanathan et al., 2000). Moreover, these systems are not affected by the settling properties of solid materials as conventional activated sludge (CAS), thus allowing operation at very high biomass concentrations and at prolonged solid retention times (SRT).

Process operation under high SRT was reported to cause limited oxygenation (i.e. increased aeration costs), higher

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membrane fouling potential resulting in increased cleaning needs, and mass transfer limitations (Yoon et al., 2004; Muller et al., 1995; Lübbeke et al., 1995; Côté et al., 1998; Rosenberger et al., 2000; Cicek et al., 2001). On the other hand, high biomass concentrations affect the cell metabolism, limit the bacterial growth and the consequent sludge production, thus reducing the operational costs of the process (Arnot and Howell, 2001; Suwa et al., 1992). These features are particularly enhanced in complete retention MBR, where the biological processes tend towards an equilibrium where the substrate provided is barely enough for the maintenance of bacterial vital functions, resulting in extremely low biomass growth rates (Muller et al., 1995; Pollice et al., 2004; Laera et al., 2005). Several experiences with membrane bioreactors operated without sludge withdrawal were reported in the literature (Muller et al., 1995; Pollice et al., 2004; Laera et al., 2005; Yamamoto et al., 1989; Benítez et al., 1995; Chiemchaisri et al., 1992; Wagner and Rosenwinkel, 2000; Rosenberger et al., 2002a). All these authors confirmed that complete sludge retention can be performed and that this mode of operation is characterized by very limited sludge production or zero net growth, although some reports refer to non-steady state conditions and/or variable loads.

Limited sludge production is very attractive in terms of the reduction of operational costs. Sludge treatment costs before disposal are dependent both on its quantity and characteristics in term of treatability with specific regard to dewaterability. MBR sludge characteristics were seldom investigated and usually referred to their influence on membrane filtration rather than on excess sludge treatability. In particular, sludge rheology affects the system's hydrodynamic regime, pressure losses and transport phenomena near the membrane surface, thus influencing filtration performance (Rosenberger et al., 2002b; Hasar et al., 2004). Rheological parameters also affect the energy requirements for mixing, aeration and permeate extraction, with consequences on the operating costs. Higher solid concentrations may have an influence on sludge viscosity, so affecting the circulation of bulk sludge and the shear stress at the filtration cake surface (Pollice et al., 2006).

In all sludge filtration processes, the particle size distribution of the suspension affects the separation efficiency. Previous studies on CAS proposed strong correlations between the dispersed mass concentration and both the resistance to filtration (in terms of capillary suction time and specific resistance to filtration), and the rheological parameters (Mikkelsen, 2001). MBR floc size distributions are usually characterized by a greater number of small flocs with respect to CAS. Since dewaterability is negatively influenced by reduced particle size, it might be generally harder to reduce the water content of MBR sludge (Karr and Keinath, 1978). Limitations to sludge dewaterability are also caused by the presence of high concentrations of slowly biodegradable extracellular polymeric substances (EPS) (Mikkelsen and Keiding, 2002). According to the literature, the EPS tend to be produced when organic substrates, nutrients, or oxygen are lacking (Barker and Stuckey, 1998; Sponza, 2002; Zhang and Bishop, 2003). When MBR are operated under longer sludge retention times and higher biomass concentrations than those normally adopted in conventional activated sludge these conditions of stress are more likely to occur. Therefore, higher EPS concentrations can be expected in MBR with respect to CAS, possibly due to the higher stress on the biomass.

This work reports the main results of a physical and rheological characterization of the biomass sampled from a bench scale membrane bioreactor operated for about 1 year with complete retention of sludge (Laera et al., 2005). The sludge was regularly sampled in order to characterize its settleability, filterability and compressibility and to evaluate its rheology. The experimental data were modelled as functions of mixed liquor suspended solids (MLSS). The data obtained were compared with the average values of the same parameters for conventional activated sludge. Moreover, the effects of the higher solid concentrations within the MBR on the energy required for mixing the bulk sludge were evaluated.

2. Materials and methods

2.1. *Experimental plant*

The bench scale submerged membrane bioreactor had 6 L operating volume, and a hydraulic retention time of about 7.5 h was always maintained. The plant was equipped with a Zenon hollow fibre membrane module having a surface of 0.047 m^2, and its description and mode of operation were reported in previous articles (Pollice et al., 2004; Laera et al., 2005).

The plant was started up without any biomass inoculum, and during the whole experimental period no sludge was intentionally withdrawn from the reactor, except for measurements of suspended solids. The limited sludge losses occurred during module cleaning was accounted for in the calculation of biomass production and the other sludge-related parameters. The biomass that tended to adhere to those parts of the reactor close to the surface level was daily removed and returned to the sludge bulk. All biomass samples were always returned to the reactor after non-destructive determinations. The volume of sludge removed and not returned to the reactor was estimated to be about 35 mL/week on average, corresponding to 0.83 g TSS/week (i.e. the biomass daily removed from the reactor is 0.09% on average). The fact that sampling frequency and membrane cleaning are not directly dependent on the biology of the system and can be varied according to the testing strategy does not allow to use these average biomass losses to define a sludge age in a rigorous way. By definition, the latter parameter (intended as the ratio between the total sludge mass in the system and the amount daily wasted) cannot be calculated under complete sludge retention, and will not be considered in the discussion of results.

2.2. *Sampling and analyses*

The influent municipal wastewater and the permeate were sampled three times per week and analysed for total and volatile suspended solids (TSS and VSS), total COD, N-NH_4, TKN, N-NO_2, and N-NO_3. All analyses were performed according to standard methods (Standard Methods for the