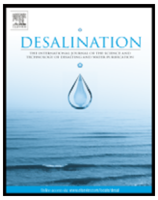
Desalination 250 (2010) 660–665

Contents lists available at ScienceDirect

Desalination

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



# Sludge filterability and dewaterability in a membrane bioreactor for municipal wastewater treatment[☆]

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ARTICLE INFO

*Article history:*
Accepted 24 June 2009

*Keywords:*
MBR
Sludge filterability
Sludge dewaterability
EPS
TOC

ABSTRACT

The physical properties of excess sludge wasted from a large pilot scale membrane bioreactor (MBR) have been routinely monitored over almost two years. A statistical analysis highlighted the significant impact of temperature on the capillary suction time and sludge filterability, due to the increase of organic matter in the liquid phase. Suspended solids have resulted to be the most important component affecting sludge filterability, although the impact of colloids and solutes increased when temperature decrease, thus confirming the generally worse characteristics of sludge in such conditions. Conditioning and dewatering test have been performed on a pilot scale fixed volume recessed plate filter press. Six different chemicals were used for sludge pre-conditioning and, for each additive, three dosages were tested in the range 5–25 $g_{polymer}$ kgMLSS$^{-1}$. After about sixty filtration trials at three different pressure values (7, 11 and 15 bar), the kind of polymer seem to be the most important factor influencing the final cake-dryness, with less evident impact for dosage and operational pressure. Finally, when performed on the aerobically digested excess sludge wasted from a conventional activated sludge plant, the filtration tests show no differences with the MBR sludge.

## 1. Introduction

Since the introduction of submerged modules the membrane bioreactor technology has been extensively applied to both municipal and industrial wastewater treatment for its several advantages including effluent quality suitable for reuse, smaller footprint and lower sludge production compared with CASP (Conventional Activated Sludge Process). This has led to a considerable interest in the process by both academic researchers and practitioners: an easy survey on scientific search engines indicates that the number of items including the terms “membrane bioreactor” in the title and “wastewater” in the full text increased with an exponential trend during the last 15 years, with its value doubled in the last three years [1]. So far, most of researches have been focused on understanding the mechanisms governing membrane fouling, with a special attention to the impact of membrane scouring aeration [2–4], the effect of soluble microbial products and extracellular polymeric substances [5–7] and the applicability of the critical flux concept for a more sustainable operation of the process [8–10]. More recently a growing interest in the application of conventional activated sludge models ASM 1, ASM2d and ASM3 has spread throughout scientific community [11–13] aimed at predicting the performances of the process under various operational conditions which are in some cases extremely different than the typical ones of conventional activated sludge. In this field many efforts are focused on coupling biological process and fouling development in integrated model. On the other hand, since early applications one of the most appealing characteristics of the MBR technology has been represented by the possibility to reduce the surplus sludge production. In general terms, two categories of membrane bioreactor can be identified: in decentralised systems or in contexts where significant seasonal loading fluctuations are observed, long SRT operation is generally preferred due to the lack of facilities for excess sludge treatment and disposal. At the same time, the number of more “conventional” centralized MBR installations is constantly increasing, where sludge age values are just slightly higher than usual CASP thus resulting in a non-negligible amount of surplus sludge. Studies on the physical and rheological properties of surplus sludge from MBRs have been carried out mainly at bench and small pilot scale. Sludge dewaterability was found to be very close to that of conventional activated sludge, regardless with the increasing suspended solids [14,15]. Concerning the apparent viscosity, there is a common consensus on the non-Newtonian thixotropic behaviour of the MBR sludge and most studies indicate an increasing trend with the MLSS concentration, generally better fit by the Ostwald model [15,16]. However, the interpretation about the actual impact of such higher viscosity on the energy demand of the process is still debated.

This paper reports results from almost 2 years operation of a large pilot scale plant which has been run in the framework of the EUROMBRA project. The behaviour of the excess sludge has been investigated in

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[☆] Presented at the Conference on Membranes in Drinking and Industrial Water Production, 20–24 October 2008, Toulouse, France.

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doi:10.1016/j.desal.2009.06.074

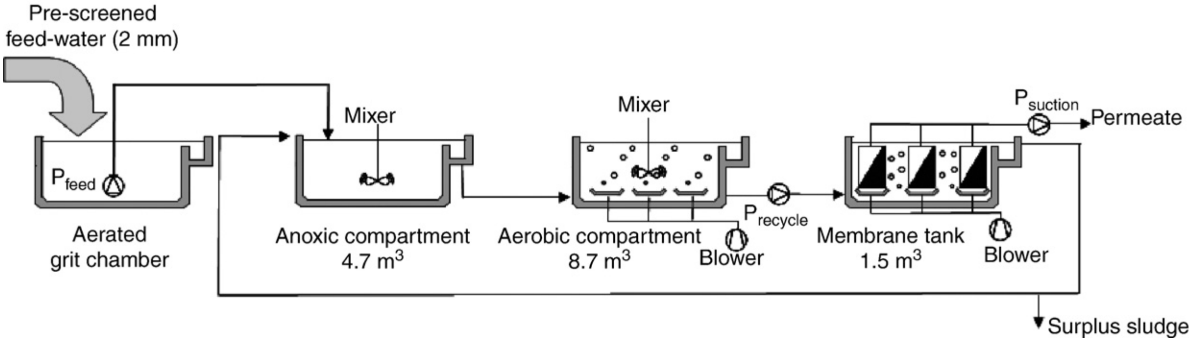

**Fig. 1.** Flow diagram of the large pilot scale MBR.

terms of filterability and dewaterability by means of conventional parameters (capillary suction time, CST; specific resistance to filtration, SRF, dilute sludge volume index, DSVI), content of carbohydrates, proteins and TOC. The experimental results presented here have been divided into two sections: first, the outcomes of a statistical analysis are reported, aim at the assessment of the correlation between sludge properties and operational conditions such as process temperature. Then, the inferences from experimental trials on a pilot scale filter press are presented, in which the actual dewatering potential of the sludge is evaluated, after conditioning with different chemicals and under various pressure values.

## 2. Materials and methods

A large pilot scale MBR has been operated since Oct. 2006. The plant is located at the WWTP of Lavis (Trento, Italy) and is fed with pre-screened (2 mm) municipal wastewater pumped after the grit chamber of the full scale installations. The flow diagram is shown in Fig. 1.

The overall process volume is 14.9 $m^3$, 10% of which being due to the membrane compartment in which three membrane modules (GE Zenon ZW500d) are immersed. The membrane material is a patented hydrophilicized PVDF, with a nominal pore size of 0.04 µm and an overall membrane surface area of ~100 $m^2$. Both hydraulics- and biology-related parameters are monitored on-line including permeate flux, TMP, MLSS (in biotank and membrane chamber), dissolved oxygen and effluent ammonia and nitrate. After the transient phase at the plant start up, the system has been usually operated at a 20–25 days SRT (Solids Retention Time) which resulted in a pseudo steady state MLSS concentration of $6.8 \pm 0.9$ kg $m^{-3}$ and; being the recycle ratio in the range 3–4, the MLSS concentration in the membrane compartment was correspondingly between $8.3 \pm 1.0$ kg $m^{-3}$. Except for some specific experiments for the critical flux assessment (data not shown) the permeate flux has been tuned in the sub critical region, i.e. at values ranging between 10 and 20 L $m^{-2}h^{-1}$. The influent wastewater characteristics have been monitored twice a week, by collecting 24 h samples analysed according to the APHA Standard Methods [17]; the values for the main macropollutants are listed in Table 1.

Sludge characteristics have been measured weekly for dewaterability, filterability and settleability. More in detail, on each sample of sludge collected from the wastage point (membrane tank) the following parameters have been determined:

- capillary suction time according to the APHA Standard Method 2710G with a portable apparatus (Triton 304B; chromatography paper Whatman no. 17)
- $\alpha C$ ($m^{-2}$) which is related to the specific resistance to filtration $\alpha$ and thus depends on the deposit properties and its built-up mechanism. $\alpha C$ has been measured by means of unstirred dead end tests on polysulphone membrane (diameter: 47 mm; pore size: 0.22 µm) at constant pressure (0.5 bar) with on-line registration of permeate volume (Sartorius Competence CP2202; one datum per second). The data collected have been elaborated according the Carman–Kozeny equation:

$$\frac{t}{V} = \frac{\mu\cdot\alpha C\cdot V}{2A^2\cdot P}\cdot V + \frac{\mu\cdot R_m}{A\cdot P}$$

  where $t$ (s) is the time variable, $V$ is the permeate volume ($m^3$), $\mu$ is the dynamic viscosity of permeate (Pa s), $\alpha$ ($m^{-1}kg^{-1}$) is the specific resistance to filtration and $C$ (kg $m^{-3}$) is accumulated matter per unit of permeate volume, $A$ is the membrane surface area ($m^2$), $P$ is the operational pressure (Pa) and $R_m$ is the intrinsic membrane resistance ($m^{-1}$). For each sludge sample, three measurement have been carried out on different aliquots: (filtration 1) sludge itself, (filtration 2) supernatant after centrifugation (4000 g; 20 min), (filtration 3) supernatant after centrifugation of a sludge quote to which a $ZnSO_4$ solution is added to flocculate colloids. The first $\alpha C$ value accounts for all components in the sludge, the second for non settleable (colloidal matter) and solutes and the third one only for solutes. In this way, by assuming the additivity of resistances as proposed by [18], the $\alpha C$ of solutes was determined by filtration 3, the $\alpha C$ of colloids as difference between filtration 2 and filtration 3, $\alpha C$ of suspended solids as difference between filtration 1 and filtration 2.
- DSVI, according to the Standard Method 2710 D; The content of proteins and polysaccharide has been weekly measured in the sludge. A centrifugation step (4000 g, 10 min) and the supernatant filtration on a 1.5 µm fibreglass filter have provided the sample for the suspended EPS. In turn, sludge pellets collected after the centrifugation have been resuspended in a buffer solution and subsequently added with a cationic exchange resin DOWEX (80 $g_{resin}\ g_{VSS}^{-1}$) and stirred at room temperature for 2 h, in order to extract the polymeric substances bound to the floc structure. On such samples, proteins and carbohydrates have been measured assuming BSA and glucose as standard, respectively. Moreover, the TOC content was determined on the same samples with cuvette test HACH-LANGE LCK385; these samples are also referred to as TOC in free EPS (TOC-$EPS_f$) and TOC in bound EPS (TOC-$EPS_b$).

Statistical analysis of the data from long term operation has been carried out to explore various interrelations among observed

**Table 1**
Composition of influent wastewater.

| Parameter | Unit | Value |
|---|---|---|
| COD | g $m^{-3}$ | $529.0 \pm 218.8$ |
| Soluble COD | g $m^{-3}$ | $127 \pm 81.0$ |
| TKN | g $m^{-3}$ | $66.3 \pm 42.0$ |
| $N–NH_4^+$ | g $m^{-3}$ | $39.7 \pm 22.2$ |
| Total P | g $m^{-3}$ | $7.8 \pm 5.1$ |
| TSS | g $m^{-3}$ | $294.3 \pm 276.0$ |
| VSS/TSS | % | $85.6 \pm 8.5$ |