DEWATERING OF EXCESS SLUDGE PRODUCED BY CAS AND MBR AEROBIC TREATMENT PLANTS. EFFECTS OF BIOCHEMICAL STABILITY AND EPS COMPOSITION

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Abstract *This paper investigates the behavior of different sludges from several treatment plants at full and pilot scale configured as Conventional Activated Sludge (CAS) and Membrane Bio Reactor (MBR) plants treating different kinds of wastewaters. The sludges collected were subjected to complete analytical and technological characterization in order to correlate the rheological properties that affect the dewatering behavior to the sludge chemical physical properties. In detail the EPS from the samples collected is extracted and characterized in terms of carbohydrates, proteins, uronic acids and humic acids content. Moreover, once characterized, the sludges were subjected to AD in order to assess their bio-methanation potential and hence their biological stability. The final aim was to find correlations between the WWTP operational parameters (i.e. HRT, SRT, volumetric load coefficient, aeration) that finally affect its chemical composition (i.e. BMP, EPS composition) and the physical behavior of the sludge.*

1. Introduction

The steadily increase of the world population and its related growing water demand, in the last decades contextually increased worldwide the number of the wastewaters treatment plants. The dewatering of sludge and consequently its disposal or incineration is nowadays considered to strongly influence the costs management and sustainability of the wastewater treatment plants (WWTPs) (Caniani et al., 2015; Capodici et al., 2016; Chen et al., 2015). Growing attention is paid to find new optimization strategies in order to reduce the environmental impact of the sludge streamline in terms of energy recovery and consequently reduction of indirect green-house gases (GHG) emissions. On the sustainability point of view, the anaerobic treatment of excess sludge from WWTPs is actually well attested as to be an optimal strategy to reduce the sludge management costs as well as the environmental impact. Anaerobic digestion (AD) of sludge gives the strong advantage of biogas energetic valorization, thus becoming seriously convenient making more sustainable and effective the sludge treatment and management (Ng & Hermanowicz, 2005). Conversely once digested, the sludge may undergo to a worsening of its dewatering capabilities, thus giving rise to an increase of the final management costs. The dewatering properties are found to be affected by several parameters. Among them, the extracellular polymeric substances (EPS) in terms of abundance and composition (Pontoni et al., 2016)play a primary role. The AD of the sludge, that involves the developing of different bacterial families with respect to the initial microbial distribution within the sludge, changes the composition and the ability to retain water of the EPS, thus affecting the final dewaterability of the digested sludge (Pontoni et al., 2015). It follows that the treatment plant configuration as well as the operational parameters have crucial importance in determining not only the total amount but also the quality of the excess sludge produced. Among the several advantages of MBR compared to traditional CAS systems is often reported the higher stability of the MBR sludge due to higher sludge retention time (SRT). This advantage is evident in the case of CAS systems that are upgraded to MBR since the upgrading allows to increase the microorganisms concentration in the biological reactor, resulting in a higher total biomass and therefore a higher SRT.

This advantage, however, cannot be generalized in the case of new construction MBR facilities. For the latter, the higher concentration of suspended solids in biological tanks corresponds to a decrease in the volume of the tanks compared to the case of CAS systems, which is one of the main advantages of the MBR technology. This decrease in volume, more or less important depending on the sensitivity of the designer, compensates for the increase in the concentration of microorganisms, resulting in a total biomass in the system, which is not very different from that which would occur in a CAS system aimed at treating the same wastewater influent. Similarly, if the influent wastewater and the mass of microorganisms in the biological reactors are the same, the amount of sludge produced by CAS and MBR and thus the SRT will be very similar and the SRT will depend only on the amount of extracted excess sludge. Therefore the two systems could be operated in such a way to have a similar SRT (Pontoni et al., 2016).

Therefore the sludge produced by MBR cannot be generally considered as already stabilized and thus as a sludge that does not require a further digestion treatment. Even some authors believe advisable to conduct the process with a very low MBR SRT compared to what is theoretically possible, in order to maximize the concentration of organic substance in the sludge and thereby increase the energy recovery due to the anaerobic digestion of the sludge itself (Ng & Hermanowicz, 2005). Such a maximization should anyway take into account the dewatering quality of the final digested sludge produced, in order to optimize the energetic cost-benefits balance of the sludge streamline.

The aim of the present paper is to evaluate the dewatering performances of several sludge before and after the anaerobic digestion. The dewatering parameters measured, are compared with the plants operational parameters and to the sludge stability expressed as Biomethane Potential (BMP).

2. Materials and Methods

Tested sludges were collected from several typologies of treatment plant. An MBR sludge was sampled from a full scale plant treating in prevalence landfill leachate, located in Prato, Italy (MBR1). Two further MBR sludges were withdrawn from two pilot scale plants located in the University laboratory of Palermo, operating in different conditions one treating synthetic wastewater (MBR2) and the other one treating a high salinity (20 g/L) Hydrocarbons rich (20 mg/L) influent (MBR3). Both the MBR2 and MBR3 plant configurations are described in detail elsewhere (Capodici and Mannina, 2016a). A further MBR sludge was sampled from the MBR municipal wastewater treatment plant of Capri (Naples, Italy) (MBR4). Two CAS sludge were sampled from the full scale municipal WWTPs located in Potenza (Italy), and Anacapri, (Naples, Italy). The operating parameters of the plants where the sludges were collected are summarized in Table 1.

Table 1. *Operational parameters of the treatment plants*

Sludge	HRT (h)	Flow Rate (m^3/h)	SRT (d)	inCOD (mg/L)	inN-NH_4^+ (mg/L)	MLSS (g/L)	Membrane
MBR1	370	19	17	9300	1450	15-20	Hollow fiber
MBR2	20	0.02	NSW*	223	50	7.85	Hollow fiber
MBR3	16	0.02	NSW*	350	32	3.45	Hollow fiber
MBR4	24	65	35	350	35	9.05	Flat sheet
CAS1	24	1300	30	200	15	3.52	/
CAS2	18	70	10	600	75	3.50	/

*NSW = no sludge withdrawal

Anaerobic digestion was at actual time terminated on MBR1, MBR2, MBR3 and CAS sludge only. All the six sludges where subjected to concentration by settling for two hours. After this time, the supernatant was discharged and the thickened sludges were therefore characterized by gravimetry in terms of TS-VS according to EPA standard Methods (1684). Once thickened aliquots of each sludge were subjected to the EPS extraction as described by Frølund et al. (1996). Dowex marathon C (Sigma-Aldrich) was chosen as Cation Exchange Resin (CER). Once extracted the EPS composition was defined in terms of Carbohydrate (CH) (Dubois et al., 1956), Uronic acids (UA) (Blumenkrantz & Asboe-Hansen, 1973; Kintner III & Van Buren, 1982), Proteins (PR) (Lowry et al., 1951) and humic substances (HA) (Frølund et al., 1996).

Bio-methanation batch tests (BMTs) (Esposito et al., 2012a; Esposito et al., 2012b; Liotta et al., 2014) were conducted, after thickening, on 400 mL of each tested sludge. BMTs were performed in triplicate on a small scale under controlled and reproducible conditions in a 1,000 mL glass bottle GL 45 (Schott Duran, Germany). Each bottle was sealed with a 5 mm silicone disc that was held tightly to the bottle head by a plastic screw cap punched in the middle (Schott Duran, Germany). All digesters were immersed up to half of their height in hot water bath at a constant temperature of 308 K. Methane production was measured periodically by water displacement method after leaving the biogas bubbling in an inverted 1,000 mL glass bottle containing a strongly basic solution (12% NaOH) in order to trap any CO_2 present in the biogas. The methane measurement was stopped once the daily biogas production was lower than 1% of the total BMP. Dewaterability was evaluated by

Specific Resistance to Filtration (SRF) as described elsewhere (Pontoni et al., 2015b) and Capillary Suction Time (CST). CST was determined by means of a Triton (UK) standard CST apparatus using a 18 mm diameter funnel on standard CST paper according to APHA standard method 2710G (APHA, 1998).

3. Results and discussion

3.1. Anaerobic digestion

Figure 1 reports the cumulative specific methane production of the tested sludges.

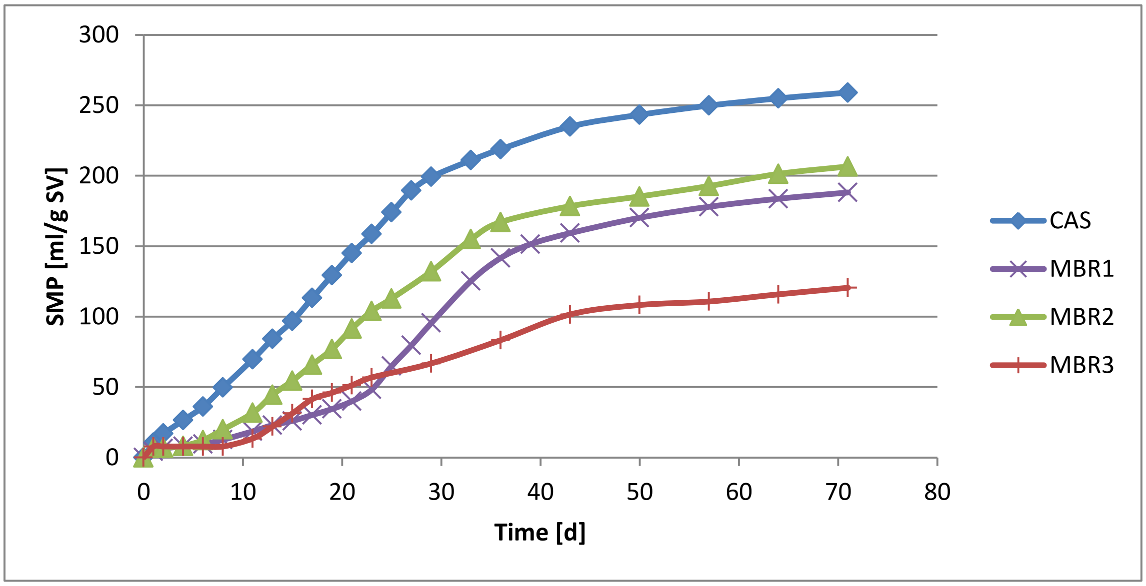

Figure 1. *Specific methane production of the tested sludge*

It is possible to notice how the methane production was higher for the CAS sludge. This higher SMP is in good accordance with previous experiments and with the consideration that usually MBR sludge is more "stabilized". Anyway, it is to take into account that the production of the two MBR it is not negligible. As found in our previous experiments (Pontoni et al. 2015) MBR sludge experience an initial lag phase to finally reach a production that is around two thirds compared to the CAS sludge. All the tested sludges, anyway experienced quite slow productions since more than 50 days of digestion were necessary to reach the production plateau. It is worth to notice the different production kinetics, indicated by the different shapes of the methanation curves. This depends from the different operating conditions of the plants of provenience of each sludge, which strongly influence the sludge composition and the biodegradability, as well as the microbial distribution. All these conditions strongly influence both the lag phase of the methanogenic biomass growth and the methane production rate. While CAS and MBR2 have the same production kinetics and shape and differ only for the final SMP expressed, MBR2 has a more sigmoidal shape. This might be attributed to the different development of biomass in the reactors. Starting from the assumption that anaerobic biomass is not predominant in the sludge at the moment of sampling, it is needed a lag phase to permit the anaerobic microorganisms enrichment and start the degradation of the sludge. This lag phase depends from the initial bacterial distribution, but is also related to the bioavailability of the organic matter. If substrates recalcitrant to hydrolysis are present it might be necessary to wait for the development of selective biomasses able to hydrolyze such compounds and finally give to the methanogen biomass the opportune substrate to grow. In this case the hydrolysis is the rate limiting step of the BMP and the curve assumes a sigmoidal shape, that is indicative for the two step mechanism described and that is observed for MBR1. Concerning the BMP expressed by MBR3, the sludge, that was from a plant treating high salinity and Hydrocarbon rich effluents, experienced inhibition of anaerobic degradation only producing around 100 ml/gVS. Such inhibition might be caused from both the conditions. In particular, high salinity is known to be a general inhibent of many bacterial activities, thus requiring the selection of halophilic consortia.

3.2. EPS Characterization

Data describing the EPS relative composition within the sludge before the anaerobic digestion in terms of CH, PR, UA, HA are reported in Figure 2.

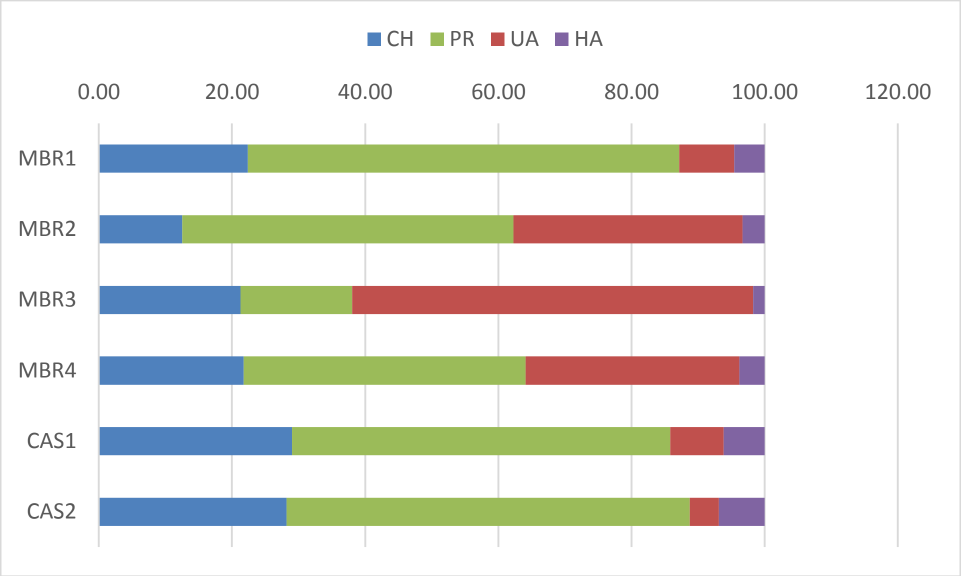

Figure 2. *EPS composition in the sludge*

It is possible to observe that the two CAS sludges have very similar EPS composition. The carbohydrate fraction is a bit lower than 30% of the total EPS. The major part results to be composed of proteins (around 60%) while the remaining part is approximately equally divided between uronic acids and humic substance. The MBR sludge presents instead a wider distribution with generally a lower content of carbohydrates and humic substances and at the same time a higher content of uronic acids. The MBR3 sludge has a much lower content of proteins and very high percentage of uronic acids. It is reasonable to hypothesize that the extremely halophilic conditions of the reactor pushed the biomass composing the MBR3 sludge to develop a different EPS structure. The EPS has in fact the function to create a protection for the bacterial aggregates against external condition allowing the biomass to survive also in extreme conditions. Moreover, the presence of high number of charged carboxylic residues gives to the EPS a higher emulsifying power, protecting bacteria against the hydrophobic hydrocarbon present in the influent wastewater (Iyer et al., 2006). Hence, the plant conditions strongly influenced the biomass selection, consequently the EPS structure, and its biological function**.**

3.3. Dewatering of sludge

Sludge dewatering results are reported in the following Table 2.

Table 2.

Sludge	SRF (m/Kg)	CST (s)
MBR1	$7{,}00\times10^{13}$	351
MBR2	$1{,}29\times10^{13}$	15.1
MBR3	$4{,}39\times10^{13}$	57.7
MBR4	$6{,}08\times10^{12}$	10.0
CAS1	$1{,}37\times10^{13}$	18.8
CAS2	$3{,}24\times10^{13}$	24.0

All the sludges present quite high values of SRF. This value is always higher than the threshold value of 5.0 $\times10^{12}$ that is indicated as maximum limit for industrial dewatering. This means that all the tested sludges need some kind of further treatment prior to be dewatered. It is anyway to highlight how the sludges have different dewatering properties, which are substantially strictly related to the operational parameters of the plant of provenience. As described before this creates different conditions for the biomass selection and production and consequently the excess sludge present different either mechanical or physical-chemical properties. It is moreover to take into account that the EPS content in the sludge is strongly related to the sludge dewatering. Figure1 shows how the SRF is function of total EPS amount for almost all the tested sludges with a very good correlation coefficient and within a quite wide range of EPS concentrations.

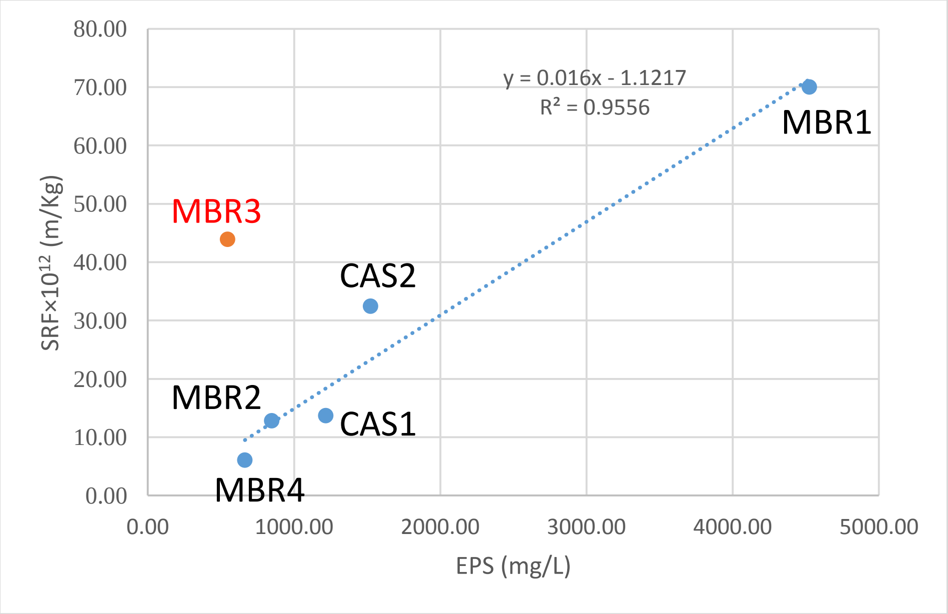

Figure 2. *Correlation between EPS in the sludge and SRF*

Comparing figures 1 and 2, it is easy to observe that the good correlation obtained for the sludge in figure 2 is due to the similar EPS composition of the sludges. This is not valid for the MBR3 since its SRF is pretty much higher compared to MBR2 and MBR4 that have a similar amount of EPS. This might be mainly attributed to the concomitance of two effects. The higher content of UA that are rich in charged carboxylic groups confers to the sludge a higher water retention capacity due the strong polar interaction that they can establish with the filtering water. On the other side the salinity itself is known to negatively influence the dewatering properties of the sludge (Mannina et al., 2016b). This means that, although it is possible to evaluate and compare the dewatering performance of sludge from different plants operating in different places and configurations, the correspondence with the EPS amount is not general and other parameters (i.e. salinity) need to be take in to account for a better comprehension of the complex phenomena happening during the dewatering process. For this reason the MBR3 was excluded from the calculation of the linear correlation in figure 2 being its salinity condition and EPS distribution too much different from the other sludges tested.

4. Conclusions

The Excess sludge from MBR WWTPs is not always to be considered biologically stabilized since the tested sludges showed a relatively high BMP. Although CAS sludges maintain a higher BMP value, the MBR potential makes sustainable and exploitable the anaerobic treatment of MBR sludge in view of the energy valorization and reduction of the indirect GHG emissions of WWTPs in which an anaerobic phase is designed in the sludge streamline. Several differences were found in the EPS composition between CAS and MBR sludges. A marked effect of salinity and hydrocarbons was revealed in shifting the biomass to produce EPS with high content of uronic acids. A strong direct correlation was found for the investigated sludges between the SRF values and the total EPS content, reflecting a dominant effect of the EPS on the rheological properties of the sludge. Such correlation although valid for the majority of the sludges tested in this study and in good accordance with our previous work, is not generalizable to sludges where the effect of salinity is predominant in worsening the overall sludge dewatering performances.

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