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Effect of Anaerobic Digestion on Rheological Parameters and Dewaterability of Aerobic Sludges from MBR and Conventional Activated Sludge Plants

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The paper investigates and compares the characteristics of sludges produced by membrane Bio-Reactor (MBR) and Conventional Activated Sludge (CAS) systems. Stability and dewaterability of full-scale MBR and CAS treatment plants are measured and compared. Obtained results show that specific methane production is higher in CAS sludge compared to MBR sludge because of the higher solid retention time of the MBR. Nonetheless MBR sludge results to be characterized by a non-negligible biometanation potential (BMP). Methane production measured during BMP tests is around 250 NmL/gVS for MBR sludge, equaling 2/3 of methane production obtained, in similar condition, for CAS sludge.
Dewaterability is evaluated by Specific Resistance to Filtration (SRF), Capillary Suction Time (CST) and Time To Filter (TTF) tests. Data obtained before and after the anaerobic digestion of the sludges show that the stabilization process affects much more the resistance to filtration of CAS sludge than the resistance to filtration of MBR sludge. The same trend is observed, for the other measured parameters. This is attributed to the variation of the rheological characteristics of the two sludges during the stabilization process, and to the different initial rheological properties of them due to the different selection process of the biomass deriving from the different biomass retention methods of MBR and CAS systems.

1. Introduction

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 microorganisms 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 as well.

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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, 2005a).
With regards to the effect of anaerobic digestion on the MBR sludge dewatering properties, it was not possible to find any data in the scientific literature. This represents a quite surprising lack, since the dewatering of sludges and consequently its disposal or incineration (Frýba et al., 2014) is strongly influencing the costs management of the treatment plants (Solisio and Dovì 2013). The purpose of this study was, therefore, to evaluate the effect of the anaerobic digestion process on the MBR sludge, both in terms of biomethane potential (BMP) and dewatering properties.

2. Materials and methods

2.1 Sludge preparation and characterization

Tested sludges were collected from two different MBR treatment plants located in Capri (Naples – Italy) (MBR sludge 1) and Marina del Cantone (Naples – Italy) (MBR sludge 2) respectively and from a CAS treatment plant located in Nola (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

	HRT (h)	Flow rate (m^3/h)	COD [mg/L]	N-NH4$^+$ [mg/L]	Membrane
MBR1	18	90	450	40	Hollow fiber
MBR2	22	12	450	35	plain
CAS1	7	3300	310	22	-

The collected sludges were concentrated 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).

2.2 Anaerobic digestion

Biomethanation batch tests (BMTs) 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 (Esposito et al., 2012) 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. Once finished the biogas production, the output digestates in each reactor were characterized again in terms of VS-TS.

2.3 Dewaterability Tests

Dewaterability is evaluated by Specific Resistance to Filtration (SRF) and Capillary Suction Time (CST) [6]. SRF is a technological parameter that gives count of the aptitude of sludges to be dehydrated via filtration. It is widely used to previse performances of full-scale filters and to compare the behavior of sludges from different plants against filtration processes. It represents the resistance to filtration of a theoretical sludge panel having unitary weight in dry solids per unity of filtering surface. The SRF was determined by pouring a 200 mL sample into a Buchner funnel lined with N° 541 Whatman filter paper. A negative differential pressure was applied of 49 kN/m^2, and kept constant by means of a pressure regulating system. The first volume of filtrate collected is discarded until the system was reaching the full vacuum and the volume of filtrate is therefore recorded at regular time intervals by means of a graduated cylinder (precision 0,25mL).
The SRF is then calculated according to the following relationship:

$$\mathrm{R} = \frac{2PA^2}{\mu \cdot C} b \qquad (1)$$

Where:
R = Specific resistance M/Kg),
P = Applied differential pressure (N/m^2),
A = Area of the filter in the funnel (m^2),
μ = Viscosity of the filtrate (Kg/m·s)
$C = \frac{C_0 C_c}{C_c - C_0}$ where C_0 e C_c are the solid concentrations (kg/m$^{3)}$ in the sludge itself and in the sludge panel formed in the filter after the filtration.

The parameter b (s/m^6) is experimentally determined by the method heretofore described. It represents the slope of the linear interval of the curve obtained by plotting the values of the filtered volume (V) at time (t) in the graph recording the volume V on the abscissa and the ratio t/V on the ordinate.
During the same test conditions, the time necessary to collect 100 mL of filtrate is defined as Time To Filter TTF and it was determined according to APHA standard method 2710H (1998). The capillary suction time (CST) test determines the water retention of a certain sludge. A sludge sample is placed in a metal cylindrical funnel on standard chromatographic paper. Water is moving through the paper sheet by capillary suction. The time necessary to reach a specified distance is defined as 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 (1998). Being both TTF and CST strongly dependent from the TSS content of the filtering sludge, the absolute values in seconds were normalized according to the respective standard method by dividing into the TSS concentration of the sludge. The values are thus expressed as s·L/g for both CST and TTF.

3. Results and discussions

3.1 Anaerobic digestion of MBR sludge

BMTs results are summarized in Figure 1 showing the specific cumulative methane production of the three studied sludges. The methane production per VS mass unit for CAS sludge was higher compared to the MBR sludge.

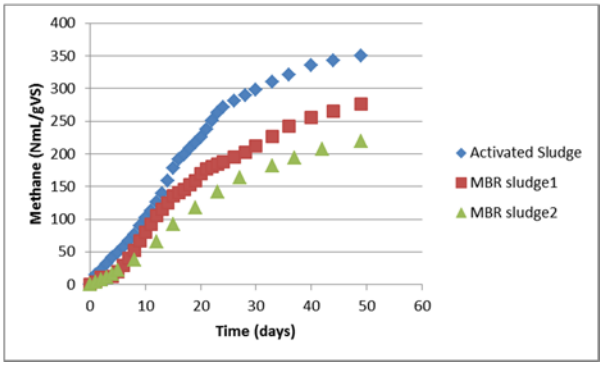

Figure 1: Cumulative specific methane productions of MBR sludge and CAS

This result was expected as MBR sludge is more stabilized than CAS sludge due the higher retention time in the plant and the showed BMP is in good agreement with Yu et al. (2012). The higher SRT of MBR sludge leads to lower methane production due to the presence of endogenous metabolism happening during the retention time of the biomass in the reactor. This could also bring to the formation of slowly or not biodegradable humic-like substances that could give lower or null contribute to the methane production having slow degradation kinetics, and can sometimes inhibit the methanogenic activity due the large presence of aromatic moieties in their own structures (Pontoni et al., 2015). This hypothesis is also confirmed by noting the different shape of the cumulative production during the first days of digestion. While CAS digestion takes place according to a first order kinetic, MBR sludges show a sigmoidal-like trend that implicates a longer lag phase due to the presence of less hydrolysable substrates which make hydrolysis, at least for a while, the rate limiting step of the process.
Prior and post anaerobic digestion, thickened sludges were characterized in terms of TS-VS as summarized in Table 2. Also these data confirm the lower digestibility of MBR sludges. The volatile solids removal is higher

for CAS according to the higher SMP expressed. Moreover either in input (0.75 and 0.82 vs 0.65) or in output (0.66 and 0.74 vs 0.54) MBR sludges have both a higher VS/TS ratio compared to the CAS sludge, confirming, also with the lower methane conversion rate, the hypothesis of a consistent presence of slowly biodegradable organic matter. Despite what mentioned above, a quite high BMP of MBR sludges (277 and 242 NmL/gVS for MBR1 and 2 respectively) was obtained, that is in both cases less than 1/3 lower than the BMP of CAS sludge (350 NmL/grVS).

Table 2: Characteristics of input and output sludge

	Input			**Output**			**Δ (%)**		**BMP**
	ST [g/l]	SV [g/l]	SV/ST	ST [g/l]	SV [g/l]	SV/ST	ST	SV	[NmL/gSV]
MBR1	16.3	12.2	0.75	12.7	8.4	0.66	-22	-31	277
MBR2	25.6	21.1	0.82	20.5	15.2	0.74	-20	-28	242
CAS1	22.9	14.8	0.65	17.6	9.5	0.54	-23	-36	350

This methane production makes clear that, although the MBR sludge is definitely more stabilized respect to CAS, further stabilization processes could be needed prior to the dewatering step. The waste sludge production for MBR plants is obviously much lower than for CAS ones, nevertheless the biogas production and valorization could make such sludge treatment economically sustainable due the not negligible BMP of MBR sludges. In particular anaerobic digestion of MBR sludge could be suitable for large WWTPs that produce high amounts of excess sludge even with MBR technology. Furthermore, even for small WWTPs the production of not completely stabilized sludge could rise serious disposal issues.

3.2 Dewaterability of sludge

Previous literature data about the effect of anaerobic digestion on sludge dewatering appear to be confusing and some way contradictory. Approximately the same number of studies show that digestion improves dewaterability or makes it worse (Lawler et al., 1986). The dewatering process is found to be influenced by several factors, i.e: properties and composition of the influent to the treatment plant (Houghton and Stephenson, 2002; Rosenberger et al., 2002), particle size distribution (Karr and Keinath, 1978), amount of suspended solids in the mixed liqueur (Rosenberger et al., 2002), salinity (Di Bella et al., 2014), presence of colloidal nanoparticles (Qi et al., 2011), abundance and structure of polyanionic substances mostly in the saccharide domain of extracellular polymeric substances (EPS) (Houghton and Stephenson, 2002). The co-presence of many heterogeneous variables is difficult to take into account and goes beyond the aim of the present work. It is anyway to highlight how the high SRT due to membrane technology application makes the sludge completely different from CAS in many of the factors affecting the dewatering process.
According to literature, the MBR sludge is generally presenting a higher resistance to filtration than CAS because of the different properties in terms of EPS concentration, suspended solids and amount of dispersed microorganisms (Ng and Hermanowicz, 2005b). This was confirmed by the results of the dewatering experiments carried on the tested sludge, before and after anaerobic digestion (Table 3).

Table 3: Rheological properties of input and output sludges

	Input			**Output**			**Output/input**		
	SRF[m/kg]	TTF[s·L/g]	CST[s·L/g]	SRF[m/kg]	TTF[s·L/g]	CST[s·L/g]	SRF	TTF	CS
MBR	1.06×10^{11}	31.53	1.17	2.63×10^{11}	68.74	1.65	2.5	2.2	1.
MBR	1.65×10^{11}	53.20	0.78	2.99×10^{11}	> d.l.*	2.93	1.8	> d.l.	3.
CAS1	7.25×10^{10}	21.18	0.74	1.41×10^{12}	63.52	5.40	19.4	3.0	7.

* d.l. : detection limit

The anaerobic digestion affected much more the filterability of CAS where the SRF values became 19.4 times higher after digestion. For MBR digested sludge a worse dewaterability was also found respect to the non-digested sludge, but the magnitude of this effect was one order lower than what described before for CAS. This is due to the difference between the sludge operational conditions.

CAS has very good dewatering capabilities before the digestion (SRF = 7.25×10^{10} m/kg), while MBR sludge is more difficult to filtrate (SRF = 1.06 and 1.65×10^{11} m/kg). Evidently anaerobic digestion affects much more the properties of CAS since its digestate goes to reach a SRF value near to the technical limit retained useful for real scale filtration of sludge (i.e. $5*10\times10^{12}$ m/kg) (IRSA-CNR, 1984). A similar trend was found also for CST and TTF, increased after anaerobic digestion in all the three tested sludges. In the case of MBR2 was even not possible to measure the TTF value since after collecting around 80 mL of filtrate, the filter was completely clogged and no sensible filtrate volume was recorded during all the carried tests, probably due to high solids content in front of low dewaterability. While SRF values are normalized by the solids content in the filtering cake, CST and TTF both depend from the suspended solids of the sample. This explains why for MBR2 a lower increase (1.8 times) than for MBR1 (2.5 times) of SRF after anaerobic digestion was found, while the increase of CST and TTF was higher for MBR2 because of the higher solid content in the filtering sludge. It is also well attested how SRF and CST are two different technical parameters that are not related one to the other (Smollen, 1986). SRF gives information about the resistance to filtration, taking thus into account the overall filtration process including all the components that are contributing to the filtration. CST is a measure of the water retention capacity of the sludge neared as the time that water takes to move through a standard chromatographic paper under capillary conditions. CST is thus less affected by the presence of small or colloidal particles that could clog the filter pores during SRF test (Houghton and Stephenson, 2002). It is instead much more affected by the presence of strong water binding polyanions present in EPS (Merlo et al., 2004). For the reasons explained above it is not clearly defined a linear correlation between the suspended solid content and the variation of CST and TTF and this makes the normalization by TSS content a “rough way” to make the data more comparable as it is assessed by the 2710G and the 2710H standard methods themselves. It is thus not easy to obtain absolute meanings from the data, although the observed behaviors of the monitored parameters clearly indicate that in the tested sludge the dewatering becomes more difficult after anaerobic digestion. It is worth noting how this change of filterability is in some-way related to the BMP giving count of how the anaerobic digestion process is strongly affecting the rheological properties of the sludge. The lower is the SMP (242 NmL/gVS for MBR2 vs 277 NmL/gVS for MBR1), the lower is the SRF increase (1.8 times vs 2.5 times). The opposite behavior is observed for the normalized CST where MBR1 shows lower increase (1.4 times the initial CST) respect to MBR2 (3.7 times the initial CST). The same trend is observed (where possible) for the normalized TTF values.
Comparing instead the behavior of CAS with the already described MBR sludge, it is easy to notice how the all three measured parameters are much higher after the digestion compared to the initial sludge. This reflects very strong modification in the composition of the contained organic matter due to anaerobic digestion that for CAS evidently happens with major weight than for digested MBR sludge.

4. Conclusions and perspectives

- Excess sludge from MBR WWTPs is not always to be considered biologically stabilized.
- The anaerobic treatment of MBR sludge could be sustained by its relatively high BMP.
- Anaerobic digestion caused worse dewatering properties in all the tested sludge. Such worsening is decidedly lower for MBR sludge respect to CAS and is related to the BMP expressed.
- Further studies are needed on higher number of sludges in different conditions to assess the correlation between the BMP and the effect of anaerobic digestion on the dewatering properties of digested MBR sludge.

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