TREATMENT OF LANDFILL LEACHATE IN SBR SYSTEMS: ANALYSIS OF BIOMASS ACTIVITY BY MEANS OF RESPIROMETRIC TECHNIQUES

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SUMMARY: In the last decades landfilling has been the main method of municipal solid waste (MSW) disposal in many countries. MSW landfills are usually considered as a large biological reactor where the MSWs undergo anaerobic digestion producing gas and liquid emissions. Aged, or mature leachate, which is produced by older landfills, can be very refractory; for this reason mature leachate is difficult to treat alone, but it can be co-treated with sewage or domestic wastewater. The aim of the study was to investigate the feasibility of co-treatment of landfill leachate and synthetic wastewater in different percentages, in terms of process performance and biomass activity, by means of respirometric techniques. Two sequencing batch reactors (SBR) were fed with synthetic wastewater and different percentages of landfill leachate (respectively 10% and 50% V/V in SBR1 and SBR2). The obtained results showed a good organic carbon removal efficiency for both reactors; ammonia removal efficiency showed different trends between SBR1 and SBR2, probably due to inhibition factors exerted by high landfill leachate percentage present in SBR2.

1. INTRODUCTION

In the last decades, landfilling has been the main method of municipal solid waste (MSW) disposal in many countries. MSW landfills are usually considered as a large biological reactor where the MSWs undergo anaerobic digestion producing gas and liquid emissions (Imhoff et al., 2007). On one hand, the biodegradable portion of the organic compounds is hydrolyzed, acidified and subsequently methanised producing the landfill gas composed of methane, carbon dioxide and trace components. On the other hand, water, which enters into the landfill as waste moisture content as well as rainfall, contributes to transport the substrates and inhibitory compounds within the landfill body and leaches out organic and non-organic compounds (Renou et al., 2008). In detail, leachate may contain large amounts of organic matter (biodegradable, but also refractory to biodegradation), where humic-type constituents consist an important group, as well as ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts (Baun et al., 2004; Öman and Junestedt, 2008; Zhang et al., 2009). The removal of organic material based on chemical oxygen demand (COD), biological oxygen demand (BOD) and ammonium from leachate is the usual prerequisite before leachate discharging into natural receiving bodies. In the

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last years, the efforts of the scientific community focused on biological, membrane and advanced oxidation (AO) process technologies for leachate treatment. Aged, or mature leachate, which is produced by older landfills, can be very refractory; for this reason mature leachate is difficult to treat alone (Renou et al., 2008), but it can be co-treated with sewage or domestic wastewater. In this context, it is of importance to evaluate the proper leachate percentage, in order to not degrade the biomass activity. Bearing in mind such considerations, the aim of the study was to investigate the feasibility to co-treat landfill leachate and synthetic wastewater in different percentages, in terms of process performance and biomass activity, by means of respirometric techniques.

2. MATERIALS AND METHODS

The experimental study was carried out on two SBR pilot plants, referred in the following to as SBR1 and SBR2, fed with different percentages of landfill leachate (10% and 50% respectively for SBR1 and SBR2) and synthetic wastewater. Each reactor was inoculated with a pre-formed biomass, derived from the aeration tank of Palermo municipal wastewater treatment plant; the inoculum concentration was equal to 4 mg TSS L^{-1}; furthermore, sludge samples withdrawn from both lines were subject to respirometric batch test to evaluate the bomass biokinetic behaviour; finally, microscopic analysis allowed to evaluate the characteristics of biomass in terms of floc structure, specific bacterial species and presence of higher life forms.

2.1 Laboratory scale SBR plants

Two identical glass cylindrical shaped vessels, each of 5 L volume, were realized according to the layout reported in Figure 1. Both reactors were equipped with a mechanical mixer and an aeration system in order to guarantee the complete mixing of mixed liquor total suspended solid (MLTSS) as well as to provide the dissolved oxigen availability, necessary for the aerobic metabolism. SBR1 and SBR2 were fed with a daily flow rate equal respectively to 570 and 530 mL d^{-1} each characterized by a different percentage of landfill leachate. In detail, SBR1 was fed with a leachate rate equal to 10% (V/V) while SBR2 leachate rate was equal to 50% (V/V).

Landfill leachate was daily derived from the equalization tank of a full scale leachate treatment plant and stored, after a 2 mm size screening, in a 5 L completely mixed tank; thus a PLC controlled two peristaltic pump properly arranged to provide the required leachate flow rate during the feeding phase; then, after the feeding was completed, the storage tank was emptied and washed with tap water so to be ready for the following day. Coupled to the leachate, a defined rate of synthetic wastewater was fed to the SBRs, by means of peristaltic pumps controlled by the PLC; in order to complete the required daily flow for each reactor. The synthetic wastewater was prepared using glucose ($C_6H_{12}O_6$), ammonium chloride (NH_4Cl) and potassium phosphate (K_2HPO_4) conveniently dosed to guarantee a C, N, P ratio equal to 100:5:1.

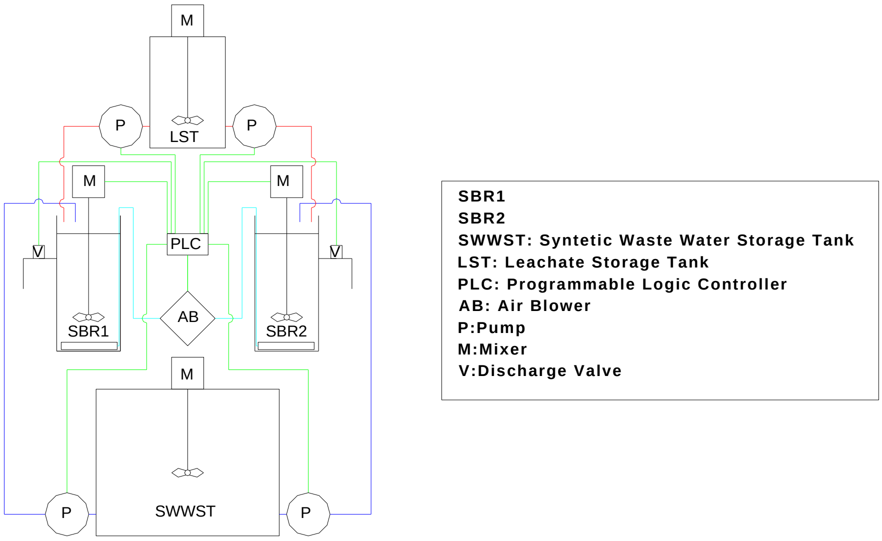

Figure 1. SBR lab scale layout.

The experimental study was carried out with cycle of 24 h for both SBRs; each cycle was composed by a feeding phase of 0.5 hour, during which leachate and synthetic wastewater were fed to the batch reactors; a reaction phase of 21.5 hours, operated under continuous aeration and complete mixing; a 1.5 h settling phase and a final discharge phase of 0.5 h, managed by a discharge valve controlled by the PLC and conveniently placed at the height corresponding to the required discharge volume.

In Table 1 the average influent characteristics and the operational conditions of both SBR plants are reported.

Table 1. Average influent characteristics and SBRs operational conditions.

Influent characteristics			*SBR1*	*SBR2*
Parameter	*Units*	*Symbol*	*Mean value*	
Flow rate	mL d^{-1}	Q	570	530
Leachate percentage	%	-	10	50
Organic substrate	mg L^{-1}	COD	2956	5821
Ammonia	mg L^{-1}	NH_4-N	113	241
Nitrate	mg L^{-1}l	NO_3-N	89	20,1
Operational parameters			*SBR1*	*SBR2*
Parameter	*Units*	*Symbol*	*Mean value*	
TSS	g L^{-1}	MLTSS	3.6	4.7
VSS	g L^{-1}	MLVSS	2.9	4.1
VSS/TSS	-	-	0.81	0.81
Volume	L	V	4.5	4.5
Hydraulic retention time	d	HRT	6.91	7.4
Organic loading rate	gCOD g^{-1}TSS d^{-1}	F/M	0.13	0.10

The reported characteristics are referred to the influent composed by the synthetic wastewater already mixed to the landfill leachate The experimental study has been carried out for 30 days with periodical sampling of influent, mixed liquor end effluent to measure process parameters (TSS, VSS, COD, NH_4-N, NO_3-N) in accordance with Standard Methods (APHA, 1995).

2.2 Respirometric analysis

Samples of mixed liquor were periodically drawn from SBRs and further analysed by means of respirometric batch tests, thus the main heterotrophic biokinetic and stoichiometric parameters have been achieved and compared. The experimental apparatus consisted in two "flowing-gas/static-liquid batch respirometer" (Spanjers et al., 1998). Samples (500 mL) were diluted with tap water in order to obtain a mixed liquor volatile suspended solid (MLVSS) concentration close to 2000 mg VSS L^{-1}; thus samples were aerated until endogenous condition were reached.

Batch test temperature was set equal to 20 ±1°C by using a thermostatic cryostat (JULABO). The dissolved oxygen concentration was measured with an oxygen probe (WTW CellOX 325) and oximeter (WTW MULTI340i), while the aeration control and data acquisition were managed by the OURsys software, whom provided also the respirograms chart. The aeration ON/OFF values were set respectively equal to 3 and 5 mg O_2 L^{-1}.

Heterotrophic parameters have been achieved adding 10 mg L^{-1} of allylthiourea (ATU) in batch test, in order to inhibit oxigen consumption by the nitrifying biomass, and by adding sodium acetate (CH_3COONa) as readily biodegradable organic substrate. Organic carbon consumption has been evaluated by solving the Monod-type kinetic expression with the finite difference procedure, through the estimation of νH,max and KS, by fitting the following equation (Metcalf and Eddy, 2002):

$$\frac{\Delta S}{\Delta t} = \nu_{H,max} \cdot \frac{S}{(K_S + S)} \cdot X_H \tag{1}$$

where $\nu_{H,max}$ is the maximum substrate removal rate, K_S is the half-saturation coefficient for organic matter, S is the carbonaceous substrate concentration and X_H is the biomass active fraction. The estimation of the endogenous decay coefficient bH was carried out according to the "single batch test" used inter alia by Vanrolleghem et al. (1992) and Ramdani et al. (2012); further, the heterotrophic active fraction has been directly determined by means of nonlinear regression to fit the observed OUR versus time decay curve, as suggested by Ramdani et al. (2012).

For the estimation of the kinetic parameters of nitrifying biomass, the the same procedure have been proposed, bearing in mind the following considerations:

- no inhibiting substance like ATU has been added;
- ammonium chloride (NH_4Cl) has been added to evaluate the biokinetic parameters;
- pH values have been constantly monitored to avoid inhibition of the process;
- the conversion factor between oxygen and ammonium (NOD: nitrogen oxygen demand) is equal to:

$$\Delta NH_4 - N = \frac{\Delta O_2}{4.57} \tag{2}$$

The autotrophic specific yield coefficient has been evaluated according to the protocol suggested by Chandran and Smets (2001).

2.3 Microscopic observations

Microscopic observations were carried out for the identification of filamentous bacteria as well as to observe the effects caused by leachate on them. Observations were made under phase contrast at 100× and 1000× magnifications. The filamentous microorganisms were morphologically identified using the Eikelboom classification system (Eikelboom, 1975). Filamentous microorganism abundance and dominance were estimated using the criteria suggested by Jenkins et al. (2003).

3 RESULTS AND DISCUSSION

3.1 Organic Carbon removal

Both pilot plants showed high COD removal efficiencies throughout the experimental campaign, with average values respectively equal to 91.64 (± 0.30) and 89.04 (± 1.14) for SBR1 and SBR2. As expected, the pilot plant SBR1 showed higher removal efficiency, since it was fed with a lower leachate percentage (10%) compared to SBR2. However, the removal efficiencies of SBR2 line, fed with 50% of leachate, were always higher than 88%, thus suggesting the feasibility of leachate co-treatment with synthetic wastewater.

In Figure 2, the COD removal efficiencies (as average) for SBR1 and SBR 2 are reported.

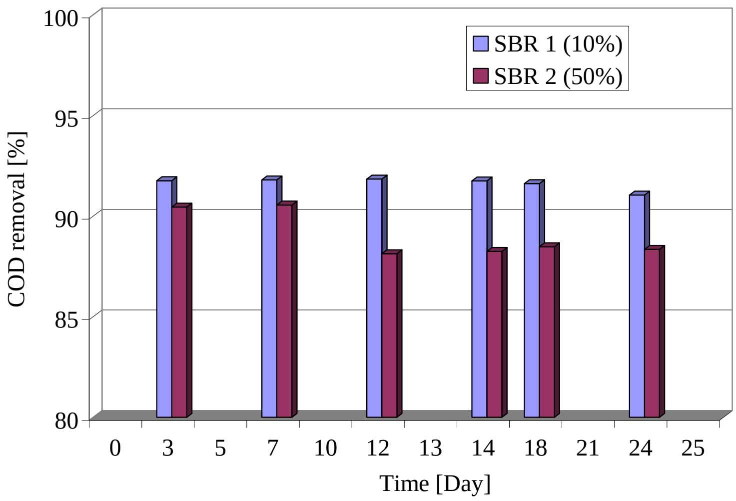

Figure 2. COD removal efficiency (as average) for SBR1 and SBR2.

3.2 Ammonia removal

Ammonia removal efficiency didn't show clear trends respectively for SBR1 and SBR2, probably due to specific inhibition factors exerted by. However, both pilot plants showed good removal efficiencies, except day 10, when a significant sludge withdrawal was carried out to perform a respirometric batch test.

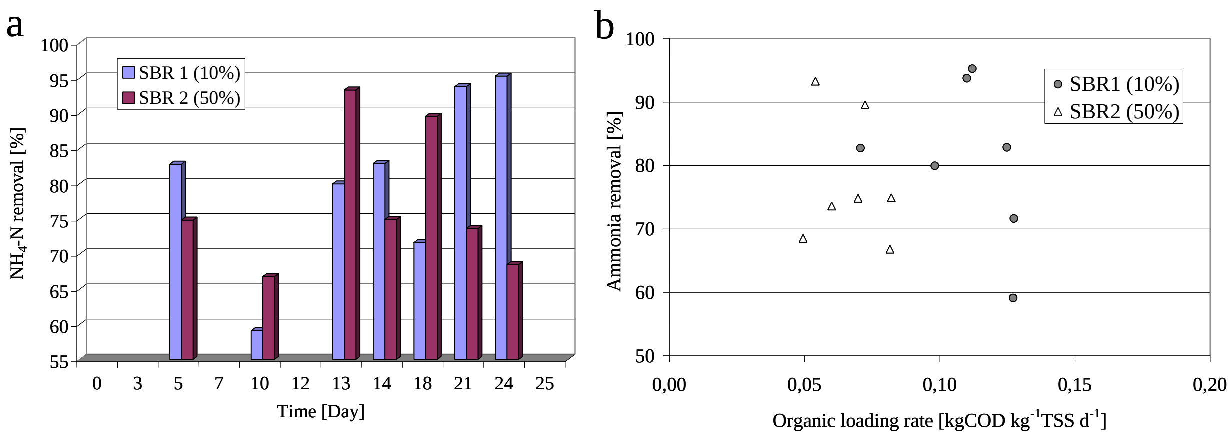

Figure 3. Ammonia removal (a) and ammonia removal vs organic loading rate (b).

In Figure 3, the ammonia removal (Figure 3a) and the ammonia removal vs organic loading rate (Figure 3b) are reported, respectively.

The average values were equal to 80.76 and 77.35 respectively for SBR1 and SBR2. The highest value was obtained in SBR1 (95.3%) at the end of the experimental period. The organic loading rate exerted a clear influence on ammonia removal only in SBR1, where a threshold value could be evaluated, over which the ammonia removal significantly decreased. On the contrary, no significant relationship between organic loading rate and ammonia removal could be established in SBR2 pilot.

3.3 Biomass activity

As previously mentioned, respirometric batch tests allowed to measure the biomass activity during the experimental period and to evaluate its biokinetic behaviour.

In general, the obtained respirograms featured the typical exogenous and endogenous respiration phases, as outlined in Figure 4, where two examples of exogenous and endogenous respirogram charts respectively for SBR1 (Figure 4a and b) and SBR2 (Figure 4c and d) are reported.

Both lines showed significant heterotrophic respiration rates, with OURmax average values equal to 37.30 and 56.68 mg O2 L-1 h-1, respectively for SBR1 and SBR2. The higher leachate percentage seemed not to hinder the activity of heterotrophs, thus suggesting the feasibility of biomass acclimatation for landfill leachate co-treatment. The obtained kinetic and stoichiometric coefficients were well in the range of the typical ones of activated sludge plants treating municipal wastwater (Henze et al., 2000); furthermore, the obtained values are in satisfying agreement with what reported by Droguel et al. (2011).

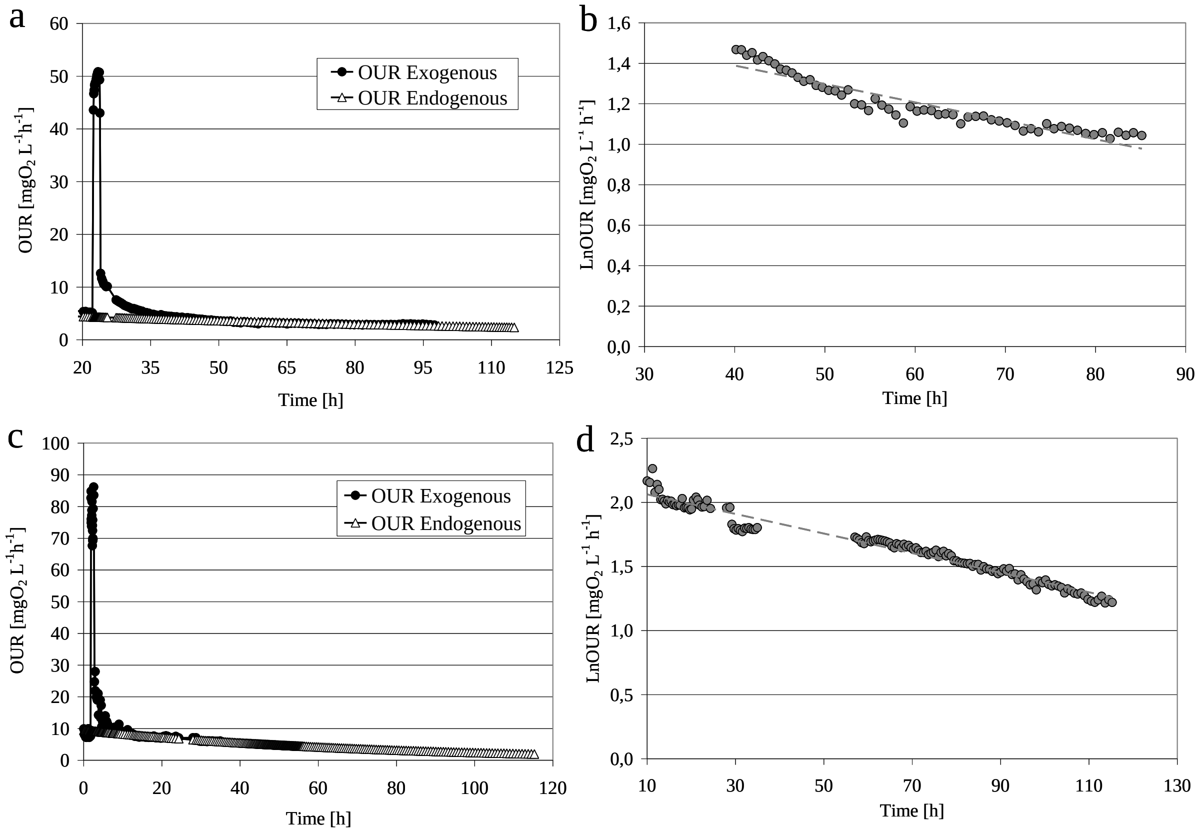

Figure 4. Exogenous and endogenous respirogram charts respectively for SBR1 (a and b) and SBR2 (c and d).

In Table 2 the average values of the main kinetic and stoichiometric coefficients for both plants are reported.

Table 2. Average values of heterotrophic kinetic and stoichiometric coefficients for both SBR plants.

Parameter	Y_H	Y_{STO}	$\mu_{H,max}$	K_S	b_H	*AF*
Units	*mgCOD mg^{-1}COD*	*mgCOD mg^{-1}COD*	d^{-1}	*mg L^{-1}*	d^{-1}	-
SBR1	0.68	0.71	7.15	5.25	0.40	0.08
SBR2	0.64	0.73	10.76	4.39	0.60	0.06

Concerning the heterotrophic active fraction, starting from an initial value equal to 0.08 of the inoculum sludge, the active fraction was quite constant throughout the experimental period for SBR1 while, on the contrary, showing a modest decreasing trend in SBR2, with average values equal to 0.08 and 0.06, respectively. In Figure 5, respectively the maximum respiration rate values (Figure 5a) and the heterotrophic active fraction trends (Figure 5b) are reported.

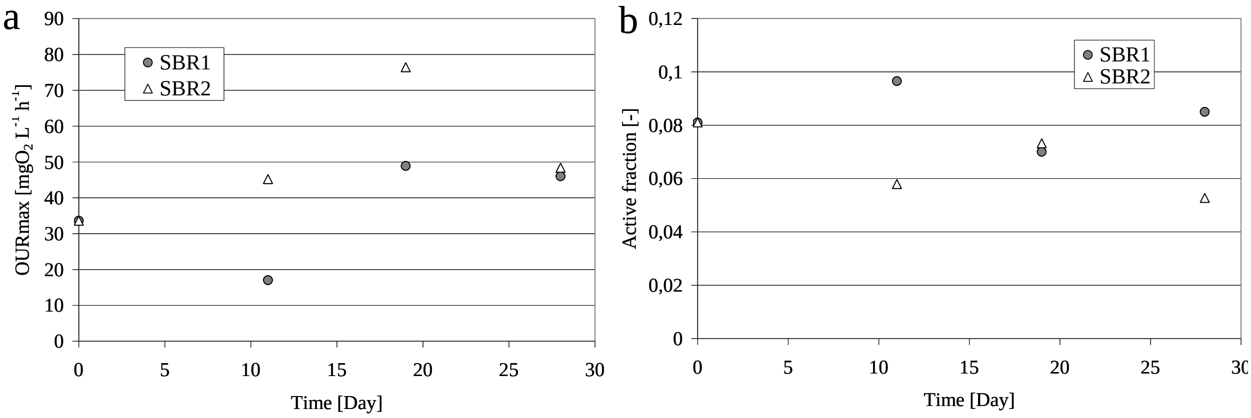

Figure 5. Maximum respiration rate values (a) and the heterotrophic active fraction trends (b).

Concerning the nitrifying activity, the obtained results suggested a good development of autotrophic nitrifiers, with similar kinetic and stoichiometric values for both plants, even for the SBR2 plant fed with 50% of landfill leachate, thus confirming the possibility to acclimatize the nitrifying biomass to significant percentage of leachate. In Table 3, the average values of the main autotrophic coefficients are summarized.

Table 3. Summary of average values of autotrophic kinetic and stoichiometric coefficients.

Parameter	Y_A	$\mu_{A,max}$	K_N	*Nitrification rate*
Units	$mgCOD\ mg^{-1}NH_4\text{-}N$	d^{-1}	$mgNH_4\text{-}N\ L^{-1}$	$mgNH_4\text{-}N\ L^{-1}\ h^{-1}$
SBR1	0.16	0.15	0.18	3.17
SBR2	0.16	0.18	0.04	3.13

3.4 Microscopic observations

Qualitative microscopic observations were carried out on mixed liquor samples of both SBR lines; they revealed at the beginning of the experimental campaign good floc structure and a relative high number of higher life forms, such as sessile ciliated colonial protozoa, amoebas, which presence could suggest enough aeration and not negligible nitrification activity (Figure 6a). In the following experimental days it was noticed the presence of filamentous bacteria, with bridge formation; in detail, it was surely noticed the presence of Type 0041 and probably of Microtrix Parvicella, as reported in Figure 6b. In general, it was possible to notice a relative abundance of filamentous bacteria (class 5, more than 20 filaments per floc) with bridge formation; the floc morphology was irregular; referring to floc size distribution, on first approximation, it is possible to say that almost the 80% was smaller than 150 μm, while only the 20% was in the range 150-500 μm. In Figure 6 two microscopic images deriving from SBR1 biomass samples are reported.

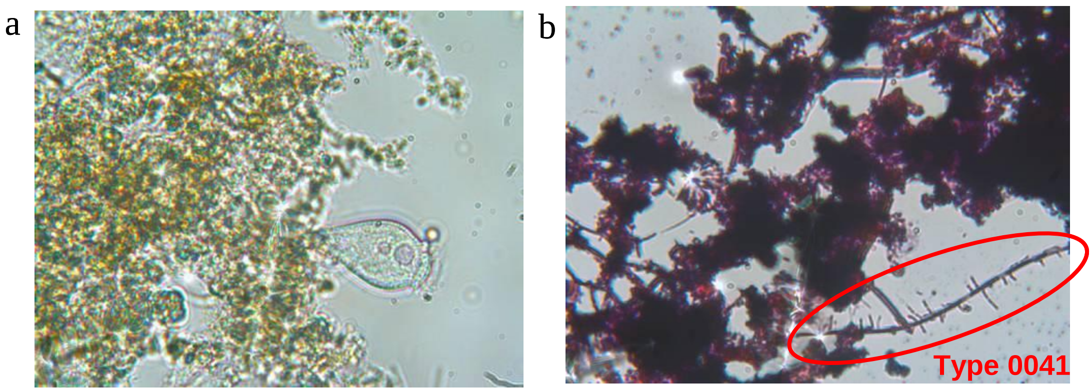

Figure 6. Microscopic images from SBR1 line, as an example: sessile ciliate (a) and filamentous Type 0041 (b).

5. CONCLUSIONS

The paper reports the main results from an experimental field campaing carried out on two lab scale SBR plants, each fed with a different percentage of landfill leachate and synthetic wastewater. The obtained results highlighted good plants performance in terms of organic carbon and ammonia removal, thus sugesting the feasibility of leachate co-treatment with synthetic wastewater. Respirometric batch tests were carried out on biomass samples in order to evaluate the biomass activity as well as the biokinetic coefficients, for both heterotrophic and autotrophic population.

The results confirmed a significant biomass activity, with high respiration rates and biokinetic parameters well in the range of that reported in the technical literature. Thus, the suggestion is that limited percentages of landfill leachate do not hinder the biomass activity, which can acclimatize to leachate, enabling the co-treatment with wastewater. Microscopic observations revealed the presence of higher life forms and moderate abundance of filamentous bacteria. Future research activities will regard the treatment of landfill leachate mixed to real municipal wastewater.

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