



UNIVERSITA' DEGLI STUDI DI PADOVA

ICEA Department
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Master Thesis

Enrico Scantamburlo

REINJECTION OF LEACHATE REVERSE OSMOSIS CONCENTRATE IN THE LANDFILL BODY

Supervisors

Prof. Raffaello Cossu

Prof. Roberto Raga

Prof. Maria Cristina Lavagnolo

Academic Year 2014 - 2015



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Part 1

Theoretical introduction

1. INTRODUCTION

The environmental impact associated to a landfill involves the biosphere, atmosphere and hydrosphere. The topic concerning the reduction of the landfill footprint in the landscape is a modern problem to deal with. Impacts reduction is a field much discussed in the scientific community. Greenhouse gasses reduction and the conservation of surface and ground water are focal points for the modern environmental politics. If for the biogas there are interests to captures and utilizes, landfill leachate is classified as a waste water with an high pollutants load , organic and inorganic, which presents a great risk to the natural aquifer(Christen et al., 1992,Liet al. 2009). The quantity and quality of leachate depends strongly on the nature and composition of the waste, on the age of the waste, on the landfill type, on the weather conditions and on the mode of operation(Kjeldsen et al., 2002). The leachate share amounts to 0.001-0.1 l/s hand often the sites are designed to deal with an average of 0.04l/s ha (Henigin, 1993). The quality of the leachate depends on the different degradation phases, acetic or methanogenic phase. Different treatments are used to clean this waste water, such us biological treatments, chemical physical treatments, membrane treatments. A good chance is offered by reverse osmosis membrane, which ensures high removal efficiency and low costs of operation.

The aim of this thesis is to evaluate the effects of the RO concentrate recirculation in the landfill body at lab scale. In particular I am focused on the chemical-physical behaviour of the waste and leachate, checking the mass balance of carbon nitrogen and chloride. From the physical point of view, I analysed the hydraulic behaviour of the waste when are undergone to the concentrate recirculation highlighting the formation of leachate lens inside the waste mass or the creation of preferential pathways. In the scientific literature are abundant the cases in which leachate is recirculated in the landfill body; laboratory tests demonstrate that with leachate recirculation can be enhanced the organic matter degradation due to the transport of nutrients and microorganisms, reduces the volume of leachate produced and facilitates the methanogenesis. On the contrary the experiences about the concentrate recirculation are quite scars.

2. THEORETICAL APPROACH

2.1 Leachate treatment

The type of treatment is strictly related to the leachate proprieties. Among the technologies available for in situ or ex situ treatment are found coagulation-flocculation, microfiltration, ultrafiltration, reverse osmosis, biological treatment (Renou et al., 2008), aerated lagoon (Robinson, 2005). Renou et al., (2008) summarizes in table 1 the treatments applicable to the leachate according to the proprieties of the waste water . Membrane treatments seem to be the most effective for old leachate.

Tab. 1: Leachate treatment (Renou et al., 2008). In the table are summarized the available treatments for the leachate depuration according its age. Are also reported the removal efficiency.

Process	Character of leachate			Average removal (%)			SS	Turbidity	Residues	
	Young	Medium	Old	BOD	COD	TKN				
Transfer										
Combined treatment with domestic sewage	Good	Fair	Poor	Depending on domestic water treatment plant						Excess biomass
Recycling	Good	Fair	Poor	>90	60-80	-	-	-	-	
Lagooning	Good	Fair	Poor	80	40-95	>80	30-40	30-40	Sludge	
Physico/chemical										
Coagulation/flocculation	Poor	Fair	Fair	-	40-60	<30	>80	>80	Sludge	
Chemical precipitation	Poor	Fair	Poor	-	<30	<30	30-40	>80	Sludge	
Adsorption	Poor	Fair	Good	>80	70-90	-	-	50-70	-	
Oxidation	Poor	Fair	Fair	-	30-90	-	-	>80	Residual O ₃	
Stripping	Poor	Fair	Fair	-	<30	>80	-	30-40	Air-NH ₃ mixture	
Biological										
Aerobic processes	Good	Fair	Poor	>80	60-90	>80	60-80	-	Excess biomass	
Anaerobic processes	Good	Fair	Poor	>80	60-80	>80	60-80	-	Excess biomass	
Membrane bioreactor	Good	Fair	Fair	>80	>85	>80	>99	40-60	Excess biomass	
Membrane filtration										
Ultrafiltration	Poor-Fair			-	50	60-80	>99	>99	Concentrate	
Nanofiltration	Good	Good	Good	80	60-80	60-80	>99	>99	Concentrate	
Reverse osmosis	Good	Good	Good	>90	>90	>90	>99	>99	Concentrate	

2.2 Membrane treatment

Membrane processes can be classified in a number of different ways including the type of material from which the membrane is made, the nature of the driving force, the separation mechanism and the nominal size of the separation achieved (Metcalf & Eddy 2004).

Tab. 2: Application of membrane technologies (Metcalf & Eddy 2004) . Are reported the performances of micro filtration, ultra filtration nano filtration and reverse osmosis membrane.

Constituent	Membrane technology				Comments
	MF	UF	NF	RO	
Biodegradable organics		✓	✓	✓	
Hardness			✓	✓	
Heavy metals			✓	✓	
Nitrate			✓	✓	
Priority organic pollutants		✓	✓	✓	
Synthetic organic compounds			✓	✓	
TDS			✓	✓	
TSS	✓	✓			TSS removed during pretreatment for NF and RO
Bacteria	✓	✓	✓	✓	Used for membrane disinfection. Removed as pretreatment for NF and RO with MF and UF
Protozoan cysts and oocysts and helminth ova	✓	✓	✓	✓	
Viruses			✓	✓	Used for membrane disinfection

RO is a technology based on a semipermeable membrane with a porosity of some nanometers in which is applied a pressure higher than the osmotic pressure so is ensured the separation between permeate and concentrate. Semipermeable means that it is permeable to some components in the feed stream and impermeable to other components. The feed water is pressurized and some water called permeate passes through the membrane, while the solutes are rejected producing an output stream more concentrated. The operating pressure is 1-100 Bar. Since RO membrane separation is produced by converting pressure into driving force without phase change, it has the characteristics of creating better energy efficiency and non space-consuming. In the recent typical landfill leachate treatment, the biodegradable organic pollutants and nitrogen are removed during the biological treatment process. Subsequently, the residual suspended solids, heavy metal, and COD are removed with coagulation setting, sand filtration, and activated carbon absorption. Thus, the development of a technology which responds to water quality matrix for new leachate components like inorganic salts and POPs is required. RO membrane can satisfy these requests. The concentrate-permeate ratio ranges from 1:2 to 1:7 depending on the loads in the leachate most often from 1:4 to 1:5 (P.L.A. Henigin, Sardinia 1993). Organic substances are held back more efficiently (80-95%) than inorganic substances (60-70%) for a single membrane process, while with further stages the hold back capacity can reach more than

99% (P.L.A. Henigin, Sardinia 1993; H.Eipper and C.Maurer Sardinia 1999). In NF and RO particles are rejected by the water layer adsorbed on the surface of the membrane which is known as a dense membrane. Ionic species are transported across the membrane by diffusion through the pores of the macromolecule comprising the membrane. RO can reject particles as small as 0.001 μm (Metcalf and Eddy, 2004). Because the pore size in RO membranes are so small the membrane are defined as dense.

Tab. 3: Removal rate and operation condition by landfill leachate treatment using NF and RO membranes (<http://www.apec-vc.or.jp>)

Parameter	Units	NF	RO Membrane
COD removal rate	%	90-95	92-97
NO ₃ ⁻ -N removal rate	%	10-20	83-93
NH ₄ ⁺ -N removal rate	%	10-20	86-94
Cl ⁻ removal rate	%	5-10	98-99.6
SO ₄ ²⁻ removal rate	%	94-98	99-99.9
Heavy metals removal rate	%	85-96	88-97
Permeation flux	L/m ²	20-40	10-20
	h		
Recovery rate	%	75-85	70-80
Pressure	bar	10-30	40-65

In the modern treatment plants membrane technologies are very utilized for the leachate depuration, due to the limited cost of the plant. Among the membrane treatments RO has the high removal efficiency, better than 99% (Renou et al., 2008), and can be used usually as final step of the treatment or in limited cases as unique treatment. This technology is rather flexible respect other technologies, because allows to add or subtract modules modifying rapidly the depuration capacity (Peters, 1998). The RO technology requires about 5 kW/h/m³ of permeate considering a recovery rate of 80% (T.A Peters, 1998). The disadvantages of this technology concerning the membrane fouling, and the management of the concentrate, which requires further treatment before to be discharged (Bart Van Der Bruggen et al., 2003). The membrane duration is affected by the leachate pretreatments. In literature are reported life time of 1-2 years before the replacement; the frequent acids washes can damage the membrane reducing its efficiency and its life. Membrane fouling is a problem well studied by different researchers (Van

der Bruggen, B. et al., 2002), whilst the management of the concentrate nowadays is a problem to deal with.

2.3 Management of leachate concentrate

The concentrate management is an economical problem due to the high disposal cost. Bart Van Der Bruggen et al., (2003) classified the concentrate treatment methods in four categories:

- reuse;
- incineration;
- treatment for pollutants removal;
- discharge in the surface water;
- discharge in the ground water;
- landfill disposal.

Peters (1998) suggested that the best technologies to manage the concentrate are the incineration in the appropriate facility, the solidification with several materials like fly ashes, sludges coming from waste water treatment plant, and the recirculation into the landfill body in order to improve the biochemical degradation and speed up the immobilisation processes of the organic substances. Due to the low treatment cost this last option is nowadays used, and probably in the next future this practise supported by the Italian law will be further applied.

The landfill can be compared to a bioreactor which produces an important amount of biogas in the optimal conditions. To reach the “optimal point” we need to spread moisture in the waste mass and blow air inside the landfill in order to promote the stabilisation and reducing the aftercare period. Where it is not possible realize a forced aeration plant the leachate concentrate recirculation can be easily implemented providing moisture and spreading nutrients. Problems can derive from the concentration of harmful substances which are not biodegradable and tends to accumulate in the system. This praxis is in fact regulated by “Decreto legislativo 36/2003” which is the decree inherent to the landfill realization and management. Some author support the thesis that the concentrate recirculation is not a sustainable practise in the long period (Robinson, 2005). The concentrate recirculation in the landfill body as previously said is nowadays applied in some Italian municipality such as “Pietramelina landfill” –Perugia, “il Fossetto landfill”-Pistoia, “Vizzolo Predabissi landfill”-Milano, “Sarcedo landfill”-Vicenza.

2.4 Italian legislation

The actual landfill legislation derives from the European directive 1999/31/CE receipts in Italy in the 2003 with the decree “Dlgs 36/2003”. This decree defines the design and management criteria of landfill facilities, in order to protect flora and fauna from potential emissions. The decree highlights in several paragraphs the protection and conservation of surface water and groundwater against leachate pollution produced from the degradation of the waste.

“L'ubicazione e le caratteristiche costruttive di una discarica devono soddisfare le condizioni necessarie per impedire l'inquinamento del terreno, delle acque freatiche e delle acque superficiali. Deve essere assicurata un'efficiente raccolta del percolato, ove ciò sia ritenuto necessario dall'ente territoriale competente.”

“Il percolato e le acque raccolte devono essere trattate in impianto tecnicamente idoneo di trattamento al fine di garantirne lo scarico nel rispetto dei limiti previsti dalla normativa vigente in materia. La concentrazione del percolato può essere autorizzata solo nel caso in cui contribuisca all'abbassamento del relativo battente idraulico; il concentrato può rimanere confinato all'interno della discarica.”

The annex two of the decree states that will be approved, before the authorization releases, the “management plan” for the operational and post operational phase (Article 13), in order to identify the necessary procedures to meet the authorization requirements that guarantee the containment of the potential sources of pollution

“I piani di gestione operativa, di ripristino ambientale, di gestione post-operativa e di sorveglianza e controllo, che rappresentano uno dei contenuti essenziali dell'autorizzazione e devono essere approvati dall'Autorità competente, definiscono compiutamente le fasi di gestione operativa, di ripristino ambientale e di gestione post-operativa della discarica“

The decree Dlgs 36/2003 allows regions to approve during the environmental integrated assessment the concentrate recirculation.

2.5 Management of RO concentrate: cases study

Are reported some literature cases about the RO concentrate reinjection. Advantages and disadvantages are briefly summarized. Available articles in the scientific papers are scars and quite old.

Peters (1998), summarizes the most meaningful processes concerning the concentrate recirculation in:

- decomposition of organic and inorganic materials into the oxides form;
- adsorption of heavy metals in the organic matter or in clay minerals;
- crystallization processes and formation of insoluble salts;
- carbonate, sulphide, sulphate formation from chemical processes.

A field experiment was conducted in the landfill denoted Fosseto (Montesummano Terme-Pistoia -Italy). The site has been opened in 1988 , with an authorized volume of 1000000 m³. Currently are stored MSW after be pre-treated, a limited amount of street clearing residues, and not hazardous bottom ashes. The concentrate is recirculated by the injection in a vertical well. In order to conduct the survey, was isolated a part of the landfill and was implemented the recirculation system. The study carried out shows that the concentrate recirculation does not increase the leachate production and seem that the concentrate spreads in the landfill body. Was recorded an increase of Ni, COD, Zn concentration, but strangely was found an attenuation capacity concerning ammonia (NH₄⁺) and chloride (Cl⁻) which probably are adsorbed in the organic matter. The biogas production decrease during the time.

Robinson (2005) evaluated the effects of the concentrate recirculation in the Wischhafen landfill in Germany. He found that the recirculation has an immediate effect on the leachate characteristics because it increases the COD, the ammonia concentration and the conductivity. The increases of the salinity affect the efficiency of the RO membranes, which have to operate at higher pressure drop in order to contrast the osmotic fluid pressure. In fact the osmotic pressure is directly proportional to the fluid salinity (Robinson, 2005). To maintain the same removal efficiency, if the salinity grows up, the operation pressure must be enhanced , with a further demand of energy. The plant can works until reaches the point in which the increase of pressure

on the membrane is no longer economically viable. Due to the high concentration of solid and salt, membrane fault can occur, therefore are required frequent washes with acid or back washing. The intense chemical washes to which it is subjected reduce the life of the membrane and decrease its productivity (Renouet al., 2008). To prevent the fouling of the RO membrane or otherwise delay it, as a pre-step is possible to concentrate pollutants, heavy metals, ammonia, organic compounds by thermal evaporation under vacuum (Luca Di Palma et al., 2002).

Henigin, (Sardinia 1993) studied the effects of the return of membrane filtration concentrate on the new formation of leachate. Henigin done a in situ test in which recirculate RO concentrate since 1987. He found that after the concentrate recirculation the leachate turnout increase considerably, but did not observe any significative trend concerning the chemical composition of the leachate. He supposed that this happened because the hold back capacity of the site has not been exhausted yet, and that within the site biochemical degradation processes happen reducing the organic loads.

T.Bouchez et al. (Sardinia 2001) in his lab-scale experiments observed that the leachate concentrate injection does not modify the hydraulic balance and produce a delay of the methanogenic phase probably due to the acid pH of the concentrate, and for the presence of metallic ions. The concentrate injection provokes an increase of the moisture content in the waste and facilitate the biological degradation, moreover some metallic ions are adsorbed by metanigenic bacteria. In fact the addition of Ni^{2+} and Co^{2+} in an anaerobic digester can increase the methane production rate (Florencio et al., 1994; Yoda et al., 1991).

3. TEST DESCRIPTION

For the test have been used six transparent columns made of plexiglas. These columns were built some years ago for another laboratory experiment, and in particular are placed above a metallic frame able to support the weight solicitation. The frame is sustained by wheels that facilitate the transport (Fig. 1)

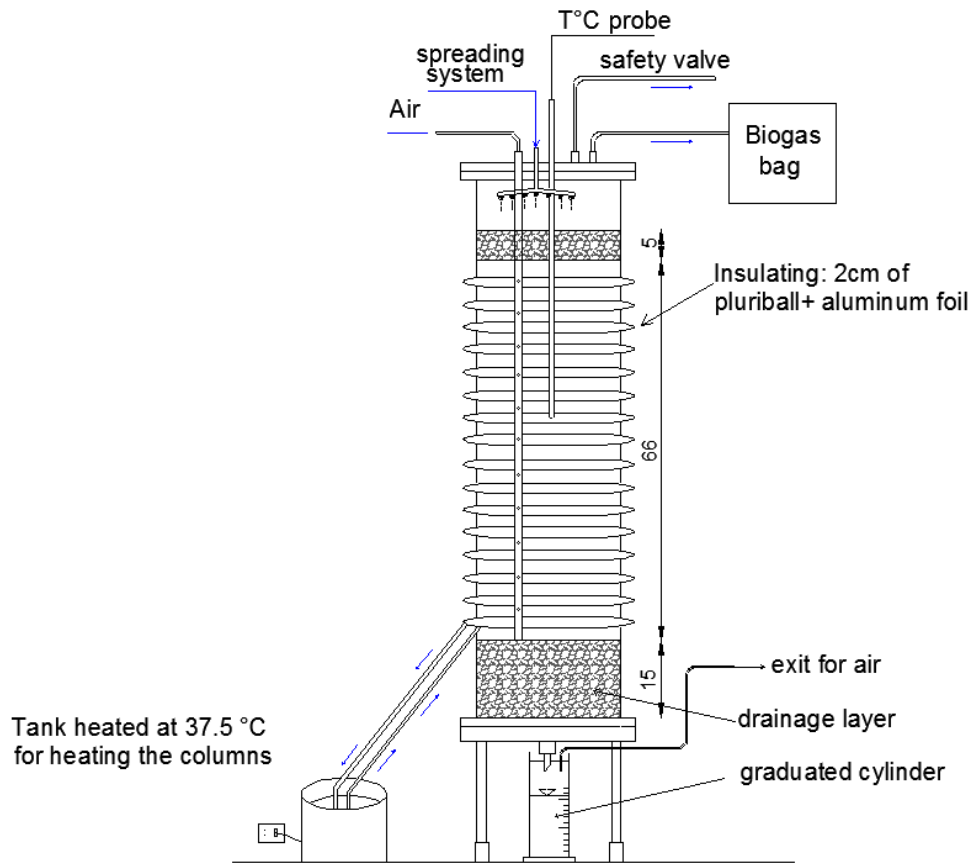


Fig. 1: Column 1 detail. Are reported an example of the columns used in the test, in particular the column 1. The only difference with the others is the waste thickness of 66 cm. The column is equipped by a drainage valve on the bottom, and four valves on the top: a safety valve, a valve that allow the biogas collection valve, one for the forced aeration and one to control the spreading system

Columns have been sealed with two flanges; in the upper and lower flange is present a rubber ring which enhance the isolation reducing biogas leaks and odors. Before the waste placement, was done a complete check of the column, disassembling and cleaning the valves of the upper and lower flange. Valves were reassembled utilizing some teflon to ensure a perfect sealing between the junctions. Flanges have been fixed with screws to the column. The upper flange is endowed with four valves which allow the biogas collection, the injection of water, the injection of fresh air and an emergency biogas exit (Fig. 1). The gas produced is collected in bags for further analysis. The emergency valve is a safety device able to discharge outside the excess of biogas. For each column the emergency valve is connected by a PVC pipe to a main pipe which discharges outdoor. Before the exit the main pipe passes through a scrubber filled with some water, and in the case of over pressure the biogas in excess is discharged. The bottom of the column is equipped by a drainage valve used to extract the leachate.

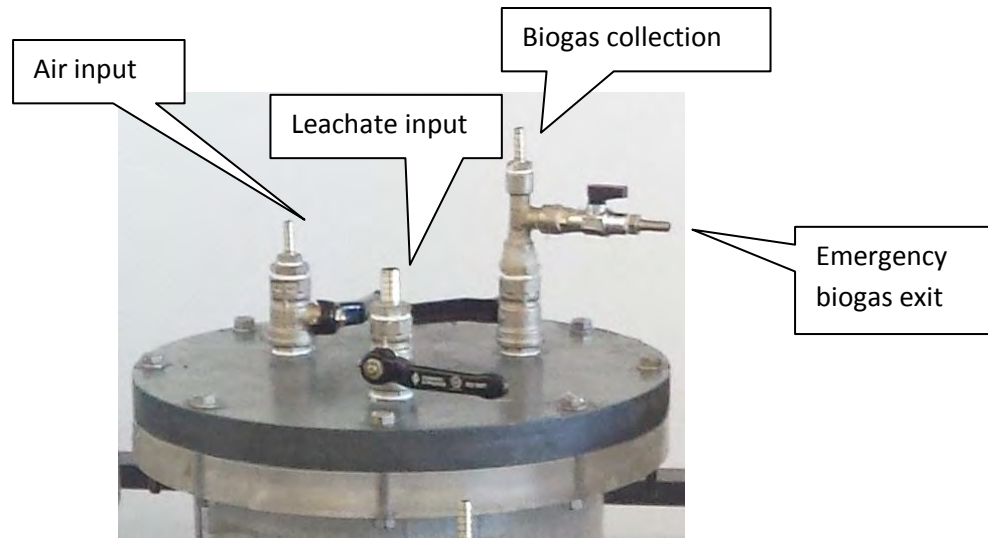


Fig. 2:Details of the upper flange

Concerning the waste have been decided to utilize a layer of 65 cm of compacted waste, ensuring a uniform thickness of gravel on the top and bottom of the column. In order to avoid the clogging of the system with the consequent leachate extraction fault a layer of gravel with diameter ranging between 20-40 mm was placed between the bottom of the column and the lower layer of waste, with a thickness of 15 cm. The same was done in the upper part of the column, to ensure a better water/concentrate distribution; were utilized gravel with the same size but placed in layer with a lower thickness of 5 cm. The concentrate spreading system was built utilizing a perforated PVC pipe. Were chosen large holes preventing the clogging of the system. Was placed a network on the bottom in each columns to reduce the particulate transport, ensuring an output a bit more cleaned. Details about the volumetric and load capacity of columns are reported in the table 4.

Tab. 4: Columns details: design value. The table reports the technical features about the columns, indicating the theoretical height of the waste for a density of 0.5 kg/l.

	Column height(cm)	$\Phi_{\text{column}}(\text{cm})$	$V_{\text{column}} (\text{m}^3)$	Waste mass (kg)	Waste density(t/m^3)
C 1	95	24	0.043	14.7	0.49
C 2	96	24	0.043	14.7	0.51
C 3	100	24	0.045	14.7	0.48
C 4	100	24	0.045	14.7	0.47
C 5	100	24	0.045	14.7	0.46
C 6	91	24	0.041	14.7	0.48

Although the different height of the columns the thickness of waste is homogeneous. During the filling phase occurred on 01/08/2014, which lasted one day, the waste were weighted and

disposed inside the column. In every loading steps was introduced 3.4 kg of waste inside the column, which were compacted up to reach the desired density. Considering the same weight of waste for column the final reached density is reported in table 5.

Tab. 5: Columns details-real value. Height and density obtained during the filling phase of the columns, inserting the same amount of waste

	Waste height(cm)	Φ_{column} (cm)	V_{waste} (m³)	Gravel bottom (cm)	Gravel top (cm)	Waste layer (cm)	Waste density(t/m³)	M_{waste} (kg)
C 1	66	24	0.030	15	5	65	0,5	14.7
C 2	64	24	0.029	15	5	65	0,5	14.7
C 3	68	24	0.031	15	5	65	0,5	14.7
C 4	69	24	0.031	15	5	65	0,5	14.7
C 5	71	24	0.032	15	5	65	0,5	14.7
C 6	68	24	0.031	15	5	65	0,5	14.7

During the whole duration of the experiment, the columns' temperature were monitored by six probes PT 100 (Endress+Hauser) placed in the core of each column during the filing phase. These are steel probes connected to an electronic device named Memograph (Endress+Hauser) able to record every half hour the temperature, plotting results at screen.

Without a heating system columns' temperature were around 25°C, that was close to the room temperature. The low temperature in the core of columns shown that the wastes were not biologically active. Furthermore total solids analysis showed a water content lower than 35%, therefore waste were mummified. Was decided to control the temperature, speeding up the reaction, reaching the optimal range of temperature. 30°- 37° . Due to the absence of automatic and electrical heating devices, was studied an alternative method. Was realized a circuit wrapping a PVC pipe around the columns creating a spiral circuit with steps of 4-5 cm (Fig. 3A). It has been decided to utilized a unique circuit, in which passes warm water. A constant temperature has been ensured by the use of a thermostatic tank sett to 37.5°C, placed near the columns. A small pump recirculates up to 1000 l of water per hour. Each column has been isolated thermally with two layers of "pluriball" (Fig. 3B) wrapped with an aluminum foil (Fig. 4). This system showed goodefficiency.



Fig. 3: Steps required for the creation of the insulating system. In the picture A can be seen the PVC pipe wrapped around all the columns. Picture B shows the two layers of pluriball and the picture on the right side the complete “jacket” with the aluminum foil



Fig. 4: Final isolation. As last layer was used an aluminum foil.

3.1 Waste history

The waste used in the test is a rather stable waste coming from Sanremo – Liguria. The sample, at the beginning almost 200 kg of waste, was sent to the University’s laboratory located in

Voltabarozzo in order to perform a survey concerning the leaching. Firstly was selected a representative sample of 30 kg of the whole mass, and was performed a merceologic analysis. The classes considered were:

cellulosic material, glass, putrescible, plastic material, metals, inerts, others, undersieve (<20mm).

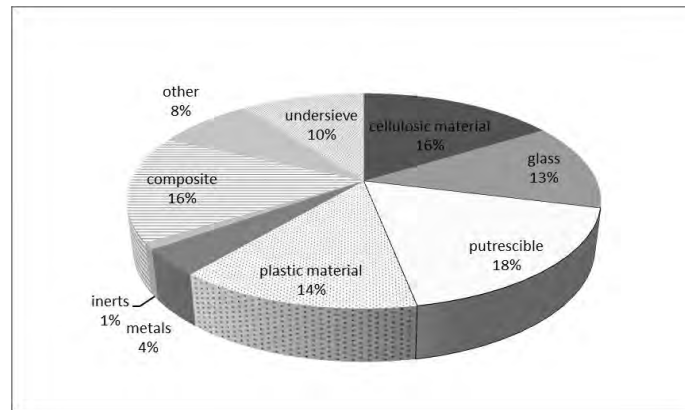


Fig.5: Merceologic analysis - composition of fresh waste in 2013

After the merceologic analysis the waste was shredded, and a part, was sieved separating the bigger fraction (>40 mm) from the smaller. The leaching test was done on the shredded waste (using two columns) as well as the oversieve (using two columns). The undersieve was stabilized in an aerobic windrow. Was added progressively water to the columns to reach L/S=1. After 15 days from the closure the quality of the biogas was monitored and was conducted the first leaching test. Was used 50 kg of under sieve 40 mm for the windrow stabilization test. Furthermore was done a quick leaching test comparing the stabilized aerobically undersieve 40 mm (the stabilisation lasted 21 days), with that one not stabilized. For this test were utilized glass columns 40 cm height and with a diameter of 5.5 cm. At the end of these tests (October 2013) wastes were extracted from the columns, mixed together and placed in three bins, which were sealed with them lids. Bins have never been opened, therefore occurred a sort of mummification due to the absence of the water and oxygen

3.2 Waste preparation and columns management

Before the columns filling, bins were emptied and the waste were mixed, in order to ensure an homogeneous degree of moisture. As second step was collected a representative sample of 10 kg of waste and was done the merceologic analysis. The waste was already shredded so were

utilized sieves with dimensions 80mm, 40mm, 20mm. Smaller fractions constitute the undersieve. The analysis done had the aim to identify the predominant waste fraction.



Fig. 6: Waste used in the test



Fig. 7: Merceologic analysis. On the left side (A) there is the picture of the undersieve ($< 20\text{mm}$). On the right side is shown how was done the merceologic analysis

The merceologic classes considered have been :

-cellulosic materials, glass and inert, plastics, metals, other, undersieve $< 20\text{ mm}$.

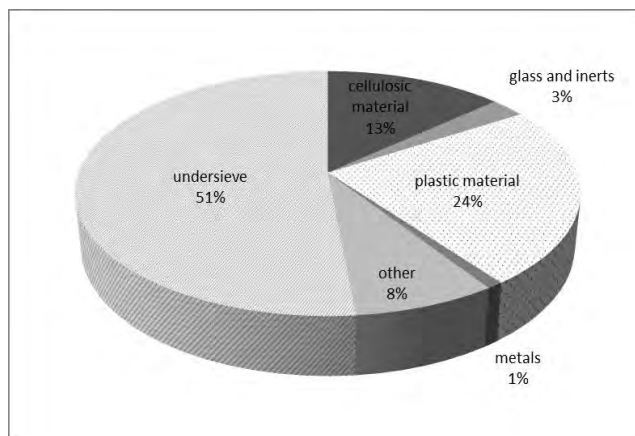


Fig. 8: Waste composition after “pre-treatments”

Were not found big pieces of putrescible waste. The merceologic classification is reported in table 6.

Tab.6:merceologic analysis. Due to the small dimentions of the waste for the merceologic analysis was used sieves of 80 mm, 40 mm, 20 mm. the analysis was done on a sample of 10 kg of waste. Results are reported in dry mass.

kg reteined	> 80 mm	>40 mm	>20 mm	total weight	% (dry mass)
cellulosic materials					
<i>paper</i>	0.034	0.315	0.275	0.623	9.3
<i>textile</i>	0.047	0.107	0.121	0.275	4.1
glass and inerts	0.000	0.013	0.161	0.174	2.6
plastics	0.040	0.760	0.791	1.591	23.8
metals	0.000	0.027	0.034	0.060	0.9
other	0.000	0.198	0.328	0.526	7.8
undersieve				3.451	51.5
TOT=	0.121	1.420	1.709	6.700	100

Tab. 7: Cumulative wet weight. Is reported the cumulative weight of the retained fraction from every sieves. The weight is also converted in percentage on the total weight.

Sieve	Weight _{dry} (kg)	%
> 80 mm	0.121	1.8
>40 mm	1.420	21.2
>20 mm	1.709	25.5
Undersieve 20mm	3.451	51.5
Total weight (kg)	6.700	100%

During the filling phase of the columns was taken from the windrow of waste a sample (some kg) and conserved in a glass jar for further analysis. Part or the sample was milled up to reach 1 cm in size. Samples have been conserved in the fridge at a constant temperature of 4 °C. The first analysis done concerned the percentage of total solids and volatile solids of the sample.

Tab. 8: Amount of TS and VS of the sample. Were taken three samples and have been considered the mean value. The analysis was done on milled waste, 1 cm in size.

sample	Sample weight (g)	Capsule weight	Gross weight 105°	%TS	Gross weight 550°	%VS
N°1	18.3022	50.6309	63.057	67.9	53.3284	78.3
N°2	18.0841	54.3226	66.3375	66.44	56.9686	78
N°3	18.134	51.6566	63.7398	66.63	54.2263	78.73
mean	18.1734	52.2033	64.3781	66.99	54.8411	78.34

The waste in mean terms has a TS percentage of about 67%, therefore the water content is 33%. Due to the low water content the bacteria cannot work well. The waste has been placed in columns in date 01-08-2014. Biogas bags were emptied and analyzed for the first time after one week on 07-08-2014. The extremely low amount of biogas produced is a further sign of the waste mummification. The “dry stabilization” occurred, reduced the production of gas, increasing the aftercare phase. The required humidity for the biological decomposition is usual 40-50% (Christen and Kjeldsen, 1989). Biogas quality has been monitored with a portable gas analyzer (LFG2000, EcoControl) sucking the biogas through an appropriate valve inside the bags. On the 07/08/2014 the water content was increased to 40%, adding 1.7 l of deionized water in each column. The added water was completely adsorbed by the waste and after 23 days waste did not still generate leachate. Was decided to gradually increase the moisture content of the waste adding 1.5 liters of water to reach 45% of humidity and 1.8 l of water reaching the 50 % and generating the first leachate.. On the 11/09/2014 the first sample of RO concentrate was injected.



Fig. 9: Filling of the columns. On the left side (A) is shown the “washing station” for the stones. Stones with a diameter of 2cm-4cm before have been placed inside the columns were washed with water. Pictures B and C show the filling phase of the columns.

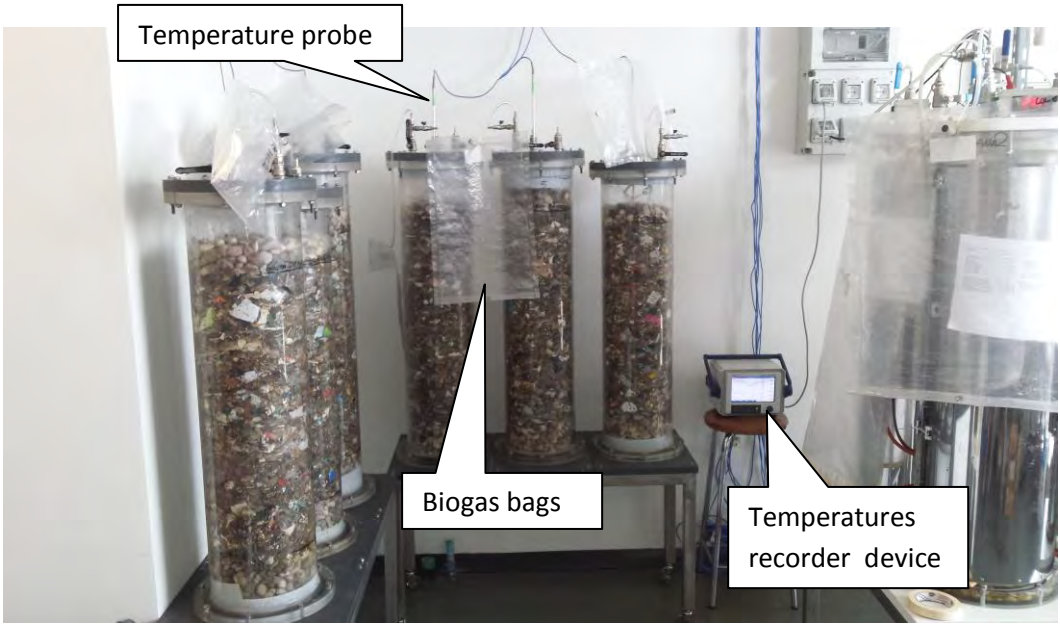


Fig.10: Column filled with waste placed into the laboratory. Is possible to see the temperature probes connected to the pc by blue wires.

The concentrate/deionized water were injected manually every day from Monday to Friday (T.Bouchez et al., Sardinia 2001) with a volume of 200 ml/day, up to reach 1 liter/week of concentrate. The volume would simulate the typical rainfall in Veneto region. The introduction of small volumes in the time would promote the biological processes and gives a better representation of the reality. The proportion between water and concentrate is reported in table 9.

Tab. 9:management of the columns. The table shows the proportion of water and concentrate injected in every columns, and reports the daily air flowrate. Daily is introduced a volume of 200 ml according to the percentages in table.

		INPUT	AERATION
ANAEROBIC	C1	100% RO concentrate	0 l/d
	C2	50% RO concentrate +50% water	0 l/d
	C3	100% water	0 l/d
AEROBIC	C4	100% RO concentrate	50 l/d
	C5	50% RO concentrate +50% water	50 l/d
	C6	100% water	50 l/d

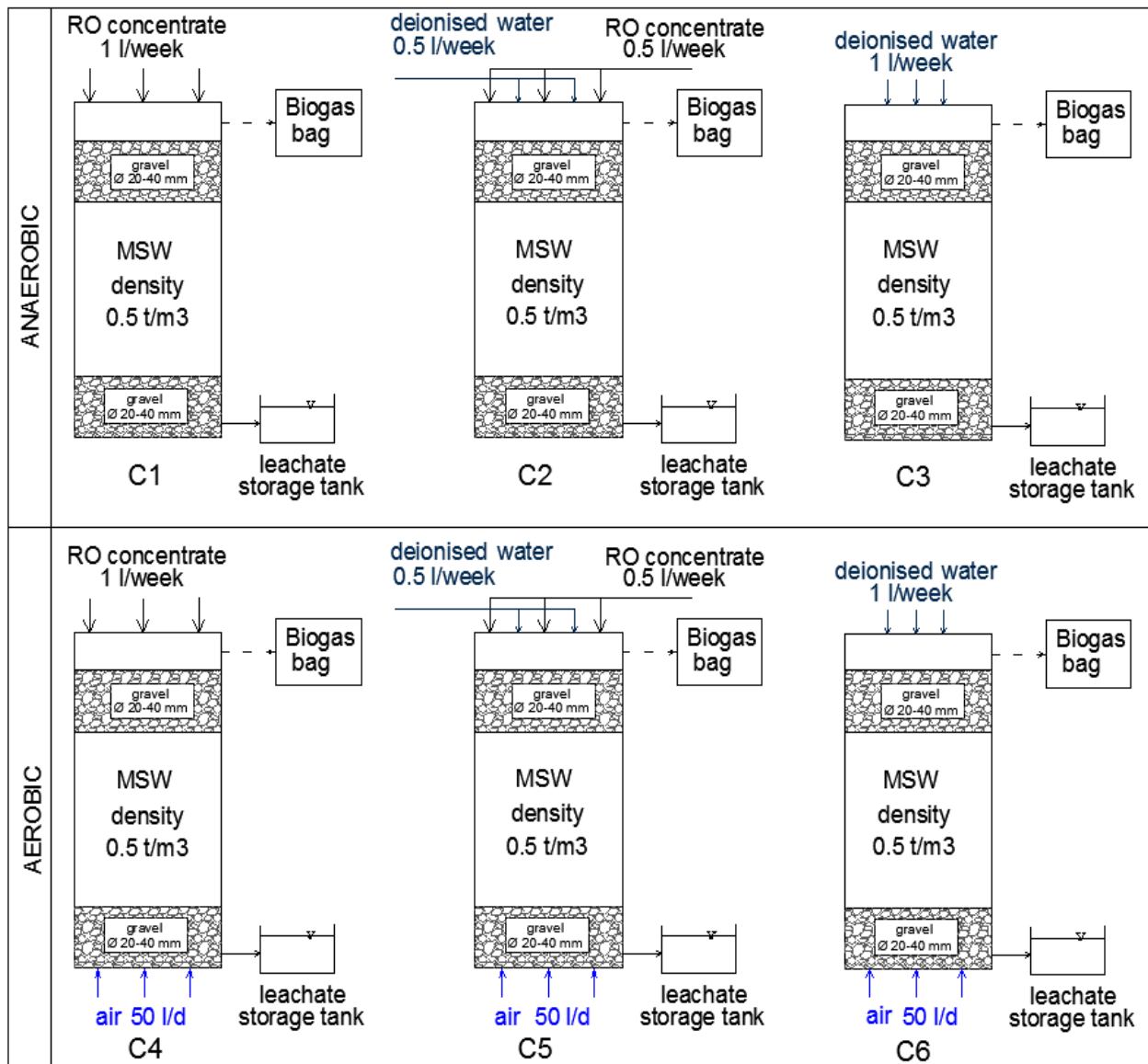


Fig.11: Columns management scheme. The picture reports the scheme of the columns and their manage. In particular three columns are anaerobic (C1, C2, C3) and three aerobic (C4,C5,C6). C1 and C4 are fed with only concentrate, C2 and C5 with a mixture of concentrate and water while C3 and C6 with only water.

4. MASS BALANCE APPROACH

Mass balances are a useful tool for analyzing mobility-stability of compounds, their chemical or biological reactions, the oxidative states and their influence in other compounds presence. The balances that generally regard a landfill are mainly the Carbon and the Nitrogen ones because biodegradable organic substance and ammonia are the main two problematic pollutants in leachate and because anaerobic conditions generate biogas that must be managed. Other secondary compounds presents in leachate are chloride, sulfates and heavy metals: the first two can be found in great quantity but they can be washed to zero by water, heavy metals emissions

are always quite low compared to the initial present in waste and often do not exceed the law limit emission (Bigili et al., 2007).

The mass balance is based on the mass conservation formula:

$$Accumulation = input - output + production - consumption$$

Where: accumulation is what remains in landfill after the time dt, input is the waste income, output are the wanted or unwanted emission of leachate and biogas, production and consumption are the reaction happening inside waste body (Cossu et al., 2004).

$$\frac{dx}{dt} fix + \frac{dx}{dt} mob = \sum_i (X_{si} * Q_{si}) - X_l * Q_{lc} - X_l * Q_{lu} - X_g * Q_{gc} - X_g * Q_{gu} - rV$$

Where:

$\frac{dx}{dt} fix$ Is the accumulation in fixed form, no more mobile, that does not cause problems anymore. This is the term is wanted to be increase.

$\frac{dx}{dt} mob$ Is the accumulation in mobile form. This matter can still react or be emitted somehow.

$\sum_i (X_{si} * Q_{si})$ Is the total waste input that is the sum of the quantity of each merceologic category multiply by the compound content of each merceologic category.

$X_l * Q_{lr}$ Is the mass of compound emitted in a controlled way by leaching: Q_{lr} is the flux of leachate collected, X_l is the compound fraction in leachate.

$X_l * Q_{lu}$ Is the mass of compound emitted in an uncontrolled way by leaching: Q_{lu} is the flux of leachate that escape the collection and reach the environment outside the barriers, X_l is the compound fraction in leachate.

$X_g * Q_{gc}$ Is the mass of compound emitted in a controlled way by gas: Q_{gc} is the flux of biogas collected, X_g is the compound fraction in biogas.

$X_g * Q_{gu}$ Is the mass of compound emitted in an uncontrolled way by gas: Q_{gu} is the flux of biogas that escape the gas collection systems, X_g is the compound fraction in biogas.

rV Is the reaction term, composed by the volume of reactor plus the kinetic constant. According with the compound characteristics and with the reaction conditions the kinetic constant can change very much.

The landfill goal is to avoid environmental pollution, before the stabilization of the waste. For this purpose it is necessary to rewrite the main equation transferring to left the uncontrolled emissions to be avoided and to right all other terms.

$$X_l * Q_{lu} + X_g * Q_{gu} = \sum_i (X_{si} * Q_{si}) - X_l * Q_{lc} - X_g * Q_{gc} - \frac{dx}{dt} fix - \frac{dx}{dt} mob - rV$$

According with this mathematical equation, in order to avoid the uncontrolled pollution it is necessary to avoid waste input (with minimization of waste, reuse, recycle), increase reactions (with increase kinetics, aerobic reactions, nutrient supply), increase stable accumulation forms, increase leachate controlled emissions (allowing and facilitating water input in landfill) and increase gas controlled emissions (with a good collection pipes system).

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6. REFERENCES

- Bart van der Bruggen, Liesbeth Lejon, and Carlo Vandecasteele, Reuse, Treatment, and Discharge of the Concentrate of Pressure-Driven Membrane processes, 2003.
- Bilgili M.Sinan , Ahmet Demir, Bestamin O`zkaya, Influence of leachate recirculation on aerobic and anaerobic decomposition of solid wastes, Journal of Hazardous Materials 143 (2007) 177–183.
- Bouchez T. , S.Bobe'e-Flandrois, M-L. Munoz, Y. Moreau-Le Gplvan, C.Bordier and C.Duqennoi, Consequences of leachate concentrate injection into municipal solid waste, Sardinia 2001.
- Calabrò Paolo S. , Silvia Scaffoni, Sirio Orsic, Emiliano Gentili, Carlo Meonie, The landfill reinjection of concentrated leachate: Findings from a monitoring study at an Italian site, Journal of Hazardous Materials, 181 (2010) 962–968.
- Cossu R., Pivato A., Raga R., 2004, The mass balance: a supporting tool for the sustainable landfill management, Third Asian-Pacific Landfilling Symposium, 2004, Kitakyushu, Japan.
- Christensen and Peter Kjeldsen, 1989, Basic biochemical processes in landfill.
- “Dlgs 36/2003- Attuazione della direttiva 1999/31/CE relative alle discariche di rifiuti.”
- Eipper H. and C.Maurer, Purification of landfill leachate with membrane filtration based on the disc tube, Sardinia 1999.
- Henigin P.L.A , Effects of the return of membrane filtration concentrates on the new formation of leachate, Sardinia 1993, volume 1.
- Henigin P.L.A. , Effects of the return of membrane filtration concentrates on the new formation of leachate, Sardinia 1993.
- Kjeldsen, P. Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A., Christensen, TH., 2002. Present and long term composition of MSW landfill leachate: a review. Crit. Rev. Environ. Sci. Technol. 32 (4), 297-336.

-Luca Di Palma, Paola Ferrantelli, Carlo Merli, Elisabetta Petrucci, Treatment of industrial landfill leachate by means of evaporation and reverse osmosis, *Waste Management* 22 (2002) 951–955.

-Metcalf & Eddy 2004

-Peters Thomas A. , Purification of landfill leachate with reverse osmosis and nanofiltration, *Desalination* 119 (1998) 289-293.

-Peters, T.A., 1998. Purification of landfill leachate with membrane filtration. *Filtr. Sep.* 35 (1), 33-36.

-Renou S. , J.G. Givaudan, S. Poulain, F. Dirassouyan, P. Moulin. Landfill leachate treatment: Review and opportunity, *Journal of Hazardous Materials* 150 (2008) 468–493.

-Robinson A.H. 2005, Landfill leachate Treatment, Membrane technology, 6-12.

-www.apec-vc.or.jp

Part 2

Scientific article

Abstract

A very wide range of treatment processes have been applied for the handling of landfill leachate. The reverse osmosis (RO) process is an alternative method widespread all over the world. The management of the RO concentrate is an economical problem due to the high disposal costs. The purpose of this work is to evaluate the effects of the RO concentrate reinjection into the landfill body, focusing on the chemical and hydraulic point of view. Six laboratory columns were filled with pre-treated municipal solid waste (MSW), and different volumes of concentrate were injected. The results show that the RO concentrate injection increases the amount of biogas production, enhancing also the fraction of gaseous ammonia. The concentrate reinjection does not affect the hydraulics performances of the waste. However, chloride and ammonia seem to accumulate in the waste mass.

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1.INTRODUCTION

Landfill leachate is a wastewater with an high pollutants load , organic and inorganic, which presents a great risk to the natural aquifer. It is generated by the percolation process of rainfall through the waste mass. The environmental impact generated from a landfill involves the hydrosphere, atmosphere and biosphere. Due to the complicated nature of the waste deposited in a landfill leachate contains a variety of pollutants which can be classified into inorganic, heavy metals, dissolved organic matter, xenobiotic organic compound, microorganism(Christensen et al., 1994; Kjeldsen el al., 2002). The problem concerning the impacts reduction has become very important in the scientific community.The European directive 1999/31/CE implemented in Italy with the decree “Dlgs 36/2003” highlights the need of the protection and conservation of surface water and groundwater against leachate pollution produced from the degradation of the waste.The leachate treatment is one of the major problem concerning the landfill management. The quantity and quality of leachate depends strongly on the type of landfill, on the weather conditions and on the mode of operation (Kjeldsen et al., 2002). The leachate share ranges to 0.001-0.1 l/s ha and often the sites are designed to deal with an average of 0.04l/s ha (Henigin, 1993). MSW landfills can be operating as bioreactor which consist to accelerate waste degradation by circulating fluids through the waste in a controlled manner. In the scientific literature are abundant the cases in which leachate is recirculated in the landfill body; laboratory

tests demonstrate that with leachate recirculation can be enhanced the organic matter degradation due to the transport of nutrients and microorganisms, reduces the volume of leachate produced and facilitates the methane production (Irem San, 2001). The leachate flow and its distribution is controlled by the hydraulic conductivity. The hydraulic conductivity is a parameter of paramount importance because it is related with the retention properties of the waste and govern the ease with which the fluids can be introduced or extracted from the landfill (G. Stoltz and JP. Gourc, Sardinia 2007). The hydraulic conductivity of the waste varies depending on the waste composition, on the extent of degradation, on the size and density. Published literature showed that for a MSW heavily compacted the hydraulic conductivity ranges between $10^{-6}/10^{-7}$ cm/s, and for slight compaction ranging between $10^{-3}/10^{-5}$ cm/s (Krishna R. Reddy et. al., 2009).

In a traditional landfill about the 90% of the degradation products are removed as biogas and the 10% as leachate (Scheelhaase et al., 1997). Among the different treatment procedures to manage the leachate for in situ or ex situ application are found coagulation-flocculation, microfiltration, ultrafiltration (UF), reverse osmosis (RO) biological treatment (Renou et al., 2008), aerated lagoon (Robinson, 2005). Membrane processes can be classified in a number of different ways including the type of material from which the membrane is made, the nature of the driving force, the separation mechanism and the nominal size of the separation achieved (Metcalf & Eddy 2004). Among the membrane treatments RO has the highest removal efficiency, better than 99% (Renou et al., 2008). Organic substances are held back more efficiently (80-95%) than inorganic substances (60-70%) for a single membrane process, while with further stages the hold back capacity can reach more than 99% (P.L.A. Henigin, Sardinia 1993; H.Eipper and C.Maurer Sardinia 1999). RO is a technology based on a semipermeable membrane with a porosity of some nanometers in which is applied a pressure higher and opposite than the osmotic pressure, promoting the separation between permeate and concentrate. The concentrate-permeate ratio ranges from 1:2 to 1:7 depending on the loads in the leachate, but most often from 1:4 to 1:5 (P.L.A. Henigin, Sardinia 1993). The RO technology requires about 5 kW/h/m^3 of permeate considering a recovery rate of 80% (S, Renou et al., 2008). The major drawbacks of the application of RO to landfill leachate treatment are membrane fouling and generation of large amount of concentrate. Membrane fouling requires extensive treatment or chemical cleaning on the membrane and results in a short life time of the membrane and decreases process productivity (Renou et al., 2008). Peters (1998) suggested that the best technologies to manage

the RO concentrate are the incineration in the appropriate facility, the solidification with several materials like fly ashes, sludges coming from waste water treatment plant and the recirculation into the landfill body in order to improve the biochemical degradation and speed up the immobilisation processes of the organic substances. Leachate concentrate dewatering and disposal in industrial landfills are very expensive procedures. To avoid high disposal costs, injection in the landfill body was proposed (Henigin, 1993; Henigin, 1995). Peters (Sardinia 2001), summarizes the most significant processes concerning the RO concentrate reinjection in decomposition of organic and inorganic materials into the oxides form, adsorption of heavy metals in the organic matter or in clay minerals, crystallization formation of insoluble salts, and carbonate, sulphide, sulphate formation from chemical processes. Experiences about the concentrate recirculation are quite scarce, and with conflicting results. The concentrate recirculation seem not to be sustainable in the long period (Henigin, Sardinia 1993) indeed the reinjection has an immediate effect on the leachate characteristics, increasing the COD and the ammonia concentration (Robinson, 2005). Nevertheless the leachate concentrate injection does not modify the hydraulic balance and a large part of the mineral load is given back (T. Bouchez et al., Sardinia 2001). A field experiment conducted in Italy shows that the concentrate reinjection does not increase the leachate production and the waste mass seems to have a buffer capacity on ammonia (NH_4^+) and chloride (Cl^-) (Paolo S. Calabrò et al., 2010). In order to evaluate advantages and disadvantages an experimental test has been necessary. So the leachate formation can be simulated under varying precipitation conditions and additional of RO concentrate. Was used six columns filled with the same type of waste. Three columns were anaerobic and three aerobic and managed as reported in table 3.

1.1 Goals

This paper presents and discusses the results of a study carried out to investigate the effects of the reinjection of RO leachate concentrate in the landfill, focusing on chemical/physical parameters and hydraulic behaviour of the waste mass. Were utilized six columns in which RO concentrate was injected. A leachate sample of each columns was analysed weekly in pH, conductivity, COD, NH_4^+ , TKN, Cl^- , and biweekly was monitored TOC and TC. From the hydraulic point of view, was monitored the behaviour of the waste when are undergone to the concentrate reinjection highlighting the formation of leachate lens inside the waste mass or the creation of preferential pathways. The density and viscosity of the leachate were monitored. The measure of the viscosity was done with the Ostwald microviscometer, suggested for concentrated saline solutions (Douglas E. Goldsack and Raymond Franchetto, 1976). Carbon, nitrogen and

chloride mass balances are presented, even if incomplete, and the extent to which these substances are degraded, leached out of or remain contained within the waste is discussed.

2.MATERIALS AND METHOD

2.1 RO sample

RO concentrate sample was taken from the landfill of Sarcedo (VI). It is an old landfill of special non dangerous waste, assimilated to urban waste. It was opened in 1990 with an authorized volume of 300000 m³, enlarged up to 500000 m³ in 1996. The landfill was closed about 10 years ago, and nowadays is in the aftercare period. The average leachate production is of 100/120 m³/week. In 2012 was implemented an in situ leachate treatment by the use of RO modules. Leachate from the landfill is received by the equalization tank to equalize water quality and flow rate. Gradually it is pre-treated by a UF unit in order to remove particulate matter. The UF concentrate is collected in a storage tank, while the permeate is treated by RO membrane. The concentrate from the 1st stage of RO unit is treated by the 2nd stage RO unit. The permeates produced from the 1st and 2nd steps are treated by the 3rd step, and in turn the permeate produced is treated from the 4th RO unit to allow an almost complete boron removal. The concentrates streams coming from 3rd module and the 4th module return at the beginning of cycle for further treatments. The final permeate is discharged in a small channel nearby, whilst the final concentrate generated from the 2nd module is sent to a storage tank. Once produced the UF and RO concentrates are mixed in a storage tank, and gradually injected in the landfill using alternatively the biogas wells. The mixture of concentrates are so done: 20-25 % comes from UF and 75-80% from RO modules. The total produced concentrated leachate represents about the 25-30% of the total incoming leachate. The scheme of the plant is reported in figure 1.

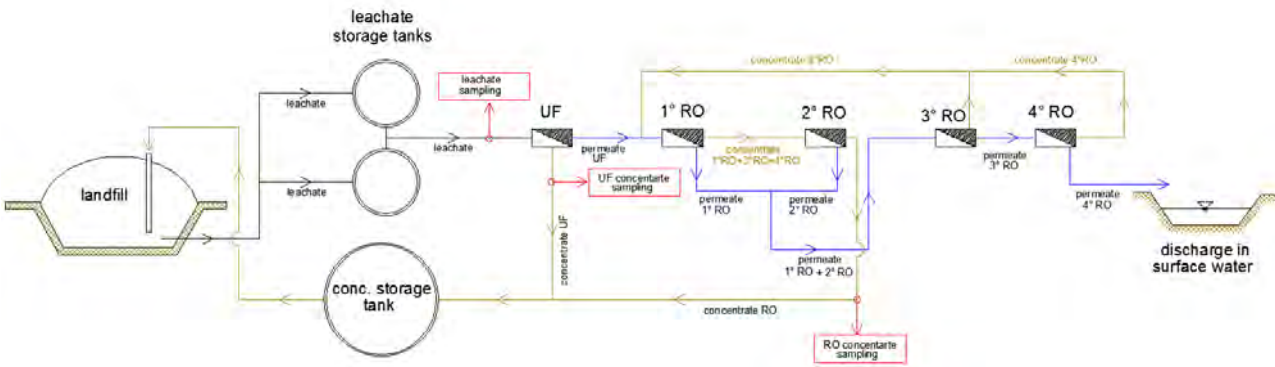


Fig. 1: Scheme of the plant: RO leachate treatment plant of Sarcedo landfill. The plant produces concentrate which is injected into the landfill. It works with a UF module as pre-treatment and four steps of reverse osmosis. The final permeate is discharged in a river, while the concentrate is re injected in the landfill.

2.2 Waste characterization

Approximately 100 kg of municipal solid waste coming from Sanremo – Liguria was used in the test. The waste is the remaining part of a series of pre-treatments done on about 200 kg of waste for other laboratory surveys. Pre-treatments involved the removal of bulky materials, shredding and screening of the remaining waste, separating the fraction bigger than 40 mm from the smaller. Tests done concerning leaching tests on shredded waste and on the fraction bigger than 40 mm. The undersieve was used in an aerobic windrow stabilization test. Furthermore was done a quick leaching test, comparing the stabilized aerobically undersieve (40 mm)(the stabilisation lasted 21 days), with that one not stabilized. At the end of these tests (October 2013) the wastes were extracted from the columns, mixed together and placed in bins, which were sealed with their lids. The original waste composition and the composition after pre-treatments are given in the figure 2.

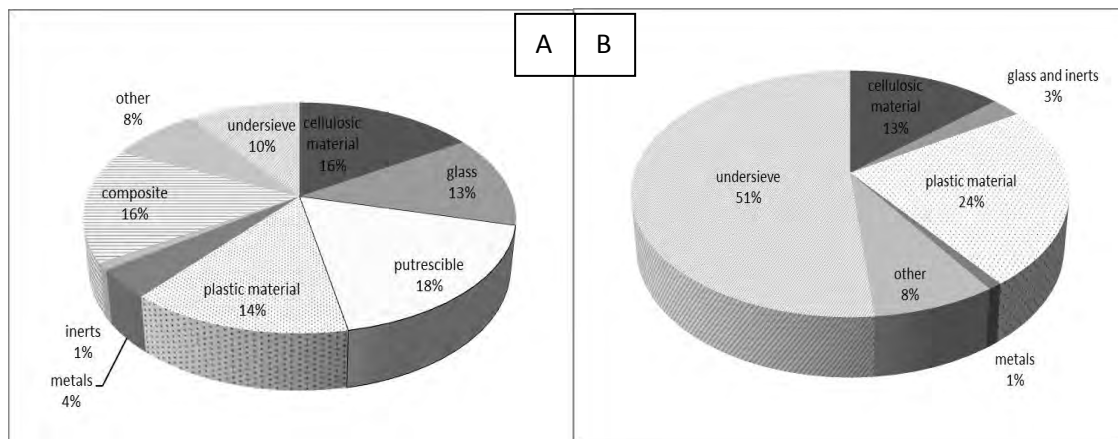


Fig. 2: Merceologic analysis of MSW before and after pretreatments: The graph on the left side shows the original waste composition, considering cellulosic materials (paper and cardboard), glass (white and non white glass), putrescible, plastic materials (plastic containers, plastic films, plastic non recyclable), metals, inerts, composite, reusable materials, undersieve (<20mm). On the right side have been considered, cellulosic materials (paper and cardboard), glass and inerts, plastic, metals, other, undersieve.

Waste samples were stored manually by visual identification into material categories of cellulosic materials, glass, putrescible fraction, plastic materials, metals, inert, other, undersieve (<20 mm). At the beginning of the experience with the RO concentrate was done again the merceological analysis on a representative sample (10 kg). The survey was aimed only to have an overview about the composition of the remaining waste. Classes considered were cellulosic materials, glass and inerts, plastics, metals, other, undersieve (<20mm) (figure 2B).

Tab.1: Fraction of waste retained by sieves: kg of waste retained, divided for materials classes per kg of dry matter. The net size of sieves used were 80 mm, 40 mm, 20 mm.

kg retained	> 80 mm	>40 mm	>20 mm	total weight	% (dry mass)
cellulosic materials					
<i>paper</i>	0.034	0.315	0.275	0.623	9.3
<i>textile</i>	0.047	0.107	0.121	0.275	4.1
glass and inerts	0.000	0.013	0.161	0.174	2.6
plastics	0.040	0.760	0.791	1.591	23.8
metals	0.000	0.027	0.034	0.060	0.9
other	0.000	0.198	0.328	0.526	7.8
undersieve				3.451	51.5
TOT=	0.121	1.420	1.709	6.700	100

Almost 52 % by mass could not be identified visually either because it was too dirty or mixed or because it was too small. Waste sample was analyzed on total carbon (TC), Kjeldahl nitrogen(TKN), respirometric index (IR4, IR7) as discussed in the following section. These results are presented in table 5.

2.3 Reactor set up

For the test have been used six Plexiglas columns filled with 14.7 kg of waste each one. Columns have been sealed by screws with two flanges equipped with a rubber ring which enhance the isolation, reducing biogas leaks and odors. The upper flange is endowed with four valves which allow the biogas collection, the injection of water, the injection of fresh air and an emergency biogas exit. The gas produced is collected in bags for quantify the volume and the composition. The bottom of the column is equipped by a drainage valve used to extract the leachate. Was disposed a plastic net on the bottom in each column, and a 15 cm thick gravel (size of 20-40 mm) drainage layer was placed at the base, over it. Waste was then placed above the gravel in layers and compacted manually up to reach a density of 0.5 kg/l. A further layer of gravel 5 cm thick was placed over the upper surface of the waste. The concentrate spreading system was built utilizing a perforated PVC pipe. During the whole duration of the experiment, the columns' temperature were monitored by six probes PT 100 (Endress+Hauser) placed in the core of each column during the filing phase. As heating system was realized a circuit wrapping a PVC pipe around the columns creating a spiral circuit with steps of 4-5 cm(V.Francois et al., 2007). A constant temperature of 33-35° (V.Francois et al., Pin-Jing He et al.,2006, Irem San et al., 2001) has been ensured by the use of a thermostatic tank set to 37.5°C. A small pump recirculates up to 1000 l of water per hour. Each column has been isolated thermally with two layers of “pluriball” wrapped with an aluminum foil.

Tab. 2: waste density. In the table are reported information on the waste before the concentrate reinjection, including the mass of waste introduced in all the columns and the density.

	Waste height(cm)	$\Phi_{\text{column}}(\text{cm})$	V (m ³)	Waste mass (kg)	Waste density(t/m ³)
C 1	66	24	0.0298	14.7	0.49
C 2	64	24	0.0289	14.7	0.51
C 3	68	24	0.0308	14.7	0.48
C 4	69	24 <td 0.0312	14.7	0.47	
C 5	71	24	0.0321	14.7	0.46
C 6	68	24	0.0308	14.7	0.48

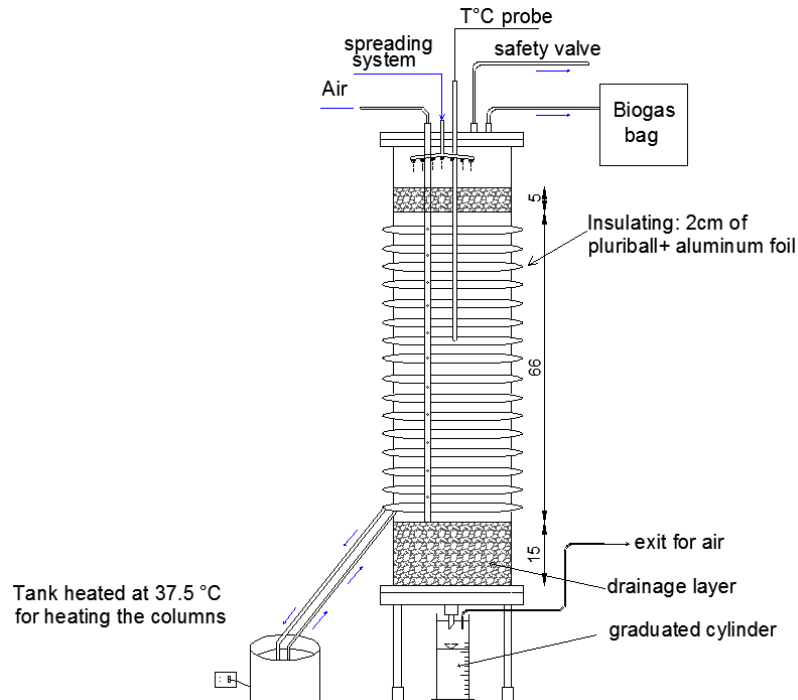


Fig.3: Column 1 details. Are reported an example of the columns used in the test, in particular the column 1. The only difference with the others is the waste thickness (in this case of 66 cm). The column is equipped by a drainage valve on the bottom, and four valves on the top: a safety valve, a valve that allow the biogas collection valve, one for the forced aeration and one to control the spreading system.

2.4 Columns management

Before starting with the concentrate injection the moisture of the waste mass was raised from 33% up to 50% adding gradually 5 liters of deionized water to ensuring the formation of at least 1-2 liters of leachate (Christen and Kjeldsen, 1989). The first leachate produced was manually recirculated for 7 days, simulating the real percolation process in landfills. Then it was collected and analyzed. Results are reported in annexes. The concentrate/deionized water were injected manually every day from Monday to Friday (T.Bouchez et al., Sardinia 2001) with a volume of 200 ml/day, up to reach 1 liter/week of concentrate. The volume would simulate the typical rainfall in Veneto region. The introduction of small volumes in the time would promote the

biological processes and gives a better representation of the reality. The proportions between water and concentrate are reported in table 3.

Tab. 3: Management of the columns. The table shows the proportions of water and concentrate injected in every columns, and reports the daily air flowrate. Daily is introduced a volume of 200 ml according to the percentages in table.

		INPUT	AERATION
ANAEROBIC	C1	100% RO concentrate	0 l/d
	C2	50% RO concentrate +50% water	0 l/d
	C3	100% water	0 l/d
AEROBIC	C4	100% RO concentrate	50 l/d
	C5	50% RO concentrate +50% water	50 l/d
	C6	100% water	50 l/d

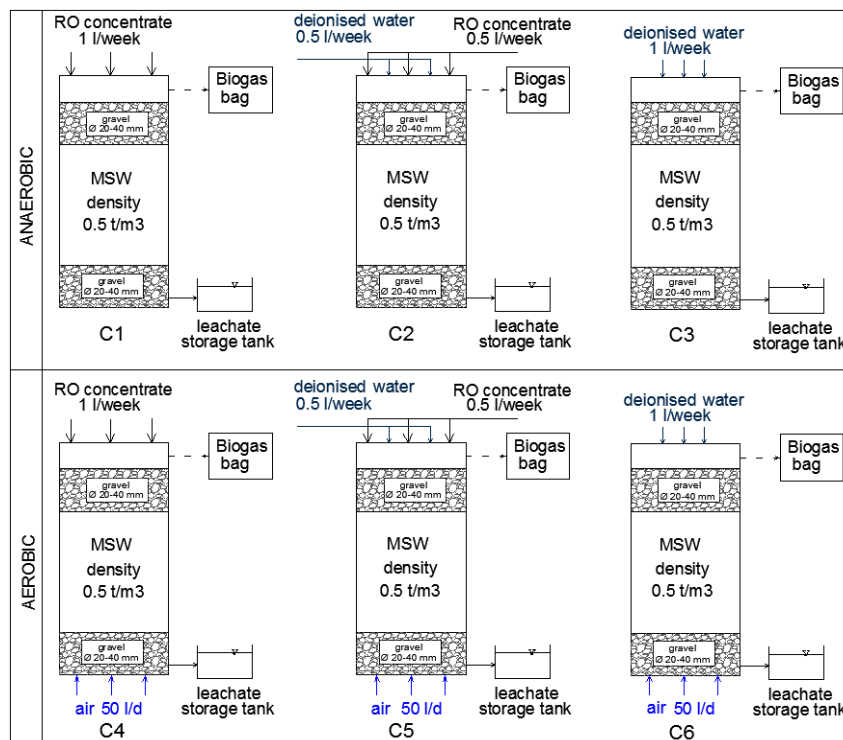


Fig. 4: Columns management scheme. The picture reports the scheme of the columns and their manage. In particular three columns are anaerobic (C1, C2, C3) and three aerobic (C4, C5, C6). C1 and C4 are fed with only concentrate, C2 and C5 with a mixture of concentrate and water while C3 and C6 with only water.

Three columns were intermittent aerobic (Nhu Sang Nguyen et al., 2009) and three anaerobic. The aeration rate was of 50 l/day (Smith et al., 2000, M. Bilgili et al., 2007, Boni et al., 1997, Cossu et al., 2003) insufflated in 10 hours. Was chosen to inject different amount of concentrate to better appreciate the changes with the reference columns. The leachate is collected daily from graduated cylinders and the level was monitored over time. Daily were measured the pH and

conductivity. Daily samples produced in a week are quantified and stored in six containers in the fridge. Every week was collected a meaningful sample from each containers and analyzed in pH, conductivity, COD, NH_4^+ , TKN, Cl^- . Biweekly was monitored TOC and TC, while BOD,FOS/TAC were done sporadically to control the advancement of biological processes.

2.5 Analytical methods

The analytical methodologies used are all certified (table 4). Leaching test is carried on the milled waste sample following the UNI EN12457-2 standard.

Table. 4: Analytical standards for leachate and waste analysis.

Analytical standards for leachate	
pH	IRSA-CNR 29/2003 vol. 1 n. 2060
conducibility	IRSA-CNR 29/2003 vol. 1 n. 2030
Chemicaloxygendemand (COD)	IRSA-CNR 29/2003 vol. 2 n. 5130
Biochemicaloxygendemand (BOD ₅)	IRSA-CNR 29/2003 vol. 2 n. 5120 A, B, B2
Chloride (Cl^-)	IRSA-CNR 29/2003 vol. 2 n. 4090 A1
Nitrates (NO_3^-)	IRSA-CNR 29/2003 vol. 2 n. 4040 A1
TKN	IRSA-CNR 29/2003 vol. 2 n. 5030
Ammonia (NH_3 , titration)	IRSA-CNR 29/2003 vol. 2 n. 4030 A2,C
Total organic carbon (TOC)	IRSA-CNR 29/2003 vol. 2 n. 5040
Total solids 105 ° (TS)	IRSA-CNR 29/2003 vol. 1 n. 2090 A mod.
Total volatile solids (TVS)	IRSA-CNR 29/2003 vol. 1 n. 2090 D mod.
Analytical standards for solid waste	
Total solids (TS)	IRSA-CNR Q 64/84 vol. 2 n. 2
Total volatile solids (TVS)	IRSA-CNR Q 64/84 vol. 2 n. 2
TKN	IRSA-CNR Q 64/85 vol. 3 n. 6 mod.
TOC	UNI EN 13137
Respirometricindex	ANPA 3/2001 n.12.1.2.3

3. RESULTS AND DISCUSSIONS

3.1 Waste characterization

During the filling phase of the columns was taken from the windrow of waste a representative sample (some kg) and conserved in a glass jar for further analysis. Part of the sample was milled up to reach 1 cm in size. Samples have been conserved in the fridge at a constant temperature of 4 °C. The TS percentage shows that only the 33% of the waste was water. The biological processes cannot start with a moisture lower than 40-50 % (Christensen and Peter Kjeldsen, 1989); it means that the wastes were mummified. The waste stability was checked with the “Sapromat” by the respirometric index. The moisture of the sample waste was raised up to 50 % adding 10 ml of deionized water. The test was stopped on the 7th day.

Tab. 5: Waste analysis. Are reported the analysis done on the milled waste sample, consisting in solids analysis, TKN, TC, IR, and tests on the eluate (pH and Cl⁻).

Waste analysis	
%TS	67
%VS	78
TKN (mg N/kg)	7885
TC (%TS)	44
pH	7.40
Cl ⁻ (mg/kg)	2170
IR 4 (mg O ₂ /g TS)	39
IR7 (mg O ₂ /g TS)	49

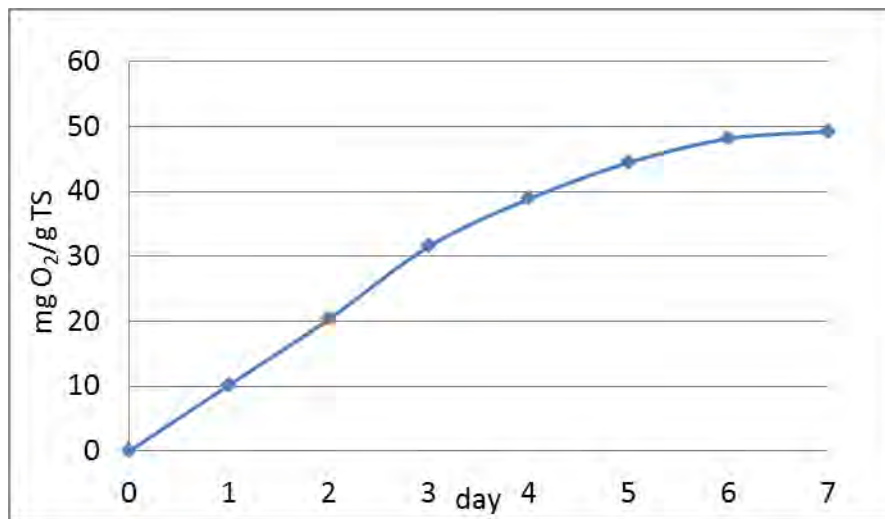


Fig. 5: Respirometric index. The graph was obtained using the “Sapromat”. Were analyzed three samples and the curve on the graph represents the mean value.. The trend growth slows after the 6th day tending to a plateau.

The pH and chloride concentration were measured in the eluate coming from the leaching test. The pH is congruent with methanogenic conditions, and the chloride are in the range proposed by Henigin, 1993. TKN and TC were analyzed to set the mass balance of nitrogen and carbon.

3.2 RO concentrate characterization

The landfill leachate and the concentrates characterization are proposed in table 6.

Tab. 6: Leachate, UF concentrate, RO concentrate features. Are reported the parameters analyzed in the landfill leachate, UF concentrate and RO concentrate to highlight the meaningful differences. The removal efficiency was calculated considering the Italian limits law for discharge to surface waters.

	leachate	UF concentrate	RO concentrate	Italian law limits	% removal
pH	7,85	7,94	7,52		
conductivity (mS/cm)	12,88	12,94	27,8		
COD (mg O ₂ /l)	1591	1994	2198	160	>90
TC (mg C/l)	1740	1810	2340		
TOC (mg C/l)	374	433	719		
NH ₄ ⁺ (mg N/l)	1122	1108	2388	15	>98.5
TKN (mg N/l)	1169	1207	2571		
Cl ⁻ (mg Cl-/l)	855	488	1823	1200	
TS (mg/l)	4750	5240	15355	80	>98
VS (mg/l)	1035	1438	4048		
TAC	-	-	6,816		
FOS	-	-	0,277		
%H ₂ O	99,53	99,48	98,47		
mg/l TS	4750	5240	15355		
mg/l VS	1035	1438	4048		

The landfill leachate is neutral or weakly alkaline with pH values of 7.85. The leachate odour and its pH demonstrate that methanogenic conditions have been reached. The indexes for the measure of the organic matter are quite low if compared with the upper limit reported by Henigin (Sardinia 1993). NH₄⁺ and TKN are similar, so it means that all the nitrogen available is in the ammoniacal form. For the purpose of this thesis only leachate RO concentrate is considered.

Concentrated leachate is a kind of brown solution with a low biodegradable fraction (Calabrò et al., 2010). The high molecular weight and non-biodegradable compounds were mostly removed by membrane processes and accumulated in the concentrated leachate (Chan et al., 2007). The higher concentration of Cl⁻ observed in the concentrate demonstrate that the membrane process can easily reject Cl⁻ usually not removed by physicochemical and biological treatment (Chan et al., 2007). Comparing the leachate sample with RO concentrate is evident the capacity of the membrane to reject salts, Cl⁻, TS, VS, NH₄⁺. The concentrate is done for the 98% of water. In order to estimate the removal efficiency of the plant have been considered the law limits for superficial waters. The plant has a removal efficiency higher than 90% for the COD, > 98.5 % for ammonia and > 98% for TS.

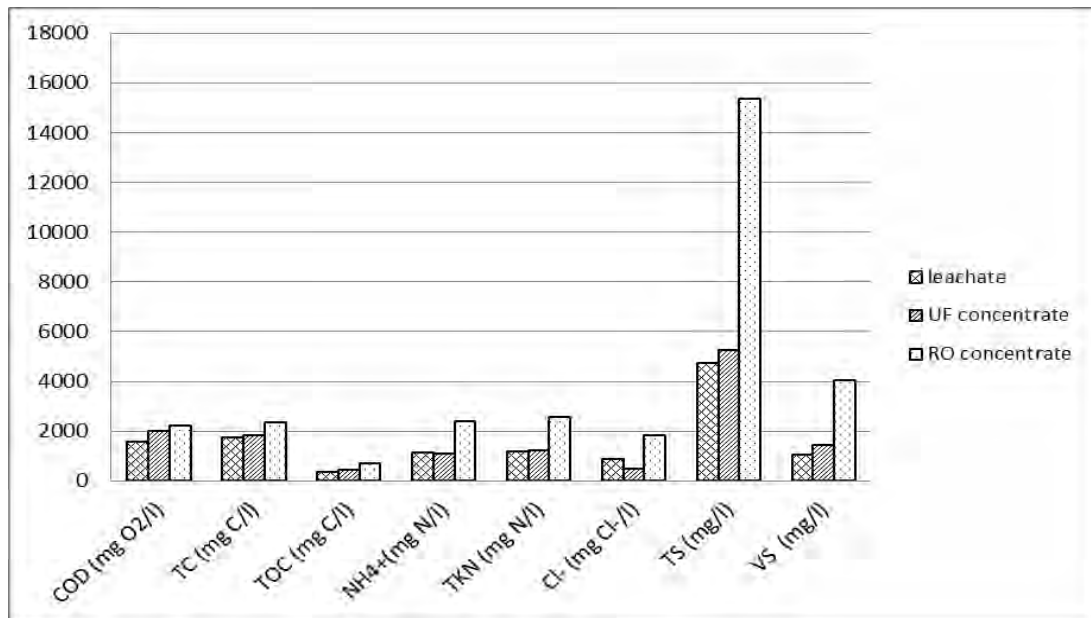


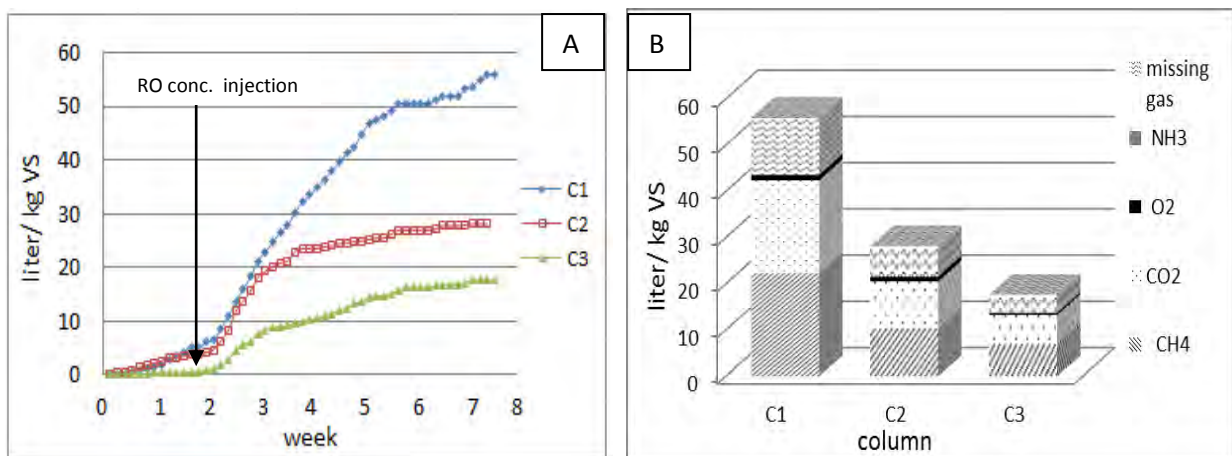
Fig.6: Chemical differences between landfill leachate, UF concentrate and RO concentrate. In the histogram is depicted the performances of the RO modules. The RO membranes are able to double the ammonia, TKN and chloride concentrations and produce a strong reduction in salts and solids.

3.3 Biogas production and leachate pH

Biogas production and leachate pH are good indicators of the progress of the biological decomposition. It is reported the cumulative biogas production for the anaerobic columns (C1, C2, C3). The biogas production is strictly dependent with the pH. The ideal range for the biogas production is 6.65-7.41 (Sandip et al., (2012)). The first concentrate sample was injected on the 13th day of the experimentation. Even if the different starting conditions of the six columns, 10 weeks later the pH was regularized. As predictable the average pH of the aerobic columns (C4, C5, C6) is higher than those anaerobic. The concentrate injection does not seem to influence much the pH; considering the anaerobic columns in all the observed period C1 had the higher pH, but this is due to the alkalinity introduced with the concentrate and to the fast consumption of VFA by the methane production. Aerobic columns don't show meaningful differences.

Concerning the biogas production the three anaerobic columns behave in different ways: C1 and C2 have a similar production up to the 20th day, while the reference column (C3) starts later because of its lower pH. Generally there was an initial lag phase lasted about 10-15 days, followed by a good biogas production. From the figure 7A it is clear the difference in volume of biogas produced. The volume generated from C1 is twice that produced by C2 and three times that produced by C3. This strong difference could be due in part to the slowdown of the degradation rate caused by the natural dissipation of the heat between the first and last column

(in fact there is a gap of 2-3°C). The nature of the heating system does not permit to ensure a constant temperature. Moreover is possible that the introduction of concentrate facilitates the diffusion of nutrients in the waste mass increasing the bacterial activity and enhancing the kinetics of degradation. After the concentrate injection occurs a reduction of methane but this trend was followed also from the reference column. Nevertheless the concentrate injection does not seem to affect the methane percentage in the biogas, but instead it is strongly related with the volume produced. The CH₄/CO₂ ratio on the total volume produced is constant, it means that the concentrate does not inhibit methanogenic bacteria. In figure 7 is reported the volumetric biogas composition. The amount of oxygen can be neglected, and it is probably due to an instrument fault. Moreover the sum of volumes calculated with the gas percentages detected are different from the real volume measured in the bags. In particular the ratio between the “missing volume” and the total real volume is constant for C1,C1,C3 and is about 0.2. It means that the instrument used had a background error. Trace of gaseous ammonia and hydrogen sulfide were detected. The concentrations were monitored with the “*landfill gas analyzer 2000*” able to reveal the CO₂, CH₄, O₂, NH₃, H₂S percentage. Ammonia concentration in the gas is related to the concentrate volume injected. The percentage distribution for C2 shows peaks probably provoked to a technical fault. However decreasing trends are detected after the 5th week. Moreover were found high percentages of H₂S but the measures are not reliable because for high concentrations (>1230 ppm) the instrument cannot work.



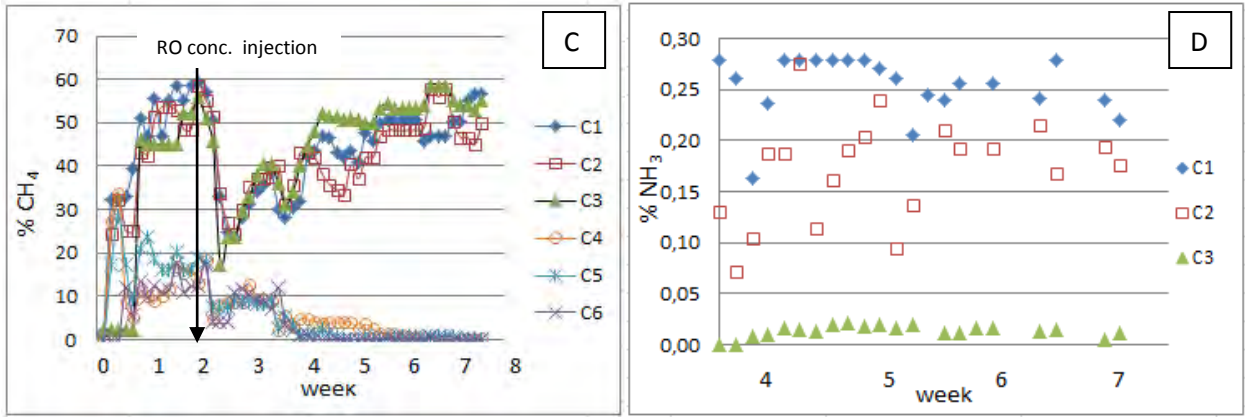
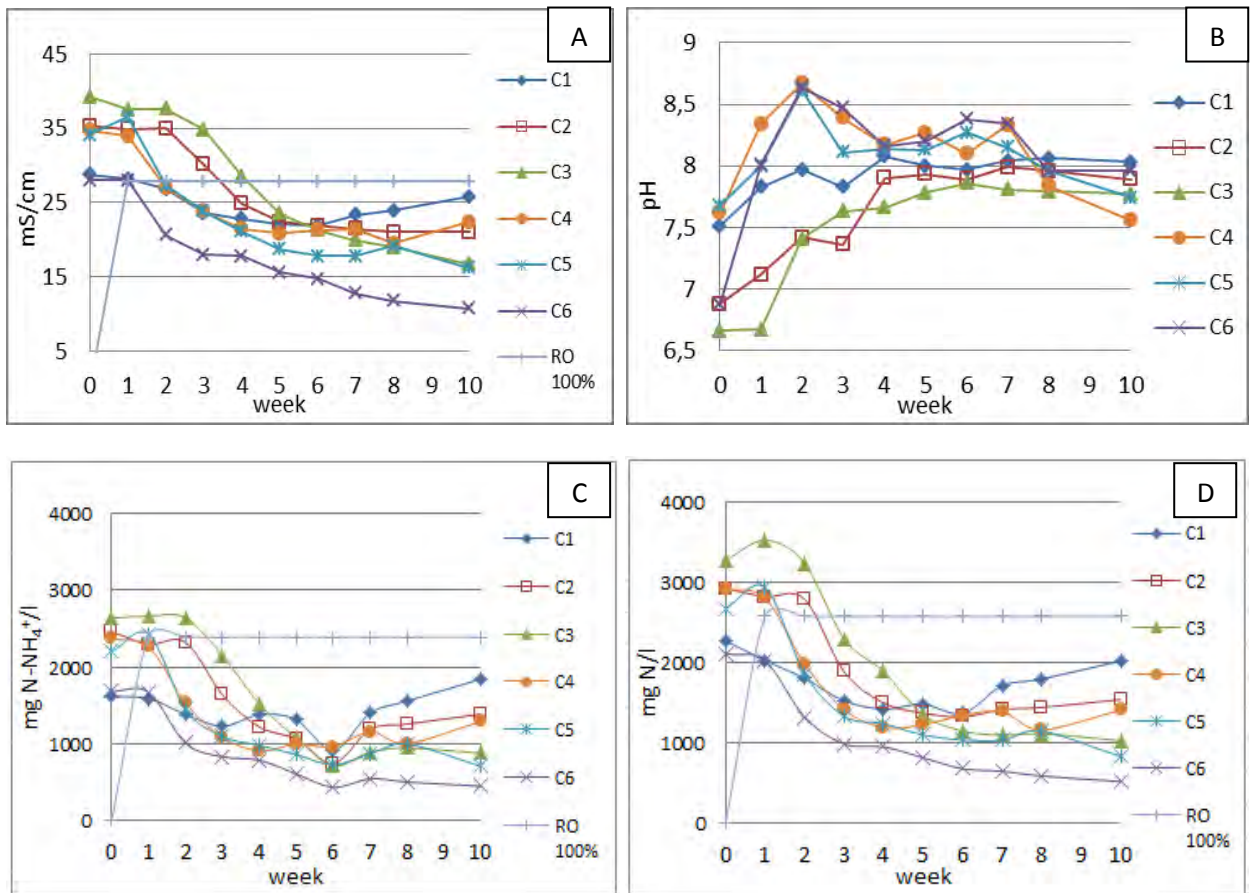


Fig.7: Cumulative gas production (A), volumetric gas composition (B), methane percentages (C) and ammonia concentration in the biogas (D). Graphs show the amount of the biogas produced and its quality in terms of methane ammonia concentration and carbon dioxide. Ammonia concentration has been monitored from the 25th day because of the lack of the instrument before that date.



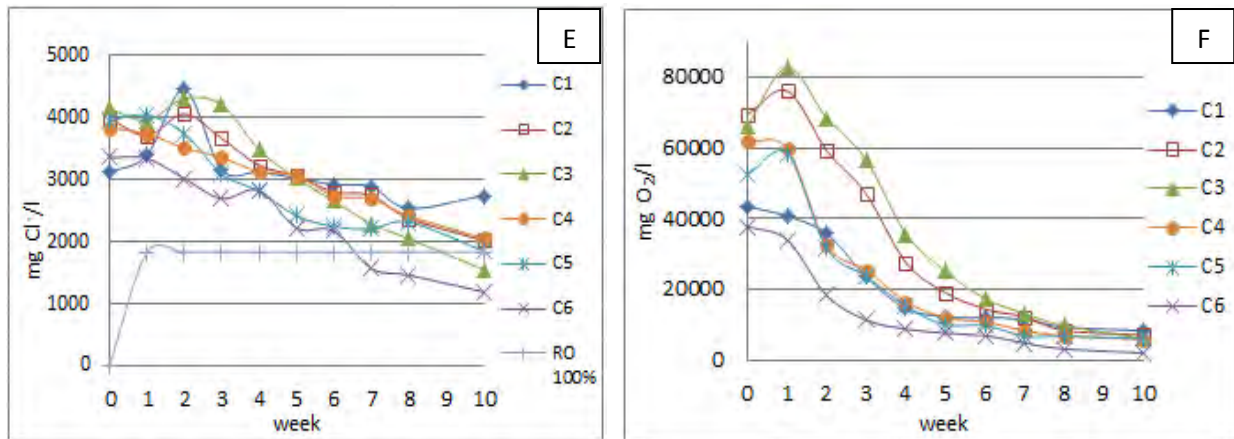


Fig. 8: Leachate conductivity (A), leachate pH trend (B), leachate NH₄⁺ trend (C), leachate TKN trend (D), leachate Cl⁻ trend (E), leachate COD trend (F).

3.4 Conductivity

After an initial adaptation phase almost all the columns behave in the same manner. The injection of clean water in C3 and C6 is consistent with the decrease of the conductivity. C2, C4 and C5 after the 6th week reached quite stationary conditions while C1 tends to increase. Using 100% of RO concentrate the aerobic conditions seem to be slightly better than anaerobic, in fact the amount of salts are lower in C4 respect C1. With the 50% of concentrate aerobic and anaerobic conditions don't show differences in the long period. Comparing C1 with C3 and C4 with C6 is evident the accumulation of salinity in the leachate landfill.

3.5 COD

The first leachate produced depicted the heterogeneity of the waste. Even after pretreatments waste shown a COD ranging between 38000-82000 mg/l. Are evident in C2, C3, C5 the peaks followed by a rapid decrease, sign that the mummification process occurred during the waste storage. The moisture restarted the biological processes causing the release of organic matter. The rapid decrease of the COD slowed around the 6th week, reaching value comparable with the COD of the concentrate injected. All the columns are seated between 9900-3300 mg/l. However is still not possible appreciate the effects of the concentrate injection because of the too high COD. However, comparing the biogas production with the COD in C1, C2, C3 is clear that its reduction is imputable to the carbon gasification. The BOD/COD ratio done on the first leachate sample gives a further proof of this fact. Concerning the aerobic columns C6 shows the best behavior with a continuously decreasing trend. No significant differences are found in C5 and C4.

Tab. 7: BOD/COD ratio. In the table are reported the BOD/COD ratio done on the first leachate collected before the concentrate injection and nine weeks later. The strong reduction is due to the washing of the waste and to the biological degradation.

Column	BOD ₅ /COD 10/09/2014	BOD ₅ /COD 28/10-3/11
C1	0,52	0,12
C2	0,51	0,27
C3	0,58	0,51
C4	0.58	0.17
C5	0,49	0,23
C6	0.42	0.06

The BOD was done at the beginning and at the end of the test showing a reduction between 93-99%. The average initial BOD₅/COD ratio was 0.5-0.6, while on the 9th week ranging between 0.5-0.06.

The partial carbon mass balance is now presented. The input and output flows of mass have been reported in table 8. The carbon concentrate content and the carbon waste content gave a positive contribution, while the leachate and the biogas extracted were losses of the system.

Tab. 8: Carbon mass balance

Column	RO conc. g C / kg TS	Gas g C / kg TS	Leachate g C / kg TS	Waste g C / kg TS	Accumulation g C / kg TS
C1	1.758	18.41	6.328	6468	6445.02
C2	0.879	9.08	7.91	6468	6451.89
C3	0	5.88	7.34	6468	6454.78
C4	1.758	14.24	5.282	6468	6450.23
C5	0.879	9.79	4.232	6468	6454.86
C6	0	15.03	2.926	6468	6450.05

Tab. 9 : Carbon balance in percentage. In the table is reported the partial carbon mass balance. Sources considered have been the RO concentrate and the waste mass as input flows, biogas and leachate as output flows. In the table are reported plus and minus, which indicates that if it is a positive component in terms on carbon or negative, removing mass from the system.

Column	% C RO conc. +	% C Leachate -	% C Gas -	% C Waste +	% residual C in the column
C1	0.03	0.10	0.28	100.0	99.6
C2	0.01	0.12	0.14	100.0	99.8
C3	0.00	0.11	0.09	100.0	99.8
C4	0.03	0.08	0.22	100.0	99.7
C5	0.01	0.07	0.15	100.0	99.8
C6	0.00	0.05	0.23	100.0	99.7

The carbon accumulation after two months of observation is still high. C1 accumulation results slightly lower than C2 and C3, consistently with the higher biogas production. However C2 and C3 percentages are intended to be reduced due to the higher BOD₅/COD respect C1. In C1, C2, C3 the carbon percentage removed by the biogas is higher than the amount of carbon removed by the leachate. Aerobic columns don't show meaningful differences. It is strange that even if the forced aeration has to be applied the amount of carbon removed is very low.

3.6 NH₄⁺ and TKN

Ammonia and TKN have similar trend in all the reactors. Columns C4, C5, C6 after a rapid decrease show stationary conditions. The ammonia released from anaerobic columns presents a strong peak on the 7th week but except this point the trend seem regular. The ammonium reduction is in part imputable to the daily pH fluctuation. Once stabilized the ammonium concentration raised up. Moreover the biogas production slows when the ammonium in the leachate increase. This is the sign of the reduction of the microbial activity, provoked to the reduction of biodegradable substances. From the 7th week the biogas amount is almost zero. As expected ammonia concentration in C1 increase more quickly than C2 due to the double concentration introduced. A comparison can be done between C1 and C3: the reinjection of RO concentrate provokes the accumulation of ammonia in the landfill. Ammonia covers an important role in the long term pollution of a landfill, because there is no mechanism for its degradation in anaerobic conditions. Therefore the best choice for the ammonia removal is the forced aeration. The TKN reduction is due to the organic fraction reduction, hydrolyzed or washed out from the system. Aerobic columns show a lower concentration in ammonia attributable to the nitrification-denitrification processes. Sporadically were found NO₃⁻ with concentrations lower than 20 mg/l but NO₂⁻ were never detected. Generalizing anaerobic columns fed with pure RO concentrate shown an higher ammonia concentration. Forced aeration is able to reduce the amount of ammonia by the conversion in bimolecular nitrogen.

The partial nitrogen mass balance is now presented. The input and output flows in terms of mass have been reported in table 10. The nitrogen concentrate content and the nitrogen waste content gave a positive contribution, while the leachate and the biogas extracted were losses of the system. Looking the accumulation expressed as percentage on the input waste mass, is clear that the nitrogen accumulation occurred in C1 and C4 where pure concentrate is injected. The phenomenon can be seen even if with a low extent, in C2 and C5. Is to note that the accumulations occurred in aerobic columns are misleading, because have not been possible to

measure the nitrogen removed by denitrification. For this reason the performances of C3 could seem better than C6.

Tab. 10: Nitrogen mass balance

Column	RO conc. mg N/kg TS	Leachate mg N/kg TS	Gas-NH3 mg N/kg TS	Waste mg N/kg TS	Accumulation mg N/kg TS
C1	1932	1409	38	11769	8370
C2	966	1405	6	11769	7440
C3	0	1305	1	11769	6579
C4	1932	1072	0	11769	8745
C5	966	968	0	11769	7883
C6	0	681	0	11769	7204

Tab. 11: Nitrogen balance in percentage. In the table is reported the partial nitrogen balance. Sources considered have been the RO concentrate and the waste mass as input flows, biogas and leachate as output flows. In the table are reported plus and minus, which indicates that if is a positive components in terms on nitrogen or negative, removing mass from the system.

Column	% N RO conc. +	% N Leachate -	% N Gas -	% N Waste +	% residual N in the column
C1	16.4	12.0	0.3	100.0	104.1
C2	8.2	11.9	0.1	100.0	96.2
C3	0.0	11.1	0.0	100.0	88.9
C4	16.4	9.1	0.0	100.0	107.3
C5	8.2	8.2	0.0	100.0	100.0
C6	0.0	5.8	0.0	100.0	94.2

3.7 Chloride

The general trend of chloride show a decrease in time, even if for C1, C2.C3 was recorded a peak on the 3rd week. However exception done for this isolated phenomenon the trend decrease progressively, thus it is probably an error. For a given mass inserted the aerobic columns seem to release lower chloride respect the anaerobic, but due to the shortness of the observed period this statement is not reliable. As expected the trend of C3 and C6 continue to decrease. Considering a long period of observation the concentration detectable in C3 and C6 should decrease up to zero, while in C2-C5, and C1-C4 the output concentration will be stationary. From the 5th week C2 and C4 trend don't show meaningful differences, showing similar values, even if it terms of mass the amount of chloride injected was double. It means that the contribution given from the RO concentrate and the waste on the total chloride production are different. Considering that chloride is a conservative pollutant and is a soluble ion, the amount of Cl⁻ injected with the

concentrate should be found in the leachate. In addition wastes release Cl^- which will be added in the leachate.

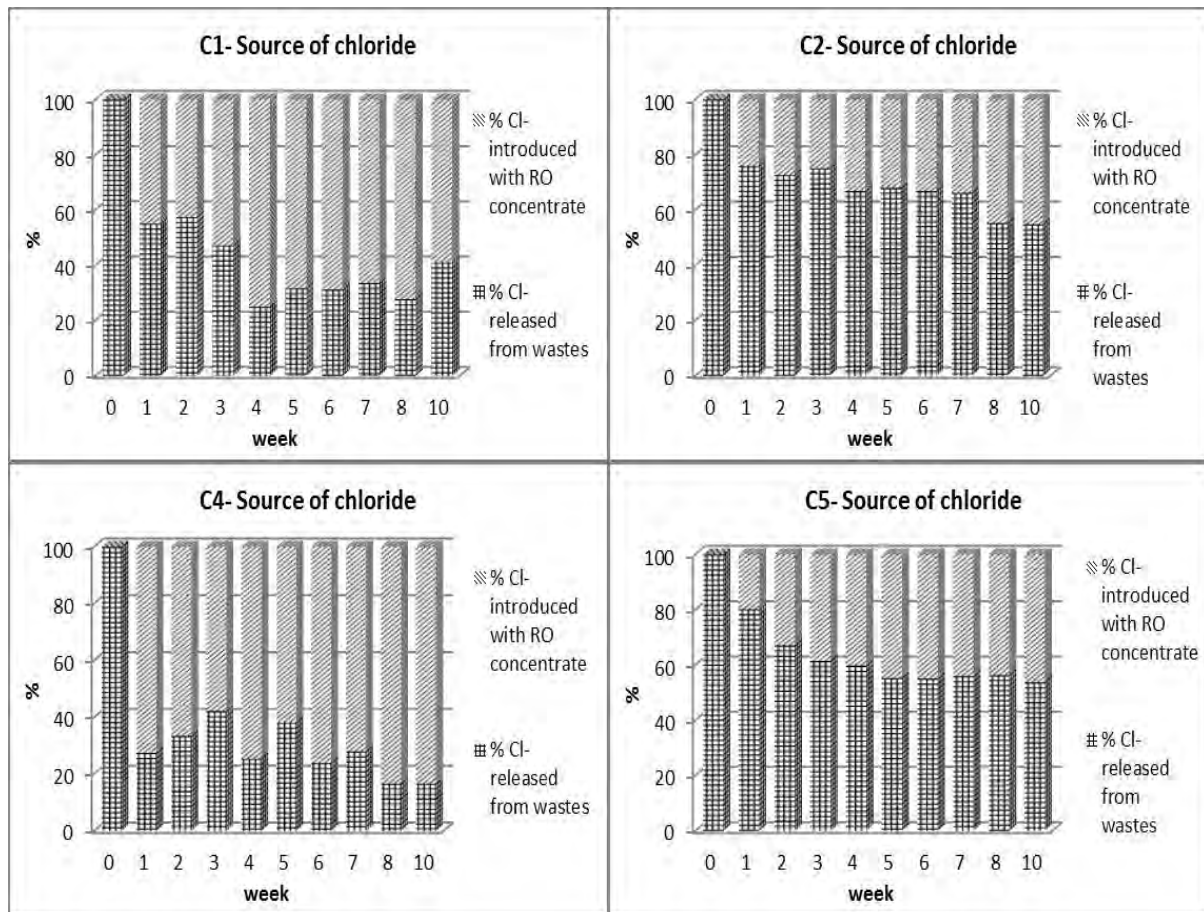


Fig. 9: Contribution of RO concentrate and waste on the total chloride output mass (mg/kgTS). The histograms show the fraction on the total mass, of chloride coming from the RO concentrate and the fraction released from the waste.

Theoretically in a long time all the chloride mass injected should be equal to the output mass; exception is done for background values releasable from the waste.

The partial chloride mass balance is now presented. The input and output flows in terms of mass have been reported in table 12. The RO concentrate and the waste gave a positive contribution, while the leachate was considered as losses of the system. Looking the accumulation expressed as percentage on the input waste mass, is clear that the chloride accumulation is stronger in the columns in which pure concentrate is injected.

Tab. 12: Chloride mass balance.

Column	RO conc. mg Cl ⁻ / kg TS	Leachate mg Cl ⁻ / kg TS	Waste mg Cl ⁻ / kg TS	Accumulation mg Cl ⁻ / kg TS
C1	1370	2623	3239	1986
C2	685	2448	3239	1476
C3	0	2213	3239	1026
C4	1370	2144	3239	2465
C5	685	1903	3239	2021
C6	0	1611	3239	1628

Tab. 13: Chloride balance in percentage. In the table is reported the partial chloride balance. Sources considered have been the RO concentrate and the waste mass as input flows, leachate as output flows. In the table are reported plus and minus, which indicates that if it is a positive components in terms of chloride or negative.

Column	% Cl ⁻ RO conc. +	% Cl ⁻ Leachate -	% Cl ⁻ Waste +	% residual Cl ⁻ in the column
C1	42.30	80.98	100.00	61.3
C2	21.15	75.58	100.00	45.6
C3	0.00	68.32	100.00	31.7
C4	42.30	66.19	100.00	76.1
C5	21.15	58.75	100.00	62.4
C6	0.00	49.74	100.00	50.3

3.8 Hydraulic performances

The hydraulic features of the compacted waste are described by the hydraulic conductivity. Waste is an unsaturated porous medium in which for the measure of hydraulic conductivity should be apply a model. Nevertheless saturating the waste and applying the Darcy law would have been possible to measure the hydraulic conductivity. The saturation of the columns created however o huge amount of leachate with the related problem of the “waste washing”. To limit the mass of pollutants exported from the columns this method was discarded. In order to monitor the hydraulic situation and capture the meaningful differences the daily leachate were collected in graduated cylinders placed under the columns. The leachate levels were recorded more times during the day. All the peaks in the distribution are provoked by the accumulation of the leachate during the weekend. Considering the cumulative curves, the leachate extracted is always lower than the input flow except for the last value monitored of C2 . This lack of volume in the anaerobic reactors is due to the biological processes. Is to note that the water accumulated in C3 is higher than C1 and C2, which are practically coincident in the final part of the experimentation. The low biogas production and the high water retaining capacity indicate the heterogeneity of the waste. The amount of leachate released from the aerobic columns, C4, C5,

C6 depends over the biological removal on the evaporation, produced blowing air. Focusing on the columns that work with the concentrate both aerobic and anaerobic conditions show a similar behavior: globally release more leachate than the reference columns (C3 and C6 respectively). This can be due to the occlusion of micro porosity with the generation of preferential pathway. Nevertheless further investigations are required.

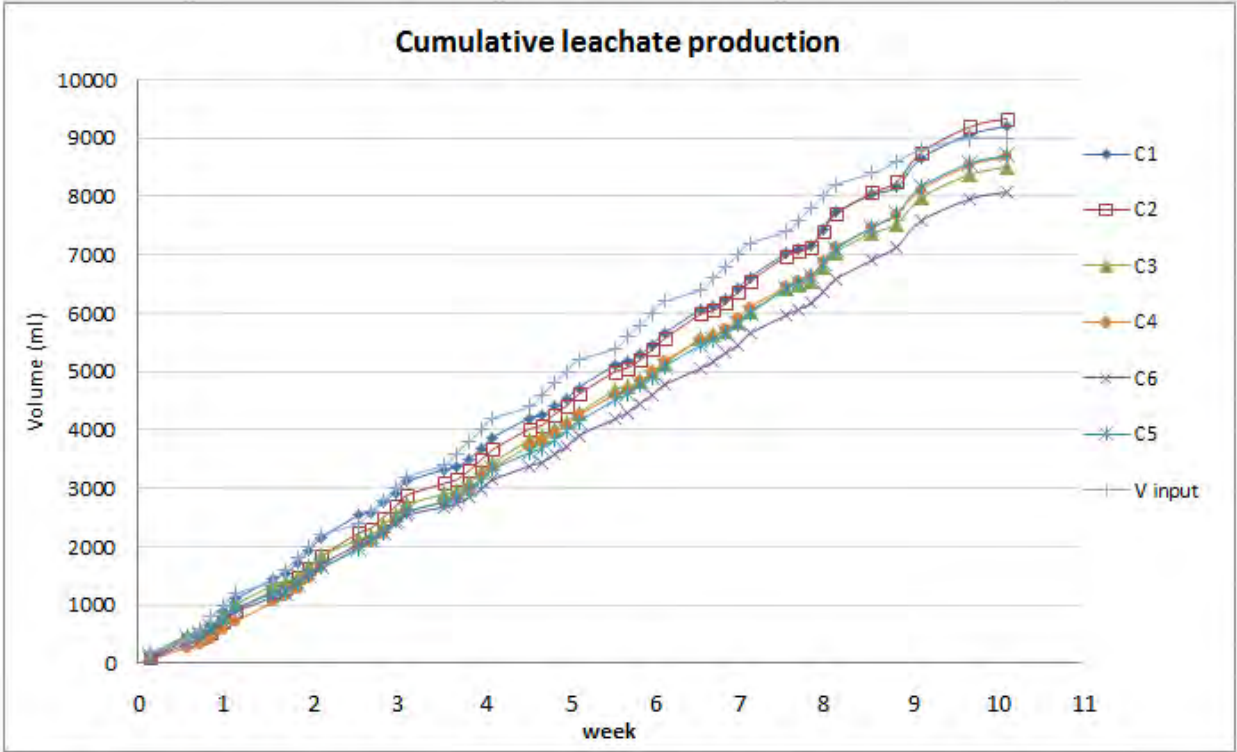


Fig. 10 :Cumulative leachate production. It represents the total volume extracted from the columns and the input volume.

The table 14 shows that an average humidity of 50% has been maintained inside each columns. The introduction of 1 liter of fluid every week is enough to promote the biological degradation with the production of biogas.

Tab. 14: Weekly moisture percentage. The table summarizes the weekly moisture content for each columns. The average humidity is about 50%, and is maintained constant in time.

Average moisture percentage						
<i>time</i>	<i>C1</i> % moisture	<i>C2</i> % moisture	<i>C3</i> % moisture	<i>C4</i> % moisture	<i>C5</i> % moisture	<i>C6</i> % moisture
Initial moisture	33,0	33,0	33,0	33,0	33,0	33,0
10/09/2014	47,0	48,4	50,5	48,4	49,8	48,8
11/09-15/09	46,8	48,3	50,3	48,6	49,7	49,2
16/09-22/09	46,9	48,8	50,7	49,1	50,3	49,8
23/09-29/10	46,6	48,8	51,2	49,4	50,9	49,9
30/09-6/10	47,3	49,2	51,7	50,3	51,4	50,5
07/10-13/10	47,6	49,4	51,9	51,0	51,8	50,6
14/10-20/10	47,8	49,4	52,2	51,5	52,0	50,9
21/10-27/10	48,0	49,5	52,5	51,8	52,1	51,0
28/10-3/11	48,1	49,5	52,8	52,0	52,2	51,2
4/11-10/11	48,1	49,3	52,9	52,2	52,1	51,9
12/11-18/11	48,0	48,9	52,9	52,1	51,9	51,7

3.9 Density and viscosity

For each sample density and viscosity were determined at 22 °C using Ostwald microviscosieter which was calibrated using 15 ml of deionized water. Measurements were repeated until three consecutive readings and the final value was done by the arithmetic mean. Each viscosity measurement was followed by at least three washings with deionized water. In order to calculate the density 100 ml of each sample were weighted with the technical balance. Viscosity did not show strong changes during the experiment, having values on the 10th week a bit higher than RO concentrate.

4. CONCLUSIONS

The use of RO modules for the leachate treatment is a reliable technology which ensures high removal efficiency. The concentrate disposal is an environmental and economic problem solved in some cases with the cheaper treatment: the reinjection into the landfill body. Experiences reported in scientific literature about the concentrate recirculation are scarce and quite old. Therefore a laboratory test was necessary to investigate the effects of the reinjection including chemical and hydraulic aspects. After 10 weeks of test, it was observed that the concentrate injection produces an accumulation of harmful substances in the waste. A decrease in ammonia concentration was observed in the leachate after the RO concentrate injection up to the 6th week. Nevertheless, after the 6th week the trend changed, starting to increase. This peak can be due to ammonia uptake by the methanogens bacteria. In fact, from the 7th week, the biogas production

slowed quickly, implying the change of the trend. The concentrate did not inhibit methanogenic bacteria and did not affect the CH_4/CO_2 ratio in the biogas, but instead it contributed to a higher biogas production. Traces of gaseous ammonia were detected in the biogas, showing the highest percentage (2700 ppm) in the column in which pure concentrate is used. The carbon accumulation, in terms of mass, is resulted slightly lower in the column in which concentrate is injected, consistently with the higher biogas production. Moreover the BOD_5/COD values showed that the leachate biological stability is increased using the concentrate.

It can be concluded that the concentrate recirculation enhances the biological activity reducing the aftercare period of a landfill. Otherwise, it was observed that RO concentrate injection produced an accumulation of salts in the leachate. Moreover looking at the partial chloride balance it is clear that the chloride accumulation was stronger in the columns in which pure concentrate was injected. The concentrate did not affect the hydraulics performances of the waste. However, further studies are necessary to understand the behavior in the long term.

5. REFERENCES

- Bart van der Bruggen, Liesbeth Lejon, and Carlo Vandecasteele, Reuse, Treatment, and Discharge of the Concentrate of Pressure-Driven Membrane processes, 2003.
- Bilgili M.Sinan , AhmetDemir, Bestamin O' zkaya, Influence of leachate recirculation on aerobic and anaerobic decomposition of solid wastes, Journal of Hazardous Materials 143 (2007) 177–183.
- Boni M., A. Delle-Site, G. Lombardi, E. Rolle, Aerobic-anaerobic operation of a lab scale municipal solid waste sanitary landfill, J.Solid waste manage. 24 (3) (1997) 137-142.
- Bouchez T. , S.Bobe'e-Flandrois, M-L. Munoz, Y. Moreau-Le Gplvan, C.Bordier and C.Duqennoi, Consequences of leachate concentrate injection into municipal solid waste, Sardinia 2001.
- Calabrò Paolo S. , Silvia Scaffoni, SirioOrsic, EmilianoGentili d, Carlo Meonie, The landfill reinjection of concentrated leachate: Findings from a monitoring study at an Italian site, Journal of Hazardous Materials, 181 (2010) 962–968.
- ChayanonSawatdeenarunat, Effects of leachate recirculation on anaerobic treatment of municipal solid waste.
- Chianese Angelo , Rolando Ranauro and Nicola Verdone, Treatment of landfill leachate by reverse osmosis, Wat. Res, Vol. 33, No. 3 pp 647-652, 1999.
- Christensen and Peter Kjeldsen, 1989, Basic biochemical processes in landfill.
- CossuRaffaello , Roberto Raga, Davide Rossetti, The PAF model: an integrated approach for landfill sustainability, Waste Management 23 (2003) 37-44.
- Douglas E. Goldsack and Raymond Franchetto, 1976, The viscosity of concentrated electrolyte solutions.I.Concentration dependence at fixed temperature.
- Eipper H. and C.Maurer, Pirification of landfill leachate with membrane filtration based on the disc tube, Sardinia 1999.
- Francois V. , G. Feuillade, G. Matejka, T. Lagier, N. Skhiri, Leachate recirculation effects on waste degradation: Study on columns, Waste Management 27 (2007) 1259–1272.
- Henigin P.L.A , Effects of the return of membrane filtration concentrates on the new formation of leachate, Sardinia 1993, volume 1.
- Henigin P.L.A , Recirculation of leachate concentrate from reverse osmosis treatment, Sardinia 1995.
- Henigin P.L.A. , Effects of the return of membrane filtration concentrates on the new formation of leachate, Sardinia 1993.

- IremŠan, Turgut T. Onay, Impact of various leachate recirculation regimes on municipal solid waste degradation, *Journal of Hazardous Materials B87* (2001) 259–271.
- Kenichi Ushikoshi, Tetsuo Kobayashi , Kazuya Uematsu, Akihiro Toji , Dai Kojima , Kanji Matsumoto, Leachate treatment by the reverse osmosis system, *Desalination* 150 (2002) 121-129.
- Kjeldsen, P. Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A., Christensen, TH., 2002. Present and long term composition of MSW landfill leachate: a review. *Crit. Rev. Environ. Sci. Technol.* 32 (4), 297-336.
- Laner D., Crest M., Scharff H., Morris M.W.F., Barlaz M.A., 2012, A review of approaches for the long term management of municipal solid waste landfills, *Waste Management Journal* n°32, 2012.
- Luca Di Palma, Paola Ferrantelli, Carlo Merli, Elisabetta Petrucci, Treatment of industrial landfill leachate by means of evaporation and reverse osmosis, *Waste Management* 22 (2002) 951–955.
- Metcalf & Eddy 2004.
- Nhu Sang Nguyen, Satoshi Soda, Daisuke Inoue, Kazunari Sei, and Michihiko Ike. Effects of intermittent and continuous aeration on accelerative stabilization and microbial population dynamics in landfill bioreactor, *Journal of Bioscience and Bioengineering*, vol. 108 No. 4, 336-343, 2009.
- Peters Thomas A. , Purification of landfill leachate with reverse osmosis and nanofiltration, *Desalination* 119 (1998) 289-293.
- Peters, TA., 1998. Purification of landfill leachate with membrane filtration. *Filtr. Sep.* 35 (1), 33-36.
- Pin-Jing He, Xian Qu, Li Ming Shao, GuoJian Li, Duu Jong Lee, leachate pretreatment for enhancing organic matter conversion in landfill bioreactor.
- Qi-Qi Zhang, Bao-Hu Tian, Xuan Zhang, Abbas Ghulam, Cheng-Ran Fang, Ruo He, Investigation on characteristics of leachate and concentrated leachate in three landfill leachate treatment plants, *Waste Management* 33 (2013) 2277–2286.
- Renou S. , J.G. Givaudan, S. Poulain, F. Dirassouyan, P. Moulin, Landfill leachate treatment: Review and opportunity, *Journal of Hazardous Materials* 150 (2008) 468–493.
- Robinson A.H. 2005, Landfill leachate Treatment, Membrane technology, 6-12.
- Sandip, M., Kanchan, K., Ashok, B., (2012). Enhancement of methane production and bio-stabilisation of municipal solid waste in anaerobic bioreactor landfill. *Bioresource Technology* 110, 10-17.

- SeldaYigitHunce, DenizAkgul, GokselDemir, BulentMertoglu, Solidification/stabilization of landfill leachate concentrate using different aggregate materials, *Waste Management* 32 (2012) 1394–1400.
- Siddiqui A.A. , D.J. Richards, W. Powrie, Biodegradation and flushing of MBT wastes, *Waste Management* 33 (2013) 2257–2266.
- Smith M.C. , D.K. Gattie, D.D.H Boothe, K.C. Das, Enhancing aerobic bioreduction under controlled conditions in a municipal solid waste landfill through the use of air injection and water recirculation, *ADV. Environ. Res.* 3 (4) (200) 459-470.
- Stoltz G. and JP, Gourc, influence of compressibility of domestic waste on fluid permeability, *Proceedings Sardinia 2007*.
- SubramaniArun, Joseph G.Jacangelo, treatment technologies for reverse osmosis concentrate volume minimization: A review.
- Ten hong Chen, David P.Chynoweth, Hydraulic conductivity of compacted municipal solid waste, *Bioresource Technology* 51 (1995) 205-212.
- Theepharaksapan S. , C. Chiemchaisri, W. Chiemchaisri, K. Yamamoto, Removal of pollutants and reduction of bio-toxicity in a full scale chemicalcoagulation and reverse osmosis leachate treatment system, *Bioresource Technology* 102 (2011) 5381–5388.

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Part 3

Annexes

1. Annex 1

Tab. 1: Leachate chemical analysis. Are reported the chemical analysis done on the weekly leachate sample and on the RO concentrate.

RO concentrate

pH	conductivity (mS/m)	COD (mg O ₂ /l)	NH ₄ ⁺ (mg N/l)	TKN (mg N/l)	TOC (mg C/l)	TC (mg C/l)	Cl- (mg/l)	TAC (mg CaCO ₃ /l)	FOS (mg HAc/l)	FOS/TAC	TS (mg/l)	VS (mg/l)
7.52	27.8	2198	2388	2571	719	2340	1823	6.816	0.277	0.04	15355	4048

C1

Date	pH	conductivity (mS/m)	COD (mg O ₂ /l)	BOD (mg O ₂ /l)	NH ₄ ⁺ (mg N/l)	TKN (mg N/l)	TOC (mg C/l)	TC (mg C/l)	Cl- (mg/l)	L/S l/kg TS	TAC (mg CaCO ₃ /l)	FOS (mg HAc/l)	FOS/TAC
10/09/2014	7.51	28.8	43433	22416	1614	2269	10540	11520	3112	0.11	7.227	4.497	0.62
11/09-15/09	7.83	28.2	40730		1588	2020		11693	3393	0.16	6.905		
16/09-22/09	7.97	26.8	35826		1383	1800	9380	12040	4449	0.26	6.603	3.846	0.58
23/09-29/10	7.83	23.6	23569		1227	1520		8039	3155	0.37	7.821	1.987	0.25
30/09-6/10	8.08	22.8	14714		1379	1418	3590	5130	3120	0.45	7.942	1.32	0.17
07/10-13/10	8	22.1	12331		1313	1478		5065	3020	0.54	8.981	0.872	0.1
14/10-20/10	7.97	21.9	12182		910	1363	2830	5000	2915	0.63	9.324	0.895	0.1
21/10-27/10	8.04	23.3	11660		1399	1706		5350	2884	0.73	10.785	0.837	0.08
28/10-3/11	8.06	23.9	9510	1184	1556	1793	2750	5700	2531	0.83			
11/11-17/11	8.03	25.8	8414		1843	2015			2740	0.93			

C2

Date	pH	conductivity (mS/m)	COD (mg O ₂ /l)	BOD (mg O ₂ /l)	NH ₄ ⁺ (mg N/l)	TKN (mg N/l)	TOC (mg C/l)	TC (mg C/l)	Cl- (mg/l)	L/S l/kg TS	TAC (mg CaCO ₃ /l)	FOS (mg HAc/l)	FOS/TAC
10/09/2014	6.88	35.3	69547	35475	2459	2920	17300	17360	3981	0.06	8.176	7.078	0.87
11/09-15/09	7.12	34.9	76068		2296	2818		17098	3707	0.11	7.958		
16/09-22/09	7.42	35	59212		2322	2785	16680	16680	4057	0.19	7.663	6.895	0.9
23/09-29/10	7.36	30.1	46931		1637	1882		13196	3661	0.29	6.794	5.135	0.76
30/09-6/10	7.9	24.9	27616		1217	1495	8160	10060	3228	0.38	6.529	2.976	0.46
07/10-13/10	7.93	22.4	19166		1061	1367		8161	3054	0.47	7.313	1.679	0.23
14/10-20/10	7.89	21.9	14503		743	1321	3850	6050	2797	0.57	7.857	1.266	0.16
21/10-27/10	7.99	21.5	12360		1187	1412		5700	2742	0.67	8.697	0.799	0.09
28/10-3/11	7.96	21	8547	2340	1257	1439	2610	5350	2374	0.77			
11/11-17/11	7.89	21	7221		1386	1535			2012	0.88			

C3

Date	pH	conductivity (mS/m)	COD (mg O ₂ /l)	BOD (mg O ₂ /l)	NH ₄ ⁺ (mg N/l)	TKN (mg N/l)	TOC (mg C/l)	TC (mg C/l)	Cl- (mg/l)	L/S l/kg TS	TAC (mg CaCO ₃ /l)	FOS (mg HAc/l)	FOS/TAC
10/09/2014	6.66	39.2	66265	38520	2636	3273	19380	19380	4143	0.03	8.272	8.06	0.97
11/09-15/09	6.67	37.5	82674		2662	3520		19080	3953	0.08	8.541		
16/09-22/09	7.41	37.6	68434		2638	3232	18540	18540	4310	0.17	8.93	7.549	0.85
23/09-29/10	7.63	34.8	56573		2148	2293		15180	4206	0.25	8.477	6.241	0.74
30/09-6/10	7.66	28.5	35691		1518	1884	8740	11820	3476	0.33	6.789	4.219	0.62
07/10-13/10	7.78	23.5	25228		1076	1347		8150	3019	0.42	6.506	2.733	0.42
14/10-20/10	7.86	21.3	17459		714	1145	4340	4480	2650	0.51	6.64	1.868	0.28
21/10-27/10	7.81	19.9	13280		890	1093		4930	2283	0.6	7.114	1.126	0.16
28/10-3/11	7.79	19	9900	5050	943	1109	3080	5330	2043	0.68			
11/11-17/11	7.77	16.7	6200		878	1028			1545	0.78			

C4

Date	pH	conductivity (mS/m)	COD (mg O ₂ /l)	BOD (mg O ₂ /l)	NH ₄ ⁺ (mg N/l)	TKN (mg N/l)	TOC (mg C/l)	TC (mg C/l)	Cl- (mg/l)	L/S l/kg TS	TAC (mg CaCO ₃ /l)	FOS (mg HAc/l)	FOS/TAC
10/09/2014	6.88	34.7	61906	35778	2368	2908	17860	20140	3836	0.05	7.605	6.922	0.91
11/09-15/09	8.01	34	59810		2260	2800		18444	3734	0.07			
16/09-22/09	8.64	27	32593		1534	1977	8880	11660	3510	0.15	7.02	3.247	0.46
23/09-29/10	8.47	23.8	25524		1083	1408		8393	3351	0.25			
30/09-6/10	8.16	21.5	16559		906	1186	4120	5780	3129	0.33	6.682	1.405	0.21
07/10-13/10	8.2	20.9	12137		995	1224		5075	3063	0.42			
14/10-20/10	8.38	21.3	10892		962	1340	2440	4370	2731	0.51	8.507	0.727	0.09
21/10-27/10	8.34	21.4	8440		1157	1387		4259	2686	0.61			
28/10-3/11	7.96	19.5	6995	1204	1003	1160	2270	4160	2411	0.7			
11/11-17/11	7.96	22.4	5962		1291	1406			2049	0.77			

C5

Date	pH	conductivity (mS/m)	COD (mg O ₂ /l)	BOD (mg O ₂ /l)	NH ₄ ⁺ (mg N/l)	TKN (mg N/l)	TOC (mg C/l)	TC (mg C/l)	Cl- (mg/l)	L/S l/kg TS	TAC (mg CaCO ₃ /l)	FOS (mg HAc/l)	FOS/TAC
10/09/2014	7.68	34.1	52441	25861	2200	2668	14640	15920	3953	0.03	8.629	5.962	0.69
11/09-15/09	8	36.5	58388		2428	2933		13212	4040	0.08			
16/09-22/09	8.61	27.3	31667		1447	1859	8020	9420	3741	0.15	7.378	3.204	0.43
23/09-29/10	8.11	23.8	23761		1095	1329		7265	3092	0.23			
30/09-6/10	8.14	21.1	15331		978	1236	3520	5110	2804	0.31	6.814	1.425	0.21
07/10-13/10	8.13	18.7	10127		859	1095		4160	2412	0.4			
14/10-20/10	8.27	17.8	9940		728	1034	1690	3210	2237	0.49	6.857	0.594	0.09
21/10-27/10	8.15	17.8	6895		868	1030		3655	2198	0.59			
28/10-3/11	7.96	19.2	6875	1591	995	1145	2150	4100	2311	0.69			
11/11-17/11	7.74	16.2	6189		706	827			1846	0.79			

C6

Date	pH	conductivity (mS/m)	COD (mg O ₂ /l)	BOD (mg O ₂ /l)	NH ₄ ⁺ (mg N/l)	TKN (mg N/l)	TOC (mg C/l)	TC (mg C/l)	Cl- (mg/l)	L/S l/kg TS	TAC (mg CaCO ₃ /l)	FOS (mg HAc/l)	FOS/TAC
10/09/2014	7.62	28	37808	15903	1680	2107	9000	11840	3353	0.06	7.262	3.904	0.54
11/09-15/09	8.34	28	34038		1672	2018		9673	3339	0.1			
16/09-22/09	8.67	20.6	18385		1007	1317	3900	5340	3012	0.18	6.046	1.431	0.24
23/09-29/10	8.39	18	11414		830	983		4104	2689	0.27			
30/09-6/10	8.17	17.8	8915		784	947	1870	3280	2825	0.33	6.087	0.578	0.09
07/10-13/10	8.27	15.6	7754		607	813		2983	2216	0.4			
14/10-20/10	8.1	14.7	7053		433	675	1300	2600	2167	0.49	4.848	0.506	0.1
21/10-27/10	8.33	12.8	4932		543	643		2440	1563	0.57			
28/10-3/11	7.84	11.8	3349	199	502	585	980	2240	1452	0.67			
11/11-17/11	7.56	10.7	2128		447	515			1186	0.76			

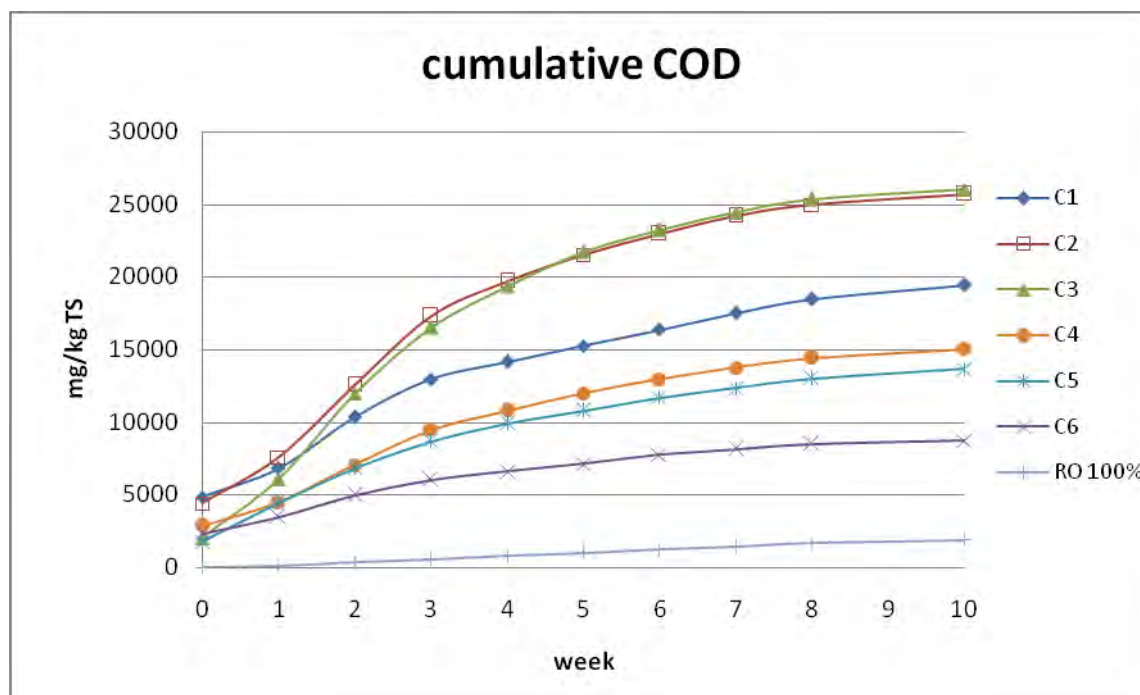


Fig. 1: Cumulative COD trend. Are reported the outputs of the leachate columns in terms of COD. Moreover is reported the curve concerning the COD introduced with the RO concentrate. In particular has been considered the case in which is injected 100% RO concentrate.

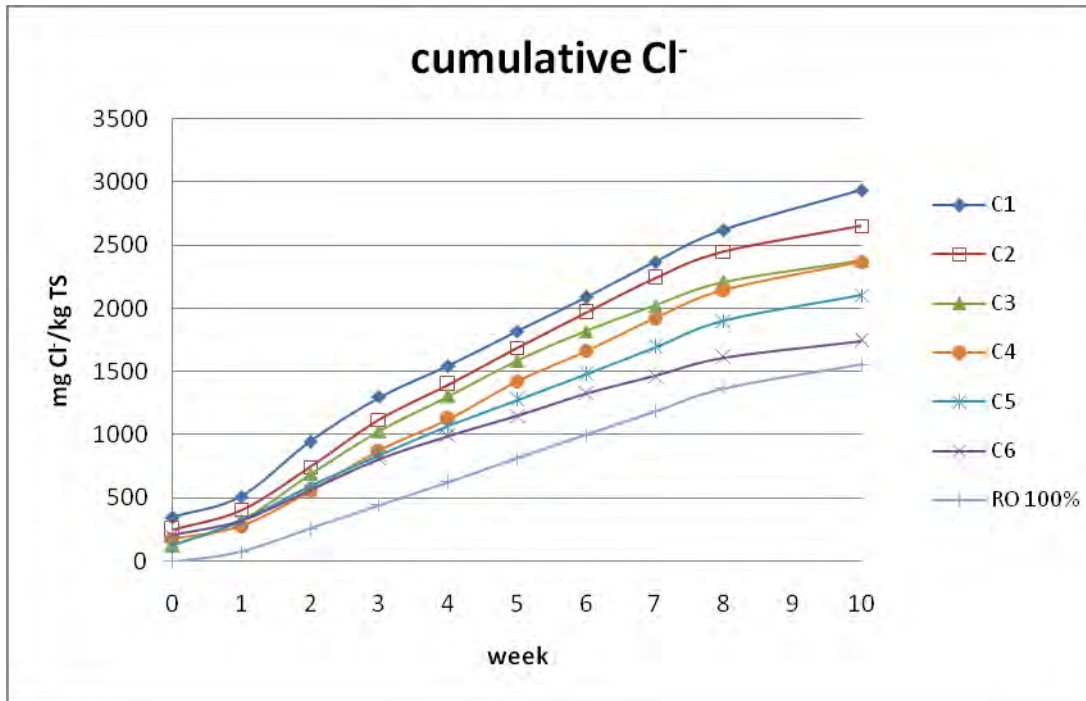


Fig. 2: Cumulative Cl⁻ trend. Are reported the outputs of the leachate columns in terms of Cl⁻. Moreover is reported the curve concerning the Cl⁻ introduced with the RO concentrate. In particular has been considered the case in which is injected 100% RO concentrate.

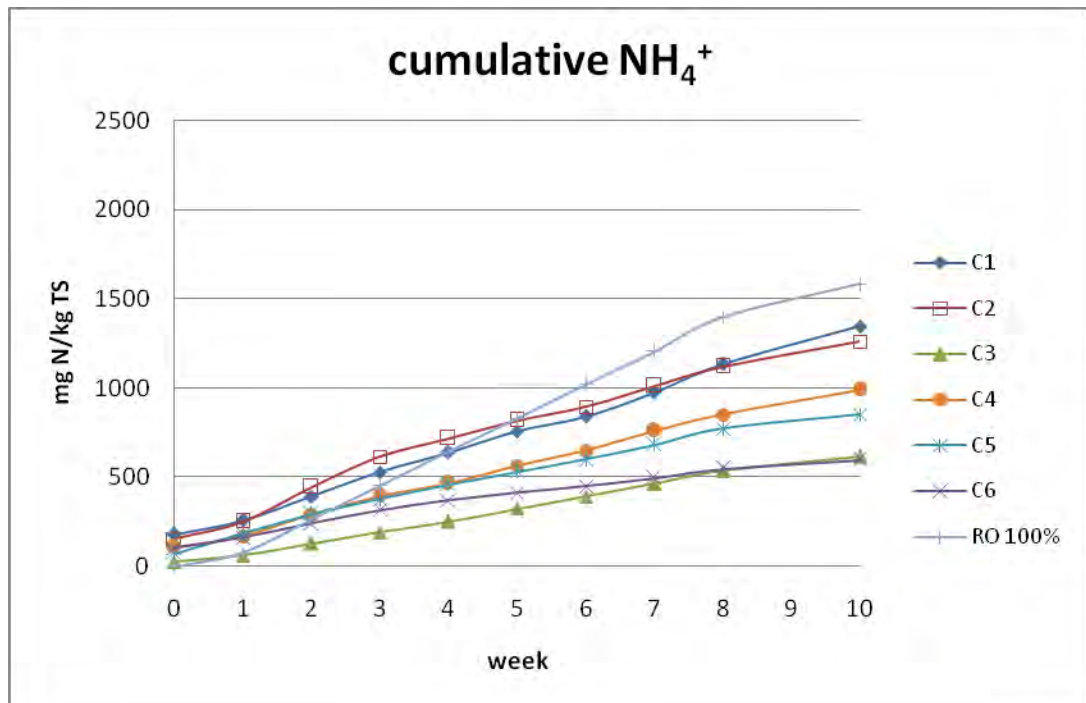


Fig. 3: Cumulative ammonia trend. Are reported the outputs of the leachate columns in terms of NH₄⁺-N. Moreover is reported the curve concerning the NH₄⁺-N introduced with the RO concentrate. In particular has been considered the case in which is injected 100% RO concentrate.

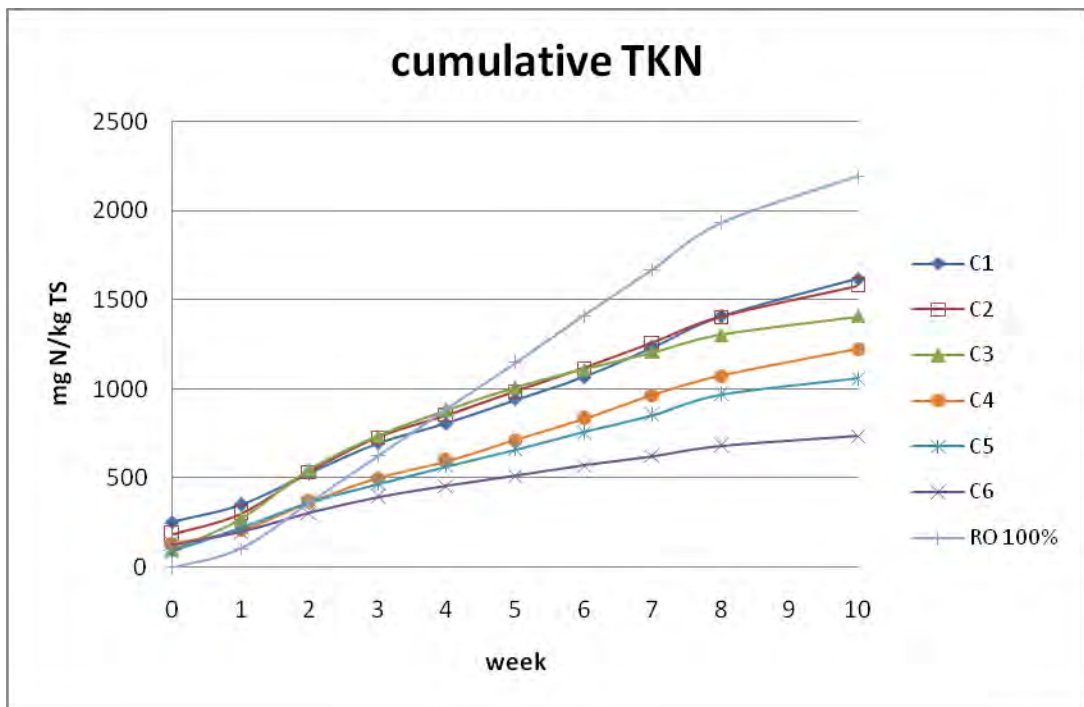


Fig. 4: Cumulative TKN trend. Are reported the outputs of the leachate columns in terms of nitrogen.. Moreover is reported the curve concerning the TKN introduced with the RO concentrate. In particular has been considered the case in which is injected 100% RO concentrate.

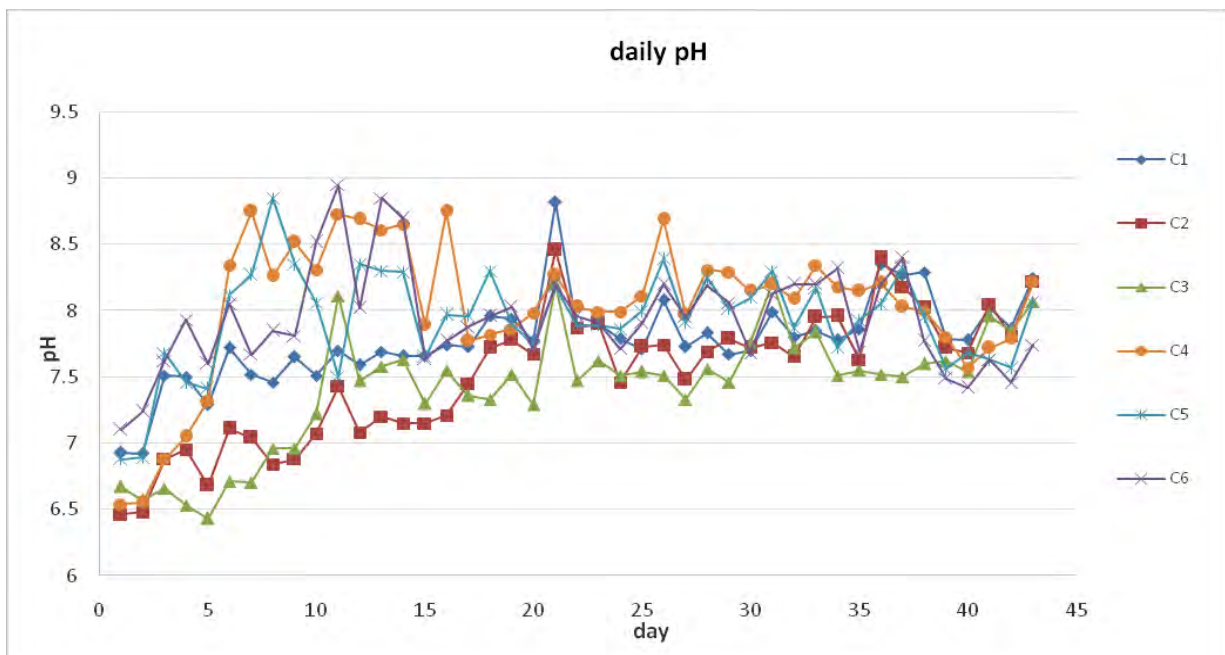


Fig. 5: Daily pH

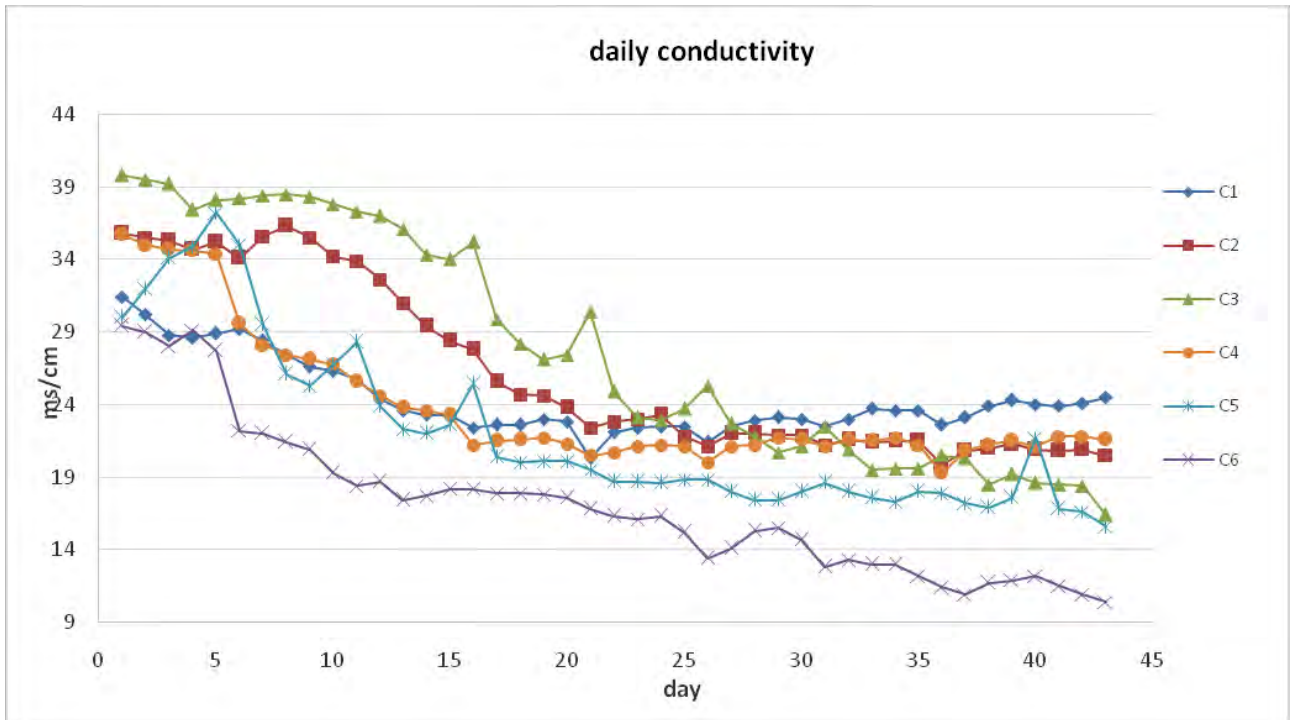


Fig:6 Daily conductivity

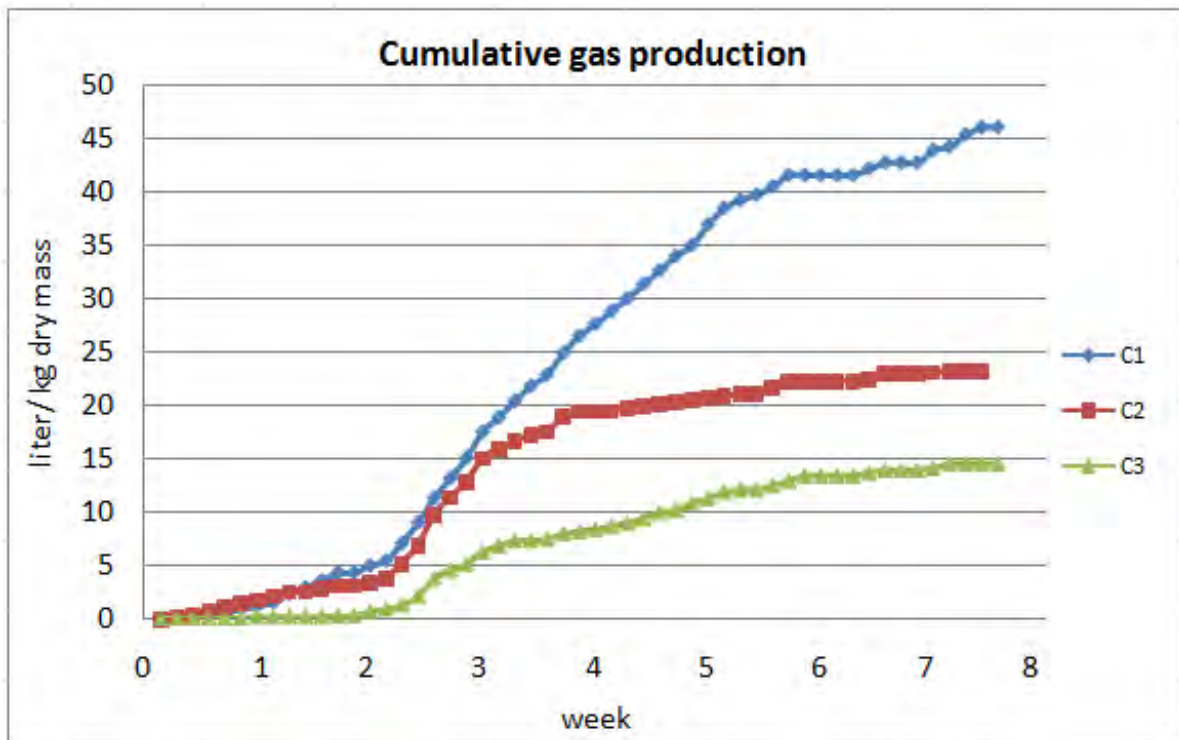


Fig. 7: Cumulative biogas production. The graph show the trends of the biogas produced by anaerobic columns per kg of dry mass

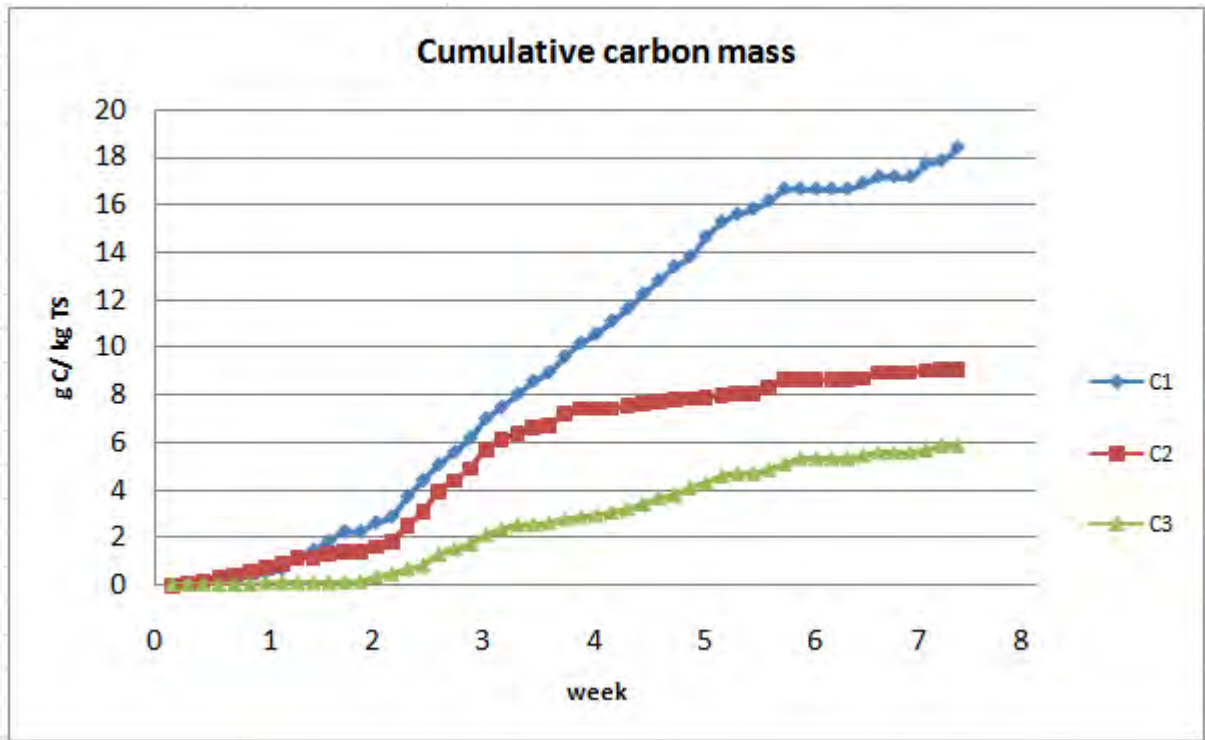


Fig. 8: Cumulative carbon removal. The graph shows the cumulative grams of carbon removed with the biogas.

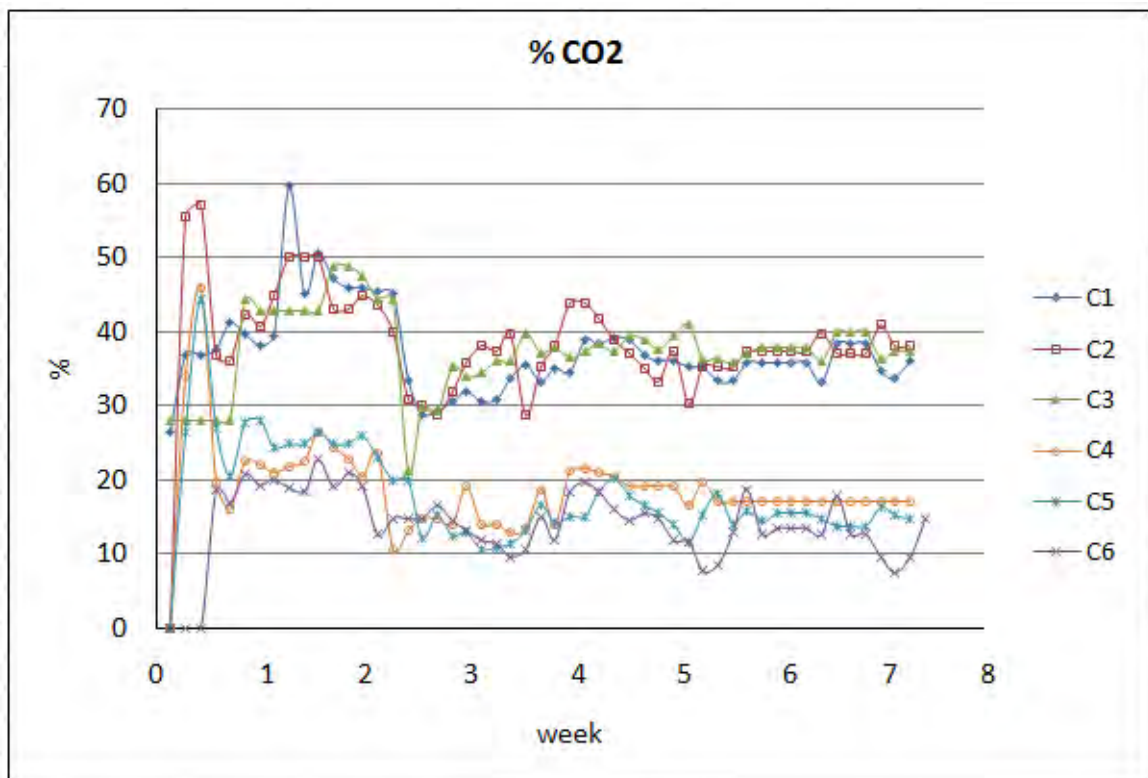


Fig. 9: Carbon dioxide percentage. It reports the fluctuation of the carbon dioxide percentage in the biogas.

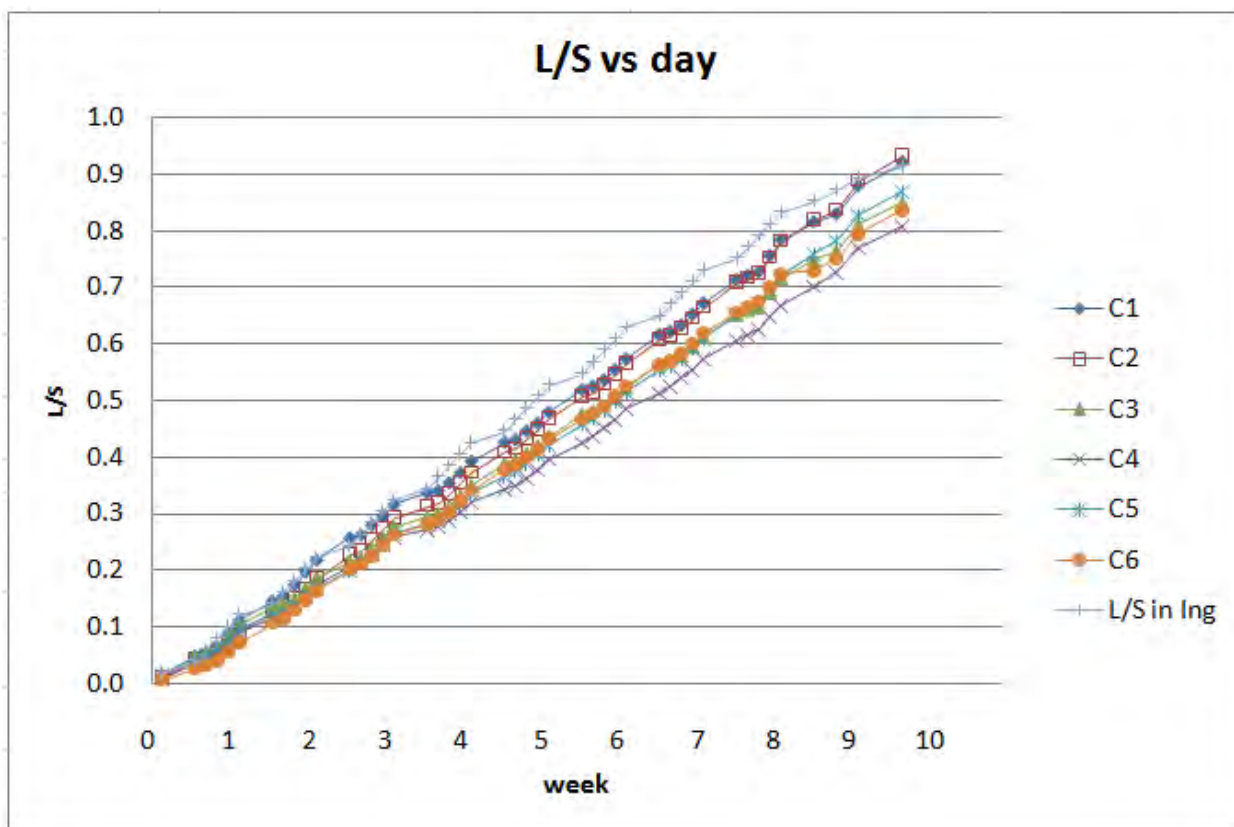


Fig. 10: Daily leachate trend. The graph shows the daily leachate collected express in function of the L/S ratio. Is reported moreover the trend of the input volume.

Tab. 2.: Leachate daily production. It shows the daily amount of leachate extracted from each column.

	Leachate daily production					
	C1 (ml)	C2 (ml)	C3 (ml)	C4 (ml)	C5 (ml)	C6 (ml)
12/09/2014	115	90	160	70	150	80
15/09/2014	365	320	320	200	305	260
16/09/2014	65	45	50	40	55	80
17/09/2014	120	80	95	95	120	140
18/09/2014	230	170	190	155	140	170
19/09/2014	210	200	200	160	180	160
22/09/2014	340	330	315	330	245	245
23/09/2014	90	65	60	80	10	90
24/09/2014	190	165	95	150	150	150
25/09/2014	225	180	170	180	160	170
26/09/2014	205	192	190	160	135	160
29/09/2014	385	400	280	370	310	330
30/09/2014	50	75	60	80	165	75

01/10/2014	180	190	185	152	130	130
02/10/2014	150	185	175	190	192	165
03/10/2014	200	200	180	180	160	140
06/10/2014	200	200	180	180	160	140
07/10/2014	40	58	50	70	80	50
08/10/2014	140	155	142	140	132	110
09/10/2014	175	180	170	200	160	142
10/10/2014	200	190	180	170	192	160
13/10/2014	330	350	380	380	280	240
14/10/2014	45	62	58	67	78	60
15/10/2014	150	186	124	137	137	135
16/10/2014	135	145	126	148	170	135
17/10/2014	190	200	160	175	150	187
20/10/2014	390	391	395	348	372	290
21/10/2014	60	60	55	87	95	110
22/10/2014	112	137	87	137	150	150
23/10/2014	175	178	150	162	150	148
24/10/2014	192	185	162	187	175	175
27/10/2014	415	425	420	370	370	280
28/10/2014	58	62	68	60	75	114
29/10/2014	108	120	65	125	124	150
30/10/2014	190	187	162	175	174	132
31/10/2014	196	187	175	195	174	198
03/11/2014	410	440	390	350	425	322
04/11/2014	72	75	75	100	100	100
05/11/2014	62	76	50	100	102	95
06/11/2014	280	281	250	235	235	208
07/11/2014	280	281	250	235	235	208
10/11/2014	310	370	325	50	370	330
12/11/2014	130	178	151	215	240	230
14/11/2014	490	510	461	430	455	440
18/11/2014	410	440	390	420	402	375
21/11/2014	140	140	132	140	135	120

Tab. 3:Leachate weekly production. It shows the amount of leachate extracted weekly from each column

	Weekly output					
	C1 (ml)	C2 (ml)	C3 (ml)	C6 (ml)	C5 (ml)	C4 (ml)
10/09/2014	1100	625	300	600	325	450
11/09-15/09	480	410	480	340	455	270
16/09-22/09	965	825	850	795	740	780
23/09-29/10	1095	1002	795	900	765	940
30/09-6/10	780	850	780	650	807	782

07/10-13/10	885	933	922	702	844	960
14/10-20/10	910	984	863	807	907	875
21/10-27/10	954	985	874	863	940	943
28/10-3/11	962	996	860	916	972	905
4/11-10/11	1004	1083	950	941	1042	720
12/11-18/11	1030	1128	1002	1045	1097	1065

2. Annex 2

2.1 Analytical Methodology

2.1.1 Analysis on Liquids

For all the leachate analysis are necessary 500 ml of liquid, 250 (more or less) for analytical tests and 250 as stock; the samples are stored in fridge for all time. The bottle is made of plastic and it has the same capacity of the liquid taken, to avoid air presence in headspace. Italian and European law certifies all the analytical procedures used.

pH: IRSA-CNR 29/2003, Vol1, n.2060. The test is carried on immediately after the sampling because requires environment temperature to be precise and because can be performed very fast. It consist in a probe input that gives immediately the pH measure.

Conducibility: IRSA-CNR 29/2003, Vol1, n.2030. Conducibility measurement is very similar to pH one and generally it is made in the same time. The analysis are made with a probe.

Total Organic Carbon (TOC): IRSA-CNR 29/2003, Vol2, n.5040. TOC is measured with the “TOC-V CSN” analytical equipment that gives directly the concentration value.

Ammonia (NH₃, titration): IRSA-CNR 29/2003, Vol2, n.4030 C. Ammonia concentration is evaluateddistilling a note volume of sample with NaOH addition. The condensation liquid is collected with boric acid and titrate with sulphuric acid. The concentration can be evaluate with a stoichiometric formula, starting from the sulphuric acid consumption.

Total Kjeldahl Nitrogen (TKN): IRSA-CNR 29/2003, Vol2, n.5030. The procedure is the same as for ammonia except that, before distillation, a digestion in acid environment is necessary, with the addition on kjeldahl tabs.

Nitrates (NO₃⁻): IRSA-CNR 29/2003, Vol2, n.4040 A1. The procedure starts with the addition of Na salicylate to the sample and with the drying in stove of the sample. After that, the sample is recover with acid, a base solution is added and the nitrates value is read on a spectrophotometer.

Biological Oxygen Demand(BOD₅):IRSA-CNR 29/2003, Vol2, n.5120 B2. The test is a batch reactor test long for five days after which the oxygen consumption is read.

Chemical Oxygen Demand (COD): IRSA-CNR 29/2003, Vol2, n.5130. COD test consist in an acid digestion (150°C for 120 minutes) with great quantities of sulphuric acid and potassium dichromate. After that the solution is titrate with Mohr salt that gives the chemical consumption of oxygen.

Chloride (Cl⁻): IRSA-CNR 29/2003, Vol2, n.4090 A1. Test is a titration with argent nitrate 0,1 molar.

2.1.2 Analysis on Solids

Solids samples are stored in fringe, in large glass containers, before the milling procedure. After that they are transfer in smaller plastic bottles to avoid air in headspace. The quantity sampled is one kilo more or less, with a volume of 2 liters.

Total Solids (TS) IRSA-CNR Q. 64/84, Vol2, n.2. A fix quantity of milled sample is weighted and dried in hoven for 12 hours. This procedure avoids the presence of water and allows the evaluation of the Total Solids in percentage respect to initial mass.

Total Volatile Solids (TVS) IRSA-CNR Q. 64/84, Vol2, n.2. The same sample coming out form TS analysis can be used. The procedure requires the burning in Moffola at the temperature of 550 °C for 3 hours. The effect is the consumption of everything organic is present in the sample. The residues are weighted and the TVS are the difference between initial TS and final inorganic residues remaining after the Moffola treatment.

Total Organic Carbon (TOC): UNI-EN 13137. The test is carried on with the same equipment of liquid TOC analysis: “TOC-V CSN”.

Chloride (Cl⁻): IRSA-CNR 29/2003, Vol2, n.4090 A1. The procedure is the same of the liquid sample, only is necessary weight a certain quantity of sample.

Total Kjeldahl Nitrogen (TKN): IRSA-CNR Q. 64/85, Vol3, n.6 mod. The procedure is the same of the liquid sample, only is necessary weight a certain quantity of sample and be more careful about the digestion.

Respirometric Index ANPA 3/2001 n.12.1.2.3. Is made with the “SAPROMAT” equipment that is a semi-dynamic test of oxygen consumption under controlled conditions. The test is perform in 4 days and in 7 days, the oxygen consumption can be visualize even continuously.

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