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Analysis of the energetic potential generable from an hybrid bioreactor landfill for waste organic fraction

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Abstract

The analysis of the amount of landfill gas generable from a full scale hybrid bioreactor landfill was investigated. The waste disposed in the landfill biocells was constituted by the waste organic fraction (WOF) arising from the mechanical pre-treatment of the residual municipal solid waste. The average humidity of the WOF was of about 40% by weight on wet basis whereas the volatile solids (VS) where about 50% by weight on total solids. The average total organic carbon concentration was of about 20% by weight of TS. The landfill gas generation potential of WOF was investigate by a standardized anaerobic test shows an average value of about 180 NL/kgVS. The construction of two full scale hybrid bioreactor landfill biocells was followed and the evolution of the composition of the landfill gas generated investigated. Results shows that in about 12 weeks the gas generated shows a methane concentration that rise rapidly from about 20% by vol. up to 55-60% by vol. In about 4 month of collection for energy recovery the amount of landfill gas generated results of about 36 Nm^3/tonne significantly higher than the one detected for other traditional landfills.

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Keywords: Aerobic treatment, Economic analysis, Electrical energy, Exergetic analysis, Organic Waste;

1. Introduction

The WOF contained in the residual MSW needs to be adequately stabilized for reducing its biological reactivity (Binner and Zhac, 1999; Di Maria et al., 2014) before being disposed of. In fact, spontaneous biodegradation processes occurring in landfill leads to the production of a huge amount of GHG as methane and di-nitrogen oxide with a global warming potential respectively of 21 and 320 times higher than carbon dioxide (Desideri et al., 2003; Di Maria et al., 2013; EEA, 2011). A suitable solution able to satisfy this aim is represented by incineration even if it results quite costly and not sufficiently widespread in all the EU areas. An alternative solution able to reduce the residual biological reactivity of the WOF is represented by MBT (Di Maria, 2012). MBT consist of a combination of mechanical, physical and biological treatment aimed reduce the mass and the biological reactivity before final disposal in landfill.

By the mechanical and physical treatment sections the MBT extracts from MSW a further fraction of recyclable and recoverable materials separating also the WOF that is conveyed to the biological section. The biological section is usually based on aerobic biological processes for achieving an adequate level of stabilization of the WOF and requires a significant amount of electrical energy mainly for supplying the necessary process air, about 30-40kWh per each tonne of WOF (Di Maria, 2012).

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Anyway several analysis shows that the aerobic treatment generates also a not negligible amount of VOC and di-nitrogen oxide affecting in a relevant manner environmental impact arising from the treatment of the single tonne of WOF (Valerio, 2010).

Di Maria et al. (2013) and Di Maria and Micale (2014) demonstrate by an LCA approach that the environmental impact of MSW management with MBT results higher than the management by landfill with energy recovery. In fact the biological anaerobic degradation of WOF in traditional landfill leads to the generation of a LFG that results compose largely of methane, from 45 up to 65 % by volume (Desideri et al., 2003), that can be exploited as renewable fuel for the generation of electrical energy. This leads to relevant environmental benefits in particular for that countries, as Italy, which exploits a large amount of fossil fuels.

These results suggested to manage the WOF arising from MBT treatment of MSW by an alternative landfill concept able to match the necessary biological reactivity reduction with the advantage represented by the energy recovery.

This goal can be achieved by the HBL. In HBL the WOF undergoes to sequential aerobic and anaerobic phases able to enhance both the micro-organism biological activity and the amount and quality of the generated LFG. Further the WOF humidity level is controlled by the practice of leachate recirculation. If properly managed HBL can lead to the recovery of a larger amount of LFG in narrowed period if compared to other traditional landfills.

In the present study the preliminary results concerning the management of two full scale pilot HBL biocells are presented. Particular attention was focused on the evaluation of the amount of LFG collectable and on its quality in terms of methane concentration.

Nomenclature

GHG	Greenhouse Gas
GS	Gas Sum anaerobic test
HBL	Hybrid Bioreactor Landfill
LFG	Landfill Gas
MBT	Mechanical Biological Treatment
MSW	Municipal Solid Waste
TN	Total Nitrogen
TOC	Total Organic Carbon
TS	Total Solid
VOC	Volatile Organic Compounds
VS	Volatile Solids
WOF	Waste Organic Fraction

2. Material and Methods

2.1 HBL biocells

The MSW is composed by different materials as plastics, metals, textile, paper and cardboard and the organic fraction (*i.e.* WOF). The extraction of the WOF from the MSW is usually performed by the aid of specific facilities.

In this study, the WOF disposed in the HBL biocell arises from the mechanical selection of the residual MSW performed in an existing facility (Fig. 1). This facility consist of a combination of mechanical and physical devices able to separate and extract from the MSW different components. The MSW is firstly loaded into a bag opener and successively is conveyed to a drum sieve with holes of 110mm diameter. The waste fraction passing through the holes represents the WOF whereas the oversize fraction results composed mainly by the high calorific component as plastics, paper, textile. A metal extraction is also performed both on the WOF and on the oversize fraction by magnets and eddy current equipment.

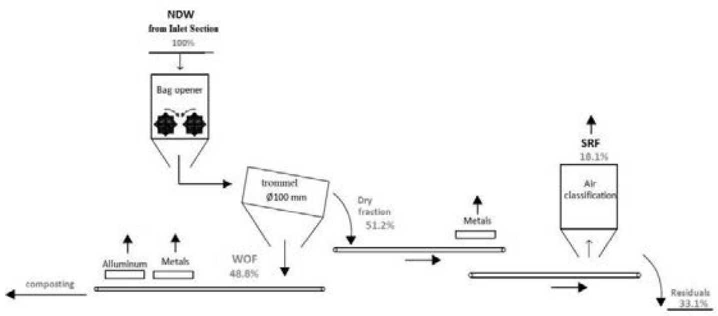

Fig. 1. Mechanical and physical sorting facility scheme.

The single HBL biocell has mean dimension of 55m large, 6 m height and 15m width (Fig. 2). Each biocell was equipped by 3 appositely designed wells able to enhance air circulation inside the disposed waste, during the aerobic phase, and to allow an efficient LFG collection, during the anaerobic phase. Wells diameter was of about 1m and the were positioned on the mean line of the cell with a constant center to center distance. WOF was disposed in each biocell by successive layers of about 0.5 m height until the maximum height of 6 m was achieved.

Once the biocell was completed a pipe network was implemented on biocell top for leachate recirculation aim. The average leachate rate recirculated was of about $2m^3$/h.

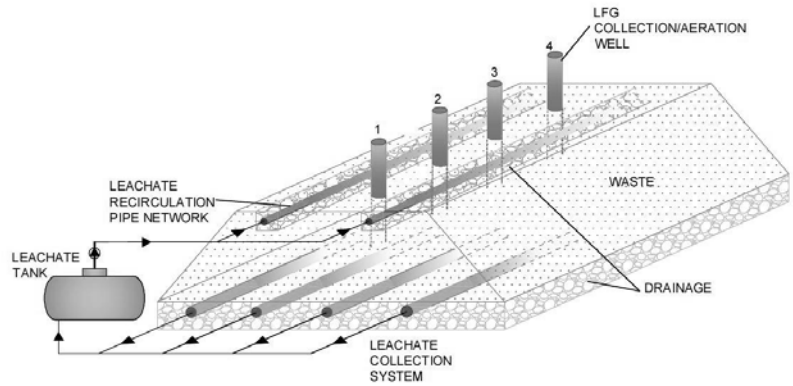

Fig. 2. HBL biocell scheme.

2.2Experimental analysis

About two sample per week of WOF were analyzed before being disposed in the biocell. The sample humidity (% by weight on wet basis) and TS (% by weight on wet basis) were measured by weight loss after heating for 24h at 378K in stove. VS (% by weight of TS) concentration was determined by measuring the weight loss after burning in furnace at 623K for 24h.TOC (%by weight of TS) was measured according to Nelson and Sommers (1996)whereas TN (% by weight of TS) content was measured by the Khjeldahl method.

On the same samples a lab scale anaerobic test was performed according with the GS proposed by Binner and Zach (1999) for evaluating the gas generation potential of the WOF. The WOF sample was wet to holding capacity by immersing it for 12h in deionized water and then draining it for 6h. In each GS anaerobic test 1 kg of saturated WOF sample was utilized and the reactors were temperature was maintained at 308K (±2K) in climate chamber. Gas generation was expressed in NL per kg of VS and measured by a water displacement system.

During the cell construction the LFG generated by the disposed WOF was measured by electrochemical sensors for H_2S and O_2 concentration (% by volume) (±2%) and by infrared sensors for CH_4 and CO_2 concentration (% by volume) (±1%). After cell closure the wells head were collected to the energy recovery system, based on internal combustion engines, and the mass flow rate was continuously measured by a thermal flowmeterProline t-mass 65 Endress+Hauser. Every day the LFG composition was also measured.

Table 1.Average physical and chemical characteristics of WOF sample and relative GS value.

Sample n°	**TS % wet basis**	**VS % of TS**	**TOC % TS**	**GS NL/kgVS**
1	61.44	55.90	22.8	30.68[a]
2	59.93	45.84	19.94	30.17[a]
3	59.31	42.83	15.59	177.70
4	58.42	59.06	18.55	172.87
5	59.80	44.76	24.50	202.25

Legend: a=test not completed yet.

3. Results and discussion

3.1 Energetic analysis

Table 1 reports the average values measured for the WOF sample withdraw before being disposed in the HBL biocell. TS ranges from about 62 % to about 58 % by weight n wet basis. VS shows a concentration ranging from about 43% TS to about 59 % TSwhereas TOC ranges from about 16% TS to about 25% TS

The amount of gas generated ranges from 170 NL/kgVS to about 200 NL/kgVS resulting in the range of the values proposed by other authors for similar organic waste (Binner and Zach, 1999; Di Maria et al., 2013).

The cell construction lasts for about 13/14weeks during which the LFG composition shows a quite rapid increase in the methane concentration as the biocell height increase (Tab. 2). Methane concentration achieves in about 13 weeks a values ranging from 43 to 55 % by vol. respectively for wells from 3 to 1.

Table 2. LFG composition during the cells construction and afterclosure at each wellhead.

Week n°	**Well n°/Cell n°**	**CH_4**	**CO_2**	**H_2S**	**O_2**
		% by volume			
5	1/1	22.8	61.4	691	0.1
5	2/1	35.8	55.8	382	0.1
5	3/1	20.8	61.6	596	0.1
9	1/1	50.4	46.8	1326	0.1
9	2/1	34.3	58.3	376	0.1
9	3/1	45.3	54.7	758	0.1
	Cell n°1 closure				
13	1/1	55.6	44.4	660	0.2
13	2/1	49.5	47.2	417	0.1
13	3/1	42.8	46.8	<	0.1
15	1/1	59.0	41.8	738	0.1
15	2/1	55.1	44.7	351	0.1
15	3/1	45.4	46.3	884	0.1
23	1/1	60.3	40.2	558	0.1
23	2/1	55.6	44.9	300	0.1
23	3/1	50.2	48.6	<	0.1
	Cell n°2 closure				
44	1/1	57.3	43.4	372	0.1
44	2/1	51.8	40.4	239	0.5
44	3/1	48.3	37.8	92	1.8
44	1/2	62.5	38.1	220	0.3
44	2/2	63.9	36.2	622	0.1
44	3/2	60.1	40.2	395	0.1
44	4/2	58.3	42.0	271	0.4
52	1/1	55.9	42.1	222	0.2
52	2/1	53.6	41.2	325	0.1
52	3/1	53.2	40.5	253	1.2
52	1/2	60.1	40.1	60.1	0.2
52	2/2	62.2	38.6	125	0.2
52	3/2	60.1	40.1	247	0.1
52	4/2	58.6	41.5	129	0.1

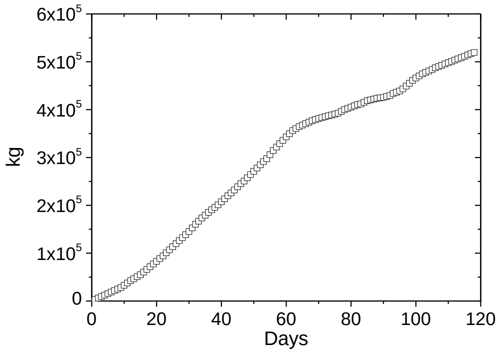

Fig. 3. Kg of LFG generated by the biocelle n°1 and 2.

After cells closure the seven wellhead were connected to the energy recovery system by a manifold on which was also positioned a mass flow meter (kg/h). The amount of LFG generated in the first 120 days collection results of about 500.000 kg. Considering that the amount of WOF disposed in the two HBL cells was about 11,470tonnes this means that per each tonne the amount of LFG produced results of 43.6 kg/tonne Corresponding to about 36 Nm^3/tonne. Comparing this value with the one detected by other authors for traditional landfills (Tab. 3). Amini et al. (2013) after an investigation period of 16 years detected for several landfills an average LFG generation ranging from 93 Nm^3/tonne to 140 Nm^3/tonne of MSW. This corresponds to an average yearly gas generation of about 6-9 Nm^3/tonne. Heyer investigates the amount of LFG generate above a period of 3 years from MSW after MBT treatment. Results shows an average LFG generation from7 to 10 Nm^3/tonne of TS. De Gioannis et al report a LFg generation potential fo about 115 Nm^3/tonne for residual MSW whereas for the same waste type Di Maria et al 2013 detected a LFG generation potential of about 128 Nm^3/tonne of TS.

The results obtained in this study shows that the HBL for WOF was able to enhance the biodegradation process and consequently the amount of LFG generable in the same period. This aspect can lead to interesting energetic advantages due to the possibility of exploiting internal combustion engines for energy recovery with an higher efficiency if compared to other engines of lower size.

Table 3. Comparison of LFG generation reported in literature with the one detected in this study.

Landfilled waste	Period of investigation (year)	LFG generation	Reference
MSW	16	93-140 m^3/tonne	Amini et al. (2013)
MSW after MBT	3	20-30 m^3/tonne TS	Heyer et al. (2013)
MSW	-	115 Nm^3/tonne	De Gioannis et al. (2009)
MSW	-	128 Nm^3/tonne TS	Di Maria et al., 2013
WOF	0.25	36 Nm^3/tonne	This study

4. Conclusions

The Hybrid Bioreactor Landfill (HBL) represents a possible solution to manage the Wet Organic Fraction (WOF) through an alternative landfill concept that match the need of biological reactivity's reduction and the advantage of energy recovery. The features of the WOF withdrawn from an existing Mechanical Biological Treatment (MBT) facility are in line with the data proposed by other authors for similar organic waste and it present a significant biological activity. The data resulting from the monitoring activities of the two HBL biocells show a quite rapid increase in the methane concentration in the Landfill Gas (LFG) produced, as the biocells's height increases. The LFG's methane content justify the possibility of an energetic exploitation of the gas. The amount of LFG collected since the closure of the cells turns out to be higher if compared with the data referred to other traditional landfills. To manage the WOF with an HBL enhances the biodegradation processes occurring in the waste mass and consequently the amount of LFG generated in the short term period. This aspect can leads to interesting energetic advantages due to the possibility of an increase in the energy recovery's efficiency.

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