Simulation of the behavior of a refuse landfill on a laboratory scale

Joan Esteban Altabella[a.1], Francisco J. Colomer Mendoza[a.2], Antonio Gallardo Izquierdo[a.3],

[a] *INGRES, Ingeniería de Residuos, Department of Mechanical Engineering and Construction, Universitat Jaume I, 12071, Castellón, Spain.*

[1] altabell@uji.es , [2] fcolomer@uji.es, [3] gallardo@uji.es

Abstract: The characteristics and properties of waste in a landfill, and its evolution over time, are difficult to estimate because of the heterogeneity of materials, biomass degradation, density, cover material, and infiltration of water. In this work, a lysimeter was used to simulate how refuse from mechanical-biological treatment (MBT) plants evolved in a landfill over a 45-day period. Water was added as a way to imitate the effects produced during rainy seasons. Field capacity and changes in the physical and chemical properties (volatile solids, biomass, and heating value) were analyzed. The results of this research show that the percentage of biomass lowers, and the heating value increases, after bringing about infiltration and percolation of water in the waste mass. Therefore in order to stabilize waste in a landfill, employing irrigation or leachate recirculation could be advisable. As the heating value increases after percolation, it could also be a good idea to recover the fuel material after stabilization.

Keywords: *waste, refuse, landfill, leachate, lysimeter*

1. Introduction

In recent years, the waste-related goals of developed countries have focused on reducing the volume of waste and exploiting the resources contained in different waste types as much as possible. As a result of such policies, the amount of municipal solid waste (MSW) sent to landfills can be minimized. By means of Directive 2008/98/EC, the European Union fosters a waste hierarchy, defined as a priority order in waste prevention management legislations and policies, where the most preferred option should be prevention, followed by preparing for reuse, recycling, other recovery choices, with disposal being the least preferred option. Accordingly, as well as the policies that promote prevention and reuse, the other rules and regulations on waste currently in force foster a better exploitation of generated MSW; first by separating the collection systems of different materials (glass, paper, cardboard, used oils, packaging, biowaste, etc.) to recycle them; second, applying mixed waste treatment prior to landfill. Ultimately, MSW management strategies and challenges in adaptation are also rendered necessary for solid waste management, which are related mainly to waste treatment technologies (Pires et al., 2011). In recent years, the treatment trend for mixed waste in some EU countries like Spain is a mechanical-biological treatment (MBT), which stabilizes organic matter by a composting process. Applying this treatment allows recyclable materials to be recovered. However, a large portion of mixed waste ends up becoming refuse, and is therefore taken to landfills (de Araújo Morais et al., 2008; Gug et al., 2015). This portion of mixed and non recyclable waste is called refuse. Refuse from MBT plants has different characteristics from those of MSW because biodegradable, inert and recyclable fractions (plastics, paper-cardboard, metals, glass, etc.) have been removed.

There are many types of MBT plants. Some separate biomass from the rest which is then biostabilized. Others perform a biological treatment and the bulk waste is then separated into biostabilized material, recyclable materials and different sources of refuse. EU legislation has expected the MBT of MSW for several years. Pre-treatment benefits include reducing the pollutant load of the produced leachate, reducing the generated amount of landfill gas, less clogging of leachate drainage systems, improving waste settlement times, as well as a shorter timescale to waste stabilization (Robinson et al., 2005). Nevertheless, a high proportion of waste cannot be recovered (refuse). Such refuse from MBT plants represents about 65-75% of the volume of the initial MSW and is usually incinerated as a solid, which is recovered fuel or landfilled (Edo-Alcón et al., 2016; Gallardo et al., 2014; Montejo et al., 2011). In many countries, refuse is dumped in sanitary landfills.

Furthermore, the MBT process includes several refuse flows: refuse from the recovery stage (A), refuse from the biological stage (B), and refuse from refining pre-matured biowaste (C) (Fig. 1). Thus the behavior of refuse landfills usually differs from that of MSW landfills. Nevertheless, refuse usually contains large amounts of combustible material, such as plastic film, paper-cardboard, and textile, which could be a future source of fuel. The technique used to recover these materials is known as landfill mining (Krook el al., 2012).

It is also very important to control pollution from landfills since incorrect management can result in hazards for both the environment and human health. This control involves conducting extensive technical and scientific studies that enable the properties of the refuse in landfills to be known (field capacity), and the amount and the physical and chemical properties of leachates to be forecast according to climatic conditions.

Moisture strongly influences degradation times in sanitary landfills (Barlaz et al., 1990). Field capacity (FC) can vary depending on the density, age and composition of waste. FC determinations allow the volume of water retained in the waste mass to be estimated. Therefore, if the initial moisture of refuse is known and climatic conditions are simulated in a lysimeter, FC can be calculated after measuring the amount of generated leachate.

Very little research on refuse landfills has been conducted, although existing studies have been conducted with MSW (Orta de Velásquez et al., 2003; Uguccioni and Zeiss, 1997). The main goal of this paper is to, therefore, supply information from a laboratory-scale simulation of refuse in landfills, the results of which can be useful for landfills located in other countries. In this work, the behavior of the refuse from an MBT plant was studied on a laboratory scale by determining the FC and evolution of the biomass content under known conditions. Moreover, the lower heating value (LHV) of refuse and its variation over time provide information about the possibility of recovering refuse as a future fuel (landfill mining).

2. Methodology

Refuse was obtained from an MBT plant in east Spain. This plant produces 65000 t/year of refuse, which represents 73.27% of the MSW generated in the study area (Gallardo et al., 2014). The MSW is submitted to a biodrying process when it reaches the MBT plant.

As shown in Figure 1, the general flow of refuse is divided into three smaller flows with the following percentages: 44% from the refuse from the recyclable materials recovery process (Flow A: size > 80 mm); 42% from the refuse before the biostabilized material refining process (Flow B: size > 25 mm); 14% from the biostabilized material refining process (Flow C: size > 8 mm).

Fig. 1: Refuse classification according to size

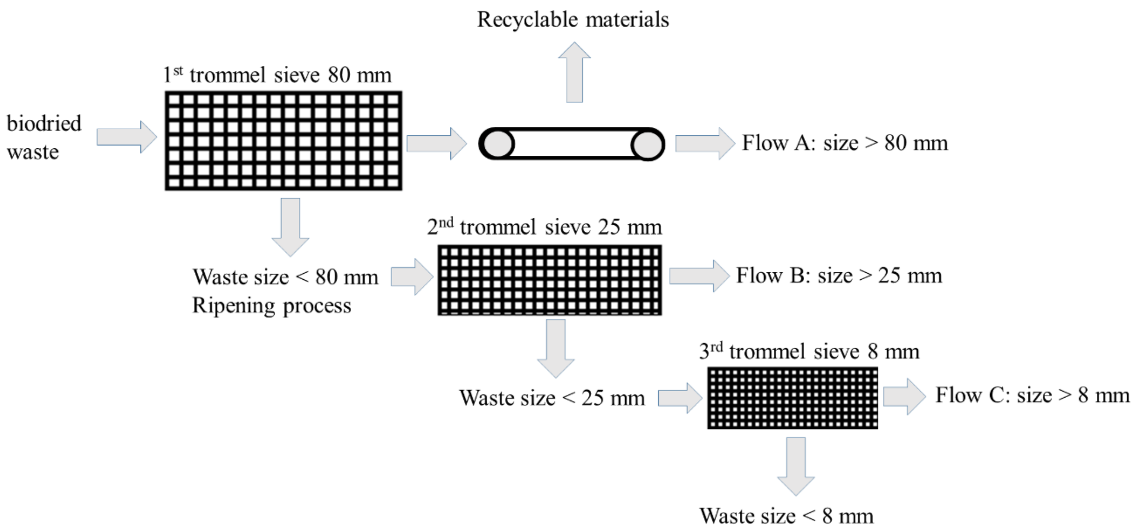
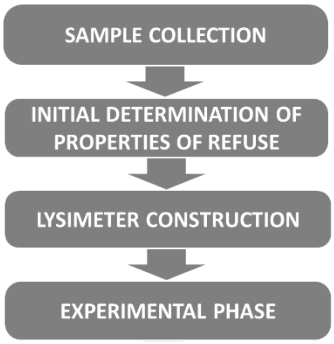


Figure 2 lists the methodology steps followed. The steps are further explained below.

Fig. 2: Summary of the steps followed in this work



2.1. Sample collection

The methodology for characterizing and sizing the sample by quartering applied in this work is described by the European Commission (2004). Following these indications, 1000 kg of refuse were collected *in situ* and a 25-kilogram sample was selected from this total amount. This procedure was applied in flows A, B and C, and samples were taken to the solid waste laboratory. Refuse (A, B and C) has to be milled to ensure that each piece is smaller than 70 mm (Stoltz et al., 2010).

2.2. Initial determination of refuse properties

In this experiment, three analyses were performed per parameter. First, moisture was determined by drying the material in an oven at 105°C (standard CEN/TS 15414-3 (2011)). Second, the composition of each flow was determined. To do so, three characterizations were made for flows A, B and C. The known proportions of flows A, B and C were then used to generate flow D, which represents the mean composition of the final refuse at the MBT plant. Table 1 shows the composition of flows A, B, C and D.

Table 1: Refuse characteristics

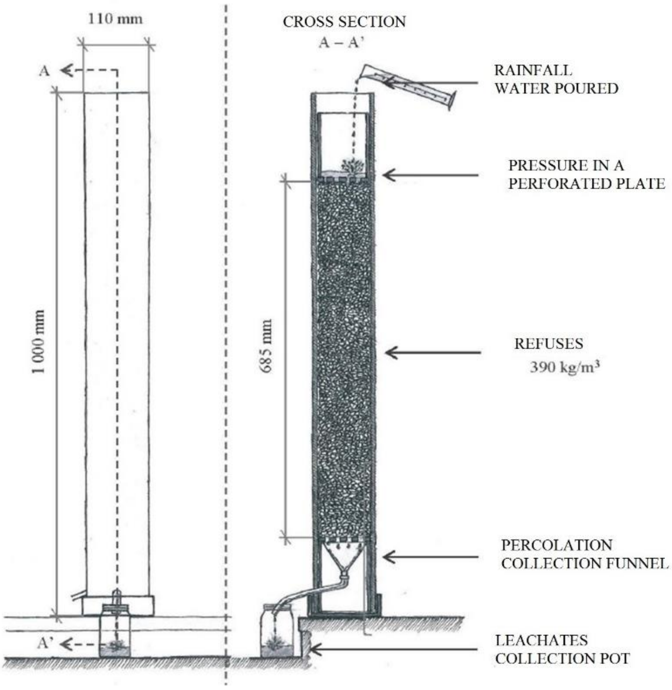
	Flows (%)			
	A	**B**	**C**	**D**
Proportion of flows	**44%**	**42%**	**14%**	**100%**
Plastic	28.95	24.44	33.69	28.31
Paper and cardboard	27.58	18.54	21.25	23.92
Textile	25.92	1.24	13.69	16.68
Glass	0.27	12.89	2.64	4.41
Inert	0.95	10.60	3.40	4.21
Organic waste	6.92	23.08	17.98	13.42
Wood	3.44	2.99	2.89	3.22
Metals	4.21	2.08	3.24	3.42
Hazardous waste	0.00	0.05	0.00	0.01
Complex waste	0.36	0.17	0.75	0.36
Others	1.41	3.93	0.47	2.03

Volatile solids, the LHV and biomass contents were determined for each flow at the beginning of the experiment. The volatile solids content was determined following standard UNE-EN 15402:2011. The LHV was analyzed with an isoperibol calorimeter PARR model 1261 following standard CEN/TS 15400 (2006). Biomass content was determined following standard UNE-EN 15440:2011.

2.3. Lysimeter construction

This assay was conducted with a lysimeter (Fig. 3). It was constructed using a pipe whose diameter was 110 mm. A PVC base was placed inside to simulate the drainage layer that consisted of gravel. The base had a hole (10 mm diameter), and it was covered by a metallic mesh with a hole diameter of 1 mm, used as a coarse filter. The generated leachate was drained off into a plastic bottle at the bottom of the lysimeter.

Fig. 3: Scheme of the lysimeter



2.4. Experimental phase

The next step consisted in placing flow D inside the lysimeter. The weight of the mixed refuse inside the lysimeter was 2.64 kg. The sample was then compacted until a density of 390 kg/m^3 was reached, which represents the average initial density in a landfill (Aguilar, 2008; Dollar, 2005; Orta de Velásquez et al., 2003; Uguccioni and Zeiss, 1997; Zeiss and Uguccioni, 1994). The following step consisted in achieving FC in the refuse. The irrigation procedure was designed to be similar to the region’s rainfall: 1.00 L of distilled water was poured until the pores inside the waste were filled with liquid and the maximum water retention capacity was reached. These data can be used to calculate FC. This irrigation was performed 3 times within 24 h to avoid evaporation. The FC value was calculated by Equation 2:

$$FC = \frac{H_{R0} \cdot D_{R0} \cdot V_{R0} + (V_{I1} - V_{F1})}{(1 - H_{R0}) \cdot D_{R0} \cdot V_{R0}} \tag{2}$$

where FC is the field capacity of the refuse (kg$_{H2O}$/ kg$_{\text{dry refuse}}$); H$_{R0}$ is the moisture of the refuse mass; D$_{R0}$ is the initial density of the refuse mass (kg/m^3); V$_{R0}$ is the volume of the refuse inside the lysimeter (m^3); V$_{I1}$ is the volume of the water added in the lysimeter (L); V$_{F1}$ is the volume of the leachate collected 24 h after the first irrigation (L). The experiment lasted 45 days. While the experiment was running, the leachate that was collected, and pH, total solids, and conductivity were measured. The calendar of irrigations is shown in Table 2.

Table 2: Calendar of irrigations

day	0	1	7	16	21	23	27	36	45
Water poured (L)	1.000	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0

Finally after 45 days, the methodology described for the analyses and determinations was completed. Three analyses were performed for all four parameters (moisture, biomass, volatile solids and LHV).

3. Results and Discussion

3.1. Initial composition

The data on the composition of the three refuse flows are shown in Table 1, where we can observe that the highest fraction in all three flows is plastic since there a high proportion of plastic film is not recovered in MBT plants. Paper-cardboard comes next because this material is dirtied during the MBT process and cannot, therefore, be recovered. Textile is an important fraction, except in flow B, because the biggest elements (> 80 mm) come out of the first trommel and the smallest (< 25 mm) come out of the third trommel. Glass and inert waste come from flow B. Finally, the biodegradable fraction in flows B and C is slightly bigger because these flows come from the refined material after the composting process. Nevertheless, while the percentage of flow C is low, the percentage of the biodegradable fraction is only 13.42% in flow D.

In order to check whether the data from this experiment were comparable with other refuse cases, a comprehensive review of different experiences found in the bibliography from experiments done with different waste sorts was conducted. In this way, it was possible to establish whether the results from refuse were similar or not to MSW. The results are shown in Table 3. Based on this information, the averages and standard deviations were calculated per fraction.

Table 3: Refuse characteristics from different MBT plants (%)

(%)	organic waste	paper-cardboard	plastics	glass	textile	metals	others
Gallardo et al., 2014	16.8	32.2	22.2	1.1	7.9	4.4	15.4
Aranda Usón et al., 2012	21.9	25.5	19.2	12.1	7.3	1.5	12.5
Montejo et al., 2013	14.0	31.0	32.1	0.2	7.5	1.8	13.4
Grosso et al., 2016	24.8	18.0	35.1	0.8	7.4	5.8	8.1
BMLFUW, 2011	20.5	22.4	27.8	5.1	5.8	2.8	15.6
Sarc and Lorber, 2013	24.2	18.5	21.0	4.3	5.0	1.2	25.8
Ramos et al., 2016	15.3	48.5	16.7	3.3	4.3	0.8	11.1
Nithikul et al., 2011	9.6	9.9	41.1	0.8	4.3	1.2	33.1
Montejo et al., 2011	23.7	27.9	24.5	0.5	3.8	3.7	15.9
Marsh et al., 2007	2.1	35.1	23.2	0.9	14.0	2.8	21.9
Bessi et al., 2016 (a)	17.0	21.4	24.0	1.8	8.0	2.2	25.6
Bessi et al., 2016 (b)	29.1	16.2	15.0	3.4	17.5	2.6	16.2
AVERAGE	18.25	25.55	25.16	2.86	7.73	2.57	17.88
ST deviation	7.44	10.28	7.67	3.33	4.11	1.47	7.25
Flow D	13.42	23.92	28.31	4.41	16.68	3.42	9.84

According to the results in Table 3, which were obtained from the averages and standard deviations in different studies, the data for flow D are similar to the average data from the different MBT plants, except for the proportion of textile wastes, since textile and sewing sector is one of the main manufacturing sector in the region. This generates a considerable increase of this sort of wastes (IVACE, 2015). Thus, with caution, the results of this work could be applied to other facilities.

3.2. Initial moisture

The initial moisture of the sample collected from flow D of the MBT plant was 24% (Table 4). This result was similar (average: 22.12%; ST deviation: 3.69) to the figures offered by most other authors who have worked with this refuse sort: 17.8% (Papageorgiou et al., 2009), 22.07% (Montejo et al., 2011), 21.20% (Konstadinos et al., 2012), 25% (Di Lonardo et al., 2012), 18.31% (Di Lonardo et al., 2012), 28.4% (Rigamonti et al., 2012) and 22.06% (Montejo et al., 2015). Nevertheless, Rotter et al. (2012) and Nithikul et al. (2011) obtained lower values; 11% and 11.5%, respectively.

3.3. Field capacity

Following the above-described methodology, 24 h after the first irrigation the refuse in the lysimeter reached FC (Table 4).

Table 4: Field capacity results

		Units	Lysimeter
D_{R0}	Density of refuse inside	kg/m^3	390
H_{R0}	Initial moisture	%	24.00
V_{I1}	Initial volume of unfiltered water	L	1.00
V_{A1}	Volume of retained water	%	93.46
V_{P1}	Volume of percolated water	%	6.54
H_{R1}	Final moisture	%	50.22
FC	Field capacity	kg_{H2O}/kg_{dry}	1.02

In order to check whether the FC data from this experiment are comparable with other waste cases, a review was conducted (see the results in Table 5). Nevertheless, the found experiments were conducted using MSW, and none in the bibliography were seen to deal with refuse .

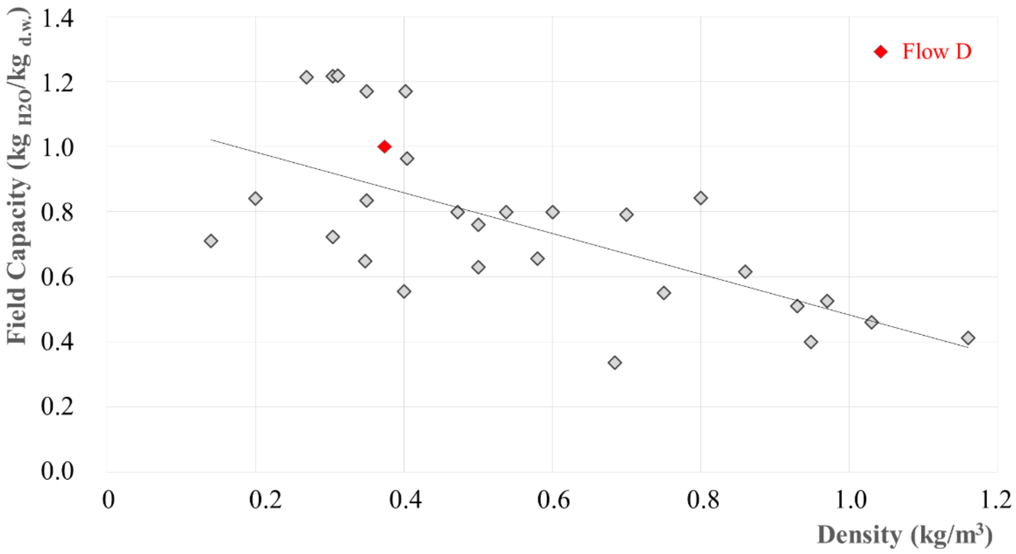
As we can see in Table 5, major differences were found between the FC values and the density in refuse, which are due to the degree of compaction, and above all to their composition. According to Wu et al. (2012) and Figure 4 below, the FC values can vary depending on the degrees of decomposition and compaction of waste. Orta de Velásquez et al. (2003) have shown that the time which elapses between the first irrigation and the beginning of percolation depends on the waste characteristics and presence of piping. Time can therefore range from a few minutes to several hours. In this work, percolation began 10 minutes after the first irrigation.

Table 5: Field capacity determined by different experiments

Authors	Density (kg/m^3)	Field capacity (kg_{H2O}/kg_{dry})
Data for flow D	390	1.02

Aguilar (2008)	269	1.213
	404	0.964
	472	0.799
	600	0.798
	700	0.791
	800	0.842
Dollar (2005)	304	0.722
	348	0.648
	948	0.400
	1030	0.460
Orta de Velásquez et al. (2003)	200	0.840
	350	1.170
	500	0.760
	750	0.550
Uguccioni and Zeiss (1997)	400	0.556
Zeiss and Uguccioni (1994)	140	0.710
Schroeder et al. (1994)	350	0.834
Sánchez Gómez (2000)	500	0.630
Zornberg et al. (1999)	860	0.616
	930	0.510
	970	0.526
	1160	0.412

Fig. 4: Relationship between field capacity and density



According to the data in Figure 4, a strong negative correlation was found between the two variables: field capacity – density (r = 0.828). Hence the linear regression line was obtained (Equation 3).

$$y =- 0.699x + 1.142 \qquad (3)$$

The data reported by Aguilar (2008) and Zornberg et al. (1999) were obtained from real landfills (in Mexico and California, respectively). The results of Sánchez Gómez (2000) were obtained from a pilot cell with a volume of 800 m^3, and the rest came from laboratory tests. The waste mass density in a landfill (real or simulated) varies from 200 to 1160 kg/m^3, depending on compaction, composition, etc. FC varies from 0.336 to 1213 kg_{H2O}/kg_{dry} and, therefore, the density and FC values shown in this work fall within the interval found in the literature. The flow D data are similar to the results offered by Aguilar (2008), which means that the flow D data could be extrapolated to waste characteristics in a landfill mass. Therefore, the FC of landfill refuse could be similar to the MSW in the landfill. This aspect could be important to calculate the leachate volume generated in refuse landfills.

3.4. Leachate characteristics

The leachate volume generated and its chemical properties are offered in Table 6, which shows the calendar of irrigation and the results of the leachate analyses. Percolation had finished after 42 days.

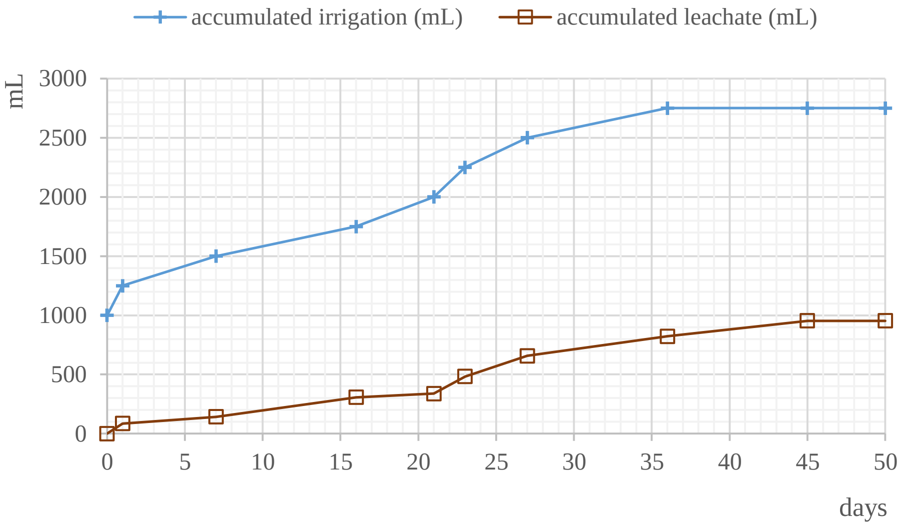
Table 6: Results of the leachate analyses

day	0	1	7	16	21	23	27	36	45
Leachate percolated (L)	0	0.085	0.058	0.165	0.030	0.145	0.175	0.165	0.130
Conductivity (S/cm)		53.30	57.00	62.30	63.50	50.80	53.60	50.70	44.40
pH		6.96	7.22	6.53	7.32	7.32	6.67	6.81	7.37
COD (mg/L)		21,032	22,748	32,102	41,158	46,020	27,070	16,026	9,336
BOD$_5$ (mg/L)		19,139	15,469	22,471	26,752	28,532	15,971	8,654	4,854
Total solids (%)		9.72	8.16	9.72	6.77	8.79	9.67	9.81	8.59

As refuse was already digested in biodrying, no more digestion occurred. Therefore, pH no longer varied since no acidogenic phase took place. The percolated liquid dragged solid particles within it, and no drop in total solids was observed after 45 days. The conductivity of the leachate, chemical oxygen demand (COD) and biological oxygen demand (BDO$_5$) started to drop from day 21 and day 23, respectively, onward because content in salts and biomass began to lower.

Figure 5 compares the accumulated irrigation water with the percolated leachate volume. Once the FC had been reached, the irrigation volume was similar to that of the collected leachate. As regards the water balance, 4.08% of water evaporated.

Fig. 5: Volumes of the liquid that accumulated during the experiment



3.5. Characteristics and evolution of the refuse in the lysimeter

Table 7 shows the initial and final data on the analyzed parameter. According to these data, moisture increased, which is logical as the collected refuse had been previously biodryed and it achieved FC by the end of the experiment. A drastic drop in biomass content (d.w.) was also observed (49%), which had to be due to the fact that most biomass dissolved and was dragged by infiltrated water. Therefore, the resulting leachate contained this biomass and, consequently, the non biomass fraction (d.w.) increased by the end of the experiment.

Table 7: Refuse evolution results before/after 45 days

d.w.: dry weight	Beginning of the experiment		End of the experiment	
	mean	standard deviation	mean	standard deviation
Moisture (%)	24.78	5.87	57.18	4.13
Biomass (%) d.w.	53.21	0.32	27.96	0.15
Non biomass (%) d.w.	25.23	2.27	49.69	0.73
Volatile solids (%) d.w.	73.28	1.00	72.38	2.30
LHV (kcal/kg) w.w.	3011.94		2239.79	
LHV (kcal/kg) d.w.	4004.17	27.44	5230.71	107.66

Conversely, no wide variation in volatile solids was observed. The LHV of refuse increased by 30.6%. This figure is interesting because it means that if a given refuse (composed mainly of plastic, paper-cardboard, and textile) is lixiviated by rain water, most of the biomass (with a lower LHV) is removed and, therefore, the LHV increases. Refuse (d.w.) could thus become a good fuel over a short period of time.

The LHV increased in dry weight (d.w.) given the higher non biomass content (plastic, paper-cardboard and textile), but its wet weight (w.w.) lowered by 25.6% because this refuse presented field capacity moisture by the end of the experiment. Notwithstanding, initial moisture was intracellular as it belonged to the biomass. In contrast, final moisture was due to the water inside the pores in the waste mass and, therefore, final moisture had to be easier to remove. In fact final moisture could be reduced by solar radiation or dry air flow. The refuse obtained at the end of the experiment could, therefore, be used as a fuel since it had a high LHV d.w., which means that refuse landfills could be a reservoir of future fuel if the daily and final covering layers were made up of refinement refuse or shredded tires, or some other non inert waste. These values are similar to, or even higher than, those for wood or different coal types (lignite, sub-bituminous coal or anthracite) (Phan et al., 2008).

Organic particles were removed by the percolated water and refuse was lixiviated. The result was a lower biomass content and a higher LHV because the proportions of plastics and paper-cardboard increased.

4. Conclusions

European Union regulations and directives on waste management to treat and separate MSW, together with the emergence of MBT plants, are modifying the characteristics of the waste dumped in landfills because, at present, an extremely high percentage of dumped waste is refuse. Therefore, it is necessary to investigate the behavior of dumped refuse to improve its management.

The refuse composition depends on the treatment process. In this work at the MBT plant under study, refuse is composed of plastic, followed by dirty paper-cardboard and textile. It is the same as that of other MBT plants like it. Nevertheless in this MBT plant, MSW is shredded and biodried for 21 days. Then the biostabilized and recyclable material is removed. As a result, the moisture of refuse is often lower than usual.

Conversely, when comparing some studies about MSW, we find that FC is inversely proportional to the density of waste. Here refuse has a density of 390 kg/m^3 and FC is 1.02 kg$_{H2O}$/kg$_{dry}$, thus its behavior is similar to the average. As no significant differences are observed, we conclude that biodegradable material influences neither density nor FC before anaerobic biodegradation. This can be explained by the fact that the biodegradable material of MSW contains a high level of moisture and does not, therefore, retain water.

Furthermore, the rainfall in the region was simulated in the lysimeter and then different parameters were measured. The pH of the leachate did not vary because of the biodegradable material left in the refuse. Conductivity and COD respectively lowered as of experiment day 21 and day 23 day because salts had been washed out of the leachate. The percentage of total solids in the leachate did not vary throughout the experiment.

A dramatic drop was observed (d.w.) in biomass because it was dissolved and washed by the leachate, hence the non biomass content proportionally increased.

Finally, the high non biomass material content meant that the plastic and paper-cardboard remained in the washed refuse. This mixture had a high LHV (5000–5500 kcal/kg), which is similar to those of lignite and anthracite. So if the covering material in the landfill was not inert, the refuse dumped in a landfill could be an interesting source of future fuel.

5. Acknowledgements

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