Characterisation study of landfilled materials with a particular focus on the fines and their potential in enhanced landfill mining

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“Enhanced landfill mining” (ELFM) aims to maximise valorisation of the excavated waste materials that have been stored in the landfill. The potential of landfill mining depends on many variables and is therefore site dependent. Factors such as the age, type and location of a landfill might have an impact on the type and condition of materials stored in the landfill and their valorisation potential. In this study, the valorisation options for the materials stored at the REMO site in Houthalen (Belgium) are assessed based on systematic excavation tests at several locations within the landfill site. Throughout all the operative years of the landfill, records of the amounts and the location of municipal solid waste (MSW) and industrial waste (IW) deposited were kept, allowing for an assessment of the ELFM potential for both these materials. The results reveal differences in the composition and the characteristics of the waste materials with regard to type of waste (MSW versus IW) and the period during which the waste was stored. Based on the characteristics of the different fractions, an initial assessment was made with regard to their valorisation potential. For the plastics, paper/cardboard, wood and textile recovered in this study, waste-to-energy is the most suitable valorisation route since the level of contamination within these separate materials was too high to allow for high quality material recycling. For metals, glass/ceramics, stones and other inerts in the waste, material valorisation might be possible when the materials can adequately be separated. The development of a treatment plant that enables maximum resource recovery is however one of the technological challenges for further development of enhanced landfill mining. The experimental and theoretical approach towards such development is discussed based on some first results.

The amount of combustibles in the excavated waste varied between 17 and 53% (w/w) with a calorific value of around 18 MJ/kg dw and confirm the large potential of waste-to-energy for landfill mining. All waste samples recovered from the landfill contained a large amount (40 up to 70% (w/w)) of a fine grained (<10 mm) mainly mineral waste material. Especially for industrial waste, the fines contained high concentrations of heavy metals (Cu, Cr, Ni and Zn) and offer opportunities for metal extraction and recovery. The fine grained and heterogeneous nature of such fines pose large challenges for effective material recovery by physical and chemical methods. A characterisation study of fines present in the samples of the excavation tests is performed. Significant differences between the compositions of MSW and IW fines exist and indicate towards the nescssity for diverse recycling approaches for these two types of material.

Keywords: Enhanced Landfill Mining, fines, waste valorisation, landfilled waste composition
1. Introduction

“Enhanced Landfill Mining” (ELFM) aims to valorise waste materials excavated from landfills as both materials (Waste-to-Material, WtM) and energy (Waste-to-Energy, WtE), while respecting stringent ecological and social criteria (Jones et al., 2012). The Closing the Circle project (CtC) in Houthalen-Helchteren (Belgium) is the first ELFM case study. The feasibility of the CtC/ELFM is investigated through several studies and analysis, ranging from economic feasibility studies to environmental evaluations of the ELFM concept (Jones et al., 2012).

Due to the heterogeneous nature of the waste streams in landfills, a selection of several separation and treatment techniques are required to enable the generation of valuable (recycled) materials of the different waste streams. In the past it was shown that factors such as the age of the landfill, type of landfill, meteorological, hydrological conditions and the country or region where the landfill is located might have an impact on the type of materials stored in the landfill and their valorisation potential (Krook et al., 2012). Therefore, it is crucial to fully understand the composition and nature of waste materials present in a specific landfill in order to design tailored treatment and separation schemes (Quaghebeur et al., 2012). In the case of ELFM, the treatment plant should be able to recover high quality waste fuel and materials (e.g. ferro and non-ferro metals). Furthermore, particle size is a key factor for optimal separation of materials. Generally, in waste separation a fines fraction is generated upon which conventional waste separation techniques cannot be applied. Moreover, the reuse of the fines fraction as a replacement for soil or as a construction fill outside the landfill site is limited due to its heterogeneous nature and elevated levels of organic and inorganic contaminants (IWCS, 2009). Therefore, further physicochemical treatment of the generated fines is essential within the ELFM concept. So far, few reports exist on the treatment of the fines fraction (Krook et al., 2012). Clearly, the composition of landfilled waste is diverse among different landfills and can be as well for different types of waste material stored in the same landfill. Hence, determining the recycling potential for a specific landfill requires quantitative and qualitative analysis of the stored waste streams (Prechthai et al., 2008).

2. Objectives

In this study, the composition and physicochemical characteristics of both municipal solid waste (MSW) and industrial waste (IW), stored at the REMO landfill in Houthalen-Helchteren (Belgium), are investigated. These results should lead to a clear view of the ELFM valorisation potential of the materials stored at the REMO landfill site. Here, some preliminary results of this characterisation study are shown with a special focus on the fines (<10 mm) fraction of the MSW and IW materials.

3. Method

For a detailed description of the sampling and characterisation procedures of the waste samples, we refer to the work of Quaghebeur et al. (2012). In this study, samples were collected at 10 different locations at the REMO landfill, of which 7 are MSW and 3 are IW. Historic records provide the period at which waste was stored in the sampling zones. At each location, samples were collected within 1 m depth intervals (0-1 m, 1-2 m, ...). A selection of samples was consecutively dried, sieved at 10 mm and separted by handpicking into material fractions, as shown in the schematic representation in Figure 1. Total concentrations and leachabilities of heavy metals from the fines...
were measured according to standard procedures by ICP analysis and a one stage leaching test, respectively (CMA, 2012). The one stage leaching test was performed on fines with a particle size <4 mm.

4. Results and discussion

No trend could be observed in the composition of the waste as a function of depth within the landfill. Thus, the composition of all samples taken at the same sampling spot at different depths are averaged. These average values are represented in Figure 2, where for each sampling spot the period during which the landfill was in use at that location is given. Furthermore, the overall average composition of all sampling spots are given for MSW and IW. The quality of the separated material fractions was further analysed to evaluate their individual recycling potentials.

![Figure 2: Composition of MSW and IW materials sampled at the REMO landfill at different zones.](image)


The main organic materials in the waste are plastics (including rubbers), textile, paper/cardboard and wood. The latter materials make up 33 ±9% (w/w) of the excavated MSW and 19 ±9% (w/w) of the IW. A salient feature of the plastic and paper/cardboard composition is their respective increasing and decreasing presence in the MSW and IW as a function of decreasing age of the waste. These trends probably reflect the increase in production and consumption of plastic (PlasticsEurope, 2009) and the degradation of paper during this period. Such presumption may be justified by available literature reporting on increasing plastic and slightly decreasing paper contents in fresh MSW during the period 1993-2000 in the Flandres (OVAM, 2003). Other organic waste, such as food, vegetables, garden waste, cannot be distinguished after 15 years of landfilling. The material degrades and is transformed into a fine, soil-like fraction. In fact, chemical analyses demonstrate that the undefined material fraction consists mainly of compacted sand and degraded organic material (Quaghebeur et al., 2012). Due to the high calorific value (16-28 MJ/kg for IW) of the undefined material, it is considered to be also part of the organic material stream.

The most indicated and feasible valorisation route for the organic material stream is “Waste-to-Energy” (WtE) with valorisation of the residues (e.g. slag, bottom ash). The average calorific value of the combustible material that can be recovered from the REMO landfill was estimated to be about 18 MJ/kg with an average ash content of 29% (w/w) (Quaghebeur et al., 2012). The amount of recoverable organic materials for energetic valorisation are, based on this study, estimated to be in the range of 17% – 53% (w/w) with an average of 28 ± 11% (w/w) for IW and 45 ± 7% (w/w) for
MSW. WtM valorisation of the organic materials is, with current technologies, not feasible due to the poor material quality because of contamination, degradation and heterogeneity of these materials (Quaghebeur et al., 2012).

4.2 Inorganic materials: Metals, glass/ceramic and stone

The inorganic materials, present in a landfill, can be catalogued in three material groups, i.e. metals, glass/ceramic and stone. The composition of landfilled waste with regard to metals shows a decrease of the metal content with decreasing age of the waste for both MSW and IW. One of the contributing factors to a decreasing metal content in MSW might be the substitution of metallic packaging materials by alternative materials, as well as the increasing recycling rate of packaging waste, containing metals, over time (EC, 2012; Fostplus, 2009). On average, IW and MSW contain 2% to 3% (w/w) metals, respectively. Degradation of metals by oxidation (corrosion) in landfills has, to our knowledge, not been studied in the scientific literature and can at the moment not be accounted for. Glass/ceramic materials account for about 1.6 ±0.6% (w/w) of the MSW, while their amounts in IW are negligible (0.1 ±0.2% (w/w)). No trend in the amount of glass/ceramic materials in the REMO landfill as a function of storage age can be observed. The average stone content for MSW and IW is identical (8% (w/w))

Waste to Material (WtM) is the only possible valorisation route for inorganic materials. Most likely, recovery of the metals combined with valorisation of the mineral material as construction material will be suitable re-use routes. In the CtC/ELFM project, large research efforts are made to investigate the feasibilities of such valorisation routes.

4.3 Fines

Figure 2 clearly shows the abundant presence of a fine grained material with a particle size below 10 mm and 4 mm. Common industrial (waste) material separation techniques are unable to separate materials with a particle size below a certain threshold, which lies often in the range of 2-10 mm. Therefore, this fine material requires a completely different treatment, similar to soil remediation, in order to render it valuable for re-use. Hence, a profound knowledge of the chemical and physical properties of this material is required to enable the development of valorisation schemes for this material. In the case of the REMO landfill, MSW consists for about 43 ± 3% (w/w) of fines (<10 mm), while the fines (<10 mm) content in IW is considerably higher at about 62 ± 7% (w/w). Upon considering materials with a particle size below 4 mm, 30 ± 5% (w/w) were present in MSW and 49 ± 9% (w/w) in IW. In other landfill mining projects, similar ratios of a soil-type material in landfilled MSW were recorded (Table 1) (Hogland et al., 2004). On average, both MSW and IW of the REMO landfill site contain about 8 ± 4% (w/w) total organic carbon (TOC) and have a calorific value in the range of 2.4-5.7 MJ/kg, which is low for WtE purposes. Furthermore, it is noted that the TOC level and the calorific value show a decreasing trend upon increasing storage age in the landfill. This can be explained by the biodegradation of the organic material to landfill gas (CH$_4$ and CO$_2$) (Mor et al., 2006). Fitting the loss of calorific value

<table>
<thead>
<tr>
<th>Reference</th>
<th>Waste</th>
<th>Size</th>
<th>Wt% ds</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>MSW</td>
<td>&lt;10 mm</td>
<td>43</td>
</tr>
<tr>
<td>This study</td>
<td>IW</td>
<td>&lt;10 mm</td>
<td>62</td>
</tr>
<tr>
<td>This study</td>
<td>MSW</td>
<td>&lt;4 mm</td>
<td>30</td>
</tr>
<tr>
<td>This study</td>
<td>IW</td>
<td>&lt;4 mm</td>
<td>49</td>
</tr>
<tr>
<td>Error!</td>
<td>MSW</td>
<td>&lt;0.425 mm</td>
<td>44.6</td>
</tr>
<tr>
<td>Error!</td>
<td>MSW</td>
<td>&lt;12.7 mm</td>
<td>50</td>
</tr>
<tr>
<td>Error!</td>
<td>MSW</td>
<td>&lt;25.4 mm</td>
<td>75</td>
</tr>
</tbody>
</table>

Table 1: Amount of materials with small particle sizes in landfilled waste found in this study vs literature of mined waste.
and TOC as a function of storage time by an exponential decay function, allowed for the estimation of the total loss of organic material stored at the REMO landfill site (Quaghebeur et al., 2012).

The WtM potential of the fines fraction has to be based upon the composition of the material. Upon comparing the average concentration of major elements in the investigated fines of MSW and IW a clear distinction between the fines coming from these types of wastes can be observed (Figure 3). Si is the most abundant element in both samples, but the IW fines are clearly richer in Ca and Fe. On the other hand, MSW fines contain more Al than IW fines. The ferromagnetic fraction of the fines could be determined by passing a handheld permanent magnet over the fines to which ferromagnetic material was attracted. The ferromagnetic fraction could then be weighted. MSW fines (<10 mm) contain 24 ± 7% (w/w) ferromagnetic material, such as ferromagnetic metals and metal oxides. Thus, a magnetic base separation and recovery step may be a possible treatment for IW fines. Furthermore, an evaluation of the environmental quality of the materials with regard to the content and leachability of contaminants is necessary to assign possible reuse routes according to local legislation (VLAREBO, 2007; VLAREMA, 2012). In Table 2 the total concentrations and leachability of heavy metals, considered in Flemish legislation, are reported for the investigated MSW and IW fines. Although the average total concentrations of the heavy metals in MSW fines comply with the guide values for reuse as a construction material (e.g. a construction sand), their leachability can sometimes exceed the limit values. However, some individual MSW fines samples comply with legislative limit values for both reuse as a construction material and as a soil. Therefore, it is advisable to devise a monitoring system to appoint recovered fines to certain reuse applications during the ELFM process. Furthermore, Table 2 shows that IW fines are certainly not suitable for reuse as a soil and it is likely that these materials have to undergo a physicochemical treatment to remove or stabilise the contaminants. High metal concentrations could offer possibilities to recover valuables such as Pb, Cu, Cr, Ni and Zn.

Table 2: Average total concentration and leachability, measured by a one stage leaching test at a liquid to solid ratio of 10. of the 8 metals for which the Flemish government (VLAREMA legislation) provides guidance concentration values or leaching limit values (for column leaching test) for reuse in or as a building material. Also the legal total concentration limit values for reuse as a soil in the Flanders is given (VLAREBO legislation). Values between parenthesis are standard deviations.

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Average Total concentration (mg/kg dw)</th>
<th>Leachability (one stage test) (mg/kg dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MSW</td>
<td>IW</td>
</tr>
<tr>
<td>As</td>
<td>27 (25)</td>
<td>20 (2)</td>
</tr>
<tr>
<td>Cd</td>
<td>6 (3)</td>
<td>17 (2)</td>
</tr>
<tr>
<td>Cr</td>
<td>720 (600)</td>
<td>5600 (1700)</td>
</tr>
<tr>
<td>Cu</td>
<td>350 (220)</td>
<td>4100 (2500)</td>
</tr>
<tr>
<td>Hg</td>
<td>2 (1)</td>
<td>5</td>
</tr>
<tr>
<td>Pb</td>
<td>660 (570)</td>
<td>7300 (9500)</td>
</tr>
<tr>
<td>Ni</td>
<td>210 (130)</td>
<td>4000 (1600)</td>
</tr>
<tr>
<td>Zn</td>
<td>560 (190)</td>
<td>4500 (1600)</td>
</tr>
</tbody>
</table>

* Limit values for column leaching test, <4 mm, L/S = 10, percolation 21 days
5. Conclusions

The estimation of the valorisation potential of ELFM materials can only be made when based upon a thorough characterisation study of the materials stored in the specific landfill. In this study a short overview of the composition of materials present at the REMO landfill site is given. The presented data show a remarkable difference in composition between stored MSW and IW. Also, some trends in composition can be observed as a function of storage time, in particular for the materials plastics, paper-cardboard and metal. WtE valorisation is the preferred route for organic matter, while WtM will be possible for the inorganic materials in the landfill. The fines fraction (<10 mm) need thorough characterisation in order to develop valorisation routes for this abundant material. Clearly, MSW fines and IW fines require different, dedicated treatment routes.

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7. References


VLAREMA, 17 February 2012. Besluit van de Vlaamse Regering tot vaststelling van het Vlaams reglement betreffende het duurzaam beheer van materiaalkringlopen en afvalstoffen