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FLOAT-SINK SEPARATION OF CONSTRUCTION AND DEMOLITION WASTE FINES

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ABSTRACT

Landfilling and waste incineration are two major waste management options. However, due to their carbon content, some wastes may be unsuitable for these systems. Therefore, methods capable of removing organic carbon from wastes should be identified. One of these wastes is represented by construction and demolition fines. In this paper, we investigate the use of water in separating the waste by density, to verify the suitability of this method in the separation of carbon-containing materials, both in lab and field scale tests. The results obtained show that half of the carbon (measured as volatile solids) can be separated. However, this method fails to reliably produce a sink fraction suitable for landfilling, as it continues to be characterized by an excessively high organic material content.

1. INTRODUCTION

Worldwide, landfilling continues to represent the main means of disposing of waste. In the EU, landfilling is the most commonly applied waste treatment method, with over one billion tons, or 48% of all waste, being landfilled in 2012 (Eurostat 2016). With the aim of reducing the amounts of waste forwarded to landfills, as well as minimizing landfill gas and leachate emissions - legislation in Europe and developed countries has created a situation in which waste with a higher than marginal organic content is being diverted from landfills towards thermal, biological and other treatment systems. As a consequence, the environmental impact and costs of treating large waste streams has risen sharply, particularly due to the presence of waste streams with properties that fit neither of the treatment systems. Construction and demolition waste (CDW) fines are an example of this type of waste. Construction and demolition waste is the largest waste stream in the EU, including mining and quarrying wastes, accounting for 33% of all waste produced (Eurostat 2016), with fines constituting a major portion of the CDW (Jang, Townsend 2001). Huang et al. (2002) reported fines <40 mm as representing 52% of CDW, and Montero et al. (2010) reported 37.5% as fines <8 mm. CDW fines from Nordic construction and demolition sites typically contain significant amounts of wood since houses in this region are frequently based on timber structures. This makes the waste heterogeneous in its physical properties (particle size, density etc.), rendering conventional mechanical separation complex and expensive. In previous CDW studies conducted in Japan (Montero et al. 2010), the feasibility of wet density-based separation of organic matter has been demonstrated, although a variety of separation steps implying an increasing complexity and higher costs was used. Di Maria et al. (2013) investigated the use of soil washing equipment for use in the wet separation of residual municipal solid waste (MSW) fines. However, the organic waste fraction was removed and not considered. Fines from an MSW landfill were treated in a wet jigger (Wanka et al. 2017), however, fines <10 mm were not studied. Float-sink devices are available in many countries, including the UK (Haith recycling group), Germany (Beyer), US (Hosokawa polymer systems) and Sweden (Norditek, since 2nd half of 2017). In this study, a residual CDW fine fraction (<40mm) was characterized with the aim of investigating a new treatment method. Float-sink separation was investigated, both in lab and field scale to verify whether this method was suitable as a single method for use in the separation of carbon-containing materials from CDW fines. The resulting sink and float fractions were then characterized to check their suitability for landfilling or incineration, respectively, without further treatment.

2. MATERIALS AND METHODS

2.1 Waste origin

A Swedish waste management company site provided unsorted CDW crushed using a Komptech Terminator 5000 crusher and sieved using two Komptech Nemus 2700 with 40 mm drum sieves. The resulting fine fraction contained a

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heterogenous mixture of wood, stones, mineral wool, plastics etc. (Figure 1), which was analyzed in both lab and field scale tests.

2.2 Sink float lab scale

From the waste processing site in the south of Sweden, three 60-liter samples were taken on 3 different days at intervals of approx.10 days in early 2016. In the lab, subsamples were taken using a method similar to that recommended in the Swedish waste association guidelines for waste analysis (Avfall Sverige 2013); an elongated loaf was formed by pouring the waste onto a long strip of construction plastic, and straight segments were taken randomly from across the loaf.

2000 g samples (wet weight) were obtained and added to 60 liters of water in a 90-liter plastic tub similar to a waste bin. The mixture was stirred vigorously and left to settle for 5 minutes. The floating parts were manually removed and put into a 200 and 250 micrometer sieve to let the water drain back. The settled parts were left in the water for the next addition. A second 2000 g sample was then taken from the loaf, added to the same water, and so on. This was repeated 10 times. For the first of the three samples, this was repeated 11 times with the last using 4600g of waste. The floating particles were put into an oven to dry at 70°C after each addition of waste. The sunk particles were left in the water for the next addition. Once all the waste had been sink-floated, the process water was removed using a 68-micrometer sieve. The settled materials were put into metal buckets and dried at 70°C for several days until dry.

2.2.1 Sink float field scale waste and sampling

Twenty cubic meters of waste was transported from the processing facility to a test site in the north of Sweden in the spring of 2017. From this pile, waste samples were initially taken using a front loader tractor, which was weighed at the plant vehicle scale, with an accuracy of ± 20 kg.

The resulting float and sink fractions were weighed using the same procedure. Fractions were sampled using the "loaf method" described above, by using the tractor to form an elongated string of approx.10 meters, and then obtaining three random samples.

FIGURE 1: Example of CDW fines <40 mm.

2.2.2 Experimental setup and procedure

In order to investigate the validity of the results from the lab scale test for use in a large-scale process, a batch field scale experiment was set up.

An open 20-m^3 bulk waste container was filled with 10 m3 water and used for density separation. Using a front loader, 2.5 tons of waste were dumped into the container and stirred with the tractor using the bucket scraping from the bottom. Subsequently, the floating particles were mechanically removed by the tractor, letting the water run off towards the side of the container. The final pieces were removed using a hand net. The water was pumped into a GT 500 D, 1000/0500 geotube, to which a flocculation agent, BASF ZETAG 8140, was added at 20 grams per m^3 to prevent clogging of the pores. Following removal of the water using a 2-inch heavy duty sludge pump, the settled particles were excavated using an excavator.

This process was repeated three times, although for the last two replicates the waste amount was changed to 1.25 tons due to the thickness of the floating material, corresponding to approx. 30 cm in 67 cm water, to prevent mixing of the float and sink fractions.

2.3 Characterization assays

Samples from the lab scale float and sink fractions were taken using a riffler and milled using cryogenic milling and/or a ring mill at an external laboratory (ALS Scandinavia, Luleå, Sweden). The untreated material and materials from the field scale tests were milled using a Blendtech xpress mixer to particle size <10 mm using the sample preparation method described in the EN 12457-4 leaching test standard.

Total solids (TS) and volatile solids (VS) of the milled samples were analyzed by first drying the samples for 24 hours at 105°C and then igniting them for 2 hours at 550°C according to Swedish standard SS 028113. TS was calculated by dividing the dry weight of the sample by the wet weight of the sample. VS was calculated by dividing the loss on ignition by the TS. Total organic carbon (TOC) was analyzed using a Shimadzu TOC-V SSM3 Total Organic Carbon Analyzer. The organic content of the sample was measured using the direct method, as described in the European standard EN 13137. Total carbon (TC) was analyzed by measuring the formed CO_2 after oxidation in oxygen at 900°C. TOC was measured in the same way, first removing carbonates through addition of HCl. These measurements were repeated five times. An analysis of the elemental, inorganic and organic carbon was performed by means of a Netch STA409 thermoanalyser using simultaneous Thermogravimetric analysis (TGA) and quadrupole mass spectrometer (QMS). Dried and milled material was used with a sample weight of 134.8 ± 2.31 mg. The heating rate used was 10°C min^{-1}, starting from room temperature up to 1000°C in argon and air atmospheres. The gas flow was 100ml min^{-1}. Elemental carbon content was calculated according to (Kumpiene, Robinson et al. 2011) using GNU Octave v. 4.2.1 to calculate the integrals.

Leaching of metals and metalloids was carried out in a one-step batch leaching test at L/S (liquid/solid ratio) 10

and performed according to European standard EN 12457-4. Water samples were analyzed using ICP-AES or ICP-SFMS for all elements with the exception of fluoride, which was analyzed according to ISO 10304-1. Sulfates (SO4) and chlorides were analyzed in the process water following final float separation. The biomethane potential (BMP), also known as GB21, was analyzed according to Chen et al. (1995) using a 3:1 waste/inoculum on a VS basis as adopted from Owen et al. (1979).

The respiration activity of the sink fraction was analyzed at an external university using a Sapromat respirometer (Comp. Voith, Germany) at 20°C. Large residues >10mm,including metal objects, stones, and glass, was sorted before analysis. Samples were taken using a riffler and watered to 70% of the water holding capacity (WHC) before analysis.

Elemental analysis was performed using a Thermo Scientific Niton XL3t XRF analyzer. The milled samples were placed in 100 ml LDPE plastic bags and sampled 3 times on each side at non-overlapping spots.

The calorific value was determined for the milled samples using an IKA c200 bomb calorimeter, using no support fuel, and oxygen at 30 bars of pressure.

The water holding capacity was measured in a similar way to that described by Bergman (1996), placing 1 liter of the saturated waste in plastic cylinders on geotextile, covering the top with plastic, letting the water run off for 2 hours, and then measuring the weight and comparing it to the dry mass.

Chlorides and sulfates were analyzed spectrophotometrically (AACE Quaatro, Bran + Luebbe, Germany).

All analyses were carried out in triplicate, at least. Unless otherwise specified, results are presented as "average value" ± "standard deviation".

3. RESULTS AND DISCUSSION

Characteristics of the raw waste are shown in Table 1. A factor 3 variation of VS was observed, clearly showing the heterogenous nature of this material. This is also reflected in the mass balance for the float-sink procedure shown in Figure 2, where 2.8 times more material floats in the field scale tests. This underlines the need for a robust treatment method.

Mass balances for TS, VS and TOC are shown in Figure 2.

3.1 Characterization of sink fraction in lab scale tests

3.1.1 Biological activity

The carbon content of the sink fraction (Table 2) is too high (>6%) for landfilling as non-hazardous waste according to Swedish regulations. However, as shown by RA4 and GB21 analysis (Table 2), biological activity is low. German regulations for landfilling of mechanically-biologically treated wastes establish a limit for RA4 of 5 mg O_2 g TS^{-1}, more than 10 times the observed value of this waste. GB21 displays a gas potential approx. 20 times lower than the German limit for mechanically-biologically treated wastes of 20 ml/g TS. TGA measurements (Table 2) also show that a significant part of the carbon is elemental or inorganic; 18%±1% of the total carbon is organic carbon, 73%±8% elemental and 10%±7% is inorganic carbon. This means that the biological activity of this waste is overestimated when using only TOC or LOI analysis, as discussed in earlier studies (Kumpiene et al. 2011), and as supported by RA4 and GB21 analysis.

TABLE 1: Characteristics of the waste used in the two experiments

	Unit	Lab scale	Field scale
Total solids (TS)	% of wet weight	73 ± 3	75 ± 2
Volatile solids (VS)	% of TS	14 ± 4	42 ± 4

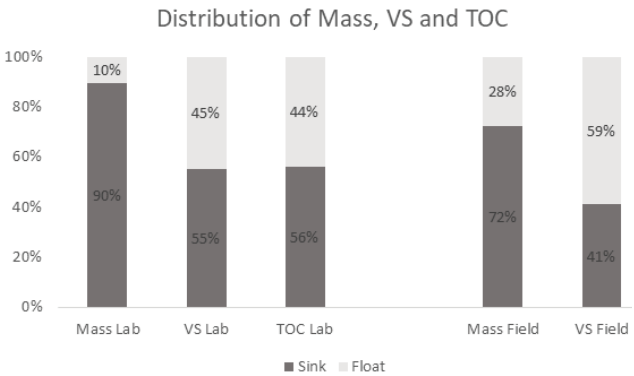

FIGURE 2: Distribution overview of lab and field scale sink-float separation tests. Average values shown, n = 3.

3.1.2 Leaching test

As shown in Figure 3, leaching from this material is low. Based on the Swedish regulation for landfilling, the majority of metals leach less than the limits for inert waste. The exceptions to this are antimony and fluoride. Antimony is used in paint, glass and ceramics (Weast 1982), and has been shown to leach from CDW in previous studies (Butera et al. 2014). Fluoride leaching is 14 mg/kg TS with a stan-

TABLE 2: Characterization data for the sink fraction of the lab scale tests.

	Unit	Value
VS	% of TS	10±2
TOC	% of TS	6.1±1.4
WHC	g water/g TS	80±10
RA4	mg O_2/g TS	0.4±0.09
GB21	ml gas/g TS	1.0±0.7
As	mg/kg TS	18.6 (17/18 measurements <LOD)
Pb	mg/kg TS	51 ± 18
Cd	mg/kg TS	<15 (LOD)
Cu	mg/kg TS	42 ± 6
Cr	mg/kg TS	86 ± 18
Hg	mg/kg TS	<15 (LOD)
Ni	mg/kg TS	76 ± 4
Zn	mg/kg TS	345 ± 109

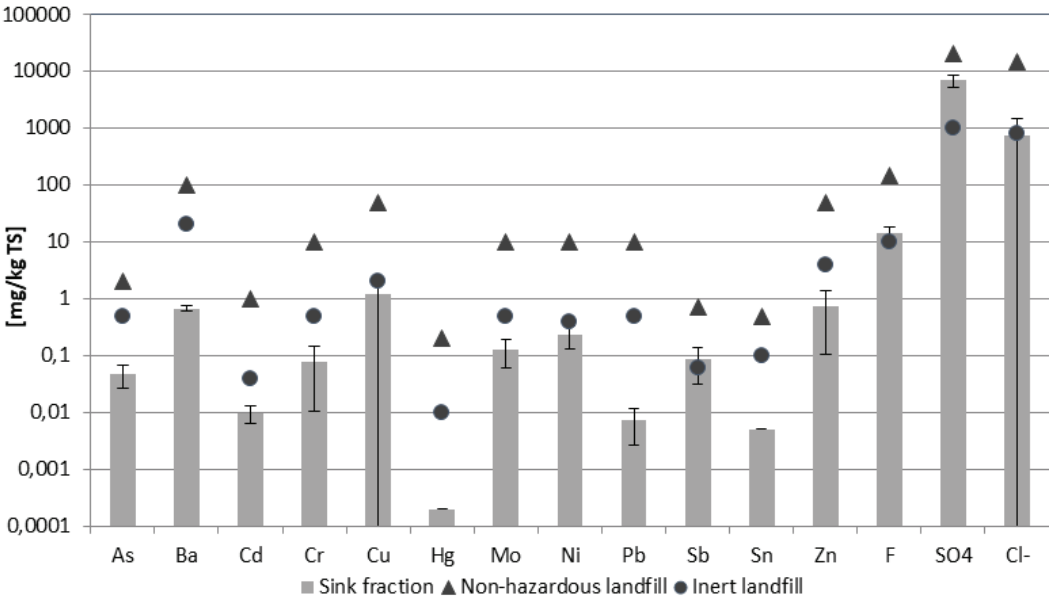

FIGURE 3: Leaching of sink fraction, n=9.

dard deviation of 3.8 mg/kg TS, which is close to the legal limit for landfilling of non-hazardous wastes of 10 mg/kg TS (NFS 2004a); a result similar to other studies (Saca et al. 2017). As for Sulfates and chlorides, these are measured in the process water after all the waste has been added, meaning that leaching of these compounds from the sink fraction will likely be lower, as the waste has already been washed in the float-sink process.

3.1.3 Landfilling of the sink fraction

In Sweden, landfilling is regulated by law NFS 2004a and subsequent amendments. Organic carbon is measured as TOC and determined using (EN 13 137 2001). The established limits in Sweden are 3%, 5% and 6% for inert, non-hazardous and hazardous wastes, respectively. Some exceptions are provided for, thus allowing homogenous wastes with less than 10% TOC to be landfilled (NFS 2004b).

In lab scale tests, the sink fraction was shown to have a TOC of 6%. If this waste could be considered as homogenous, it would be suitable for landfilling as provided for by the exception rules mentioned above. However, field scale experiments showed a VS content of 25% in the sink-fraction, which, in line with the VS/TOC ratio of lab scale tests, would imply a TOC of 15%, thus not suitable for landfilling. However, in other EU countries, such as Germany and Austria, other means may be applied to assess whether a waste features an appropriate organic carbon content for landfilling. Germany has established limits for respiration activity for wastes treated by mechanical-biological processes (Abfallablagerungsverordnung 2001) of 5 mg O_2 g^{-1}, for which the sink fraction from the abovementioned lab scale tests yielded values as illustrated in the table below. Assuming the same VS/RA4 ratio as in the lab scale test, this would provide an RA4 value for the field test of 1 mg O_2/g TS, still well within the German limit for landfilling.

As shown in Table 4 and Table 5, both the sink and float fraction absorbed significant amounts of water corresponding to three- and two-fold the dry weight, respectively. Accordingly, it would be necessary to dry the material following separation to avoid the landfilling of excessive amounts of water.

Due to the considerably wide variability between the different tests, this method cannot be considered adequate for reliably producing a sink fraction suitable for landfilling in Sweden.

3.2 Characterization of the float fraction in lab scale

Ocular characterization shows a high content of wood and organics in the float fraction, which is consistent with the VS of 69% (Table 3). For incineration, typically a VS content of 20% (Williams 2005) and 25% (Hulgaard, Vehlow

TABLE 3: Basic characteristics of the float fraction in the lab scale test.

	Unit	Value
VS	% of TS	69 ± 8
Ash	% of TS	31 ± 8
TOC	% of TS	42 ± 3
HHV	kJ/g TS	14.2 ± 1.38
As	mg/kg TS	17 ± 7
Pb	mg/kg TS	20 ± 8
Cd	mg/kg TS	<10 (LOD)
Cu	mg/kg TS	53 ± 14
Cr	mg/kg TS	130 ± 34
Hg	mg/kg TS	<11 (LOD)
Ni	mg/kg TS	<61 (LOD)
Zn	mg/kg TS	215 ± 39
Ca	g/kg TS	69 ± 20
S	g/kg TS	13 ± 6

2010) of wet weight is needed for a waste to be incinerated without using support fuel. Given that the VS to ash ratio is 2:1, the float fraction from the lab scale tests will be combustible at any moisture content below 70%. As shown in Table 4 and Table 5, after the sink-float separation the float fraction had a moisture content of approx. 50%, meaning there is no need for drying of the float material after separation.

The heating value of the float fraction was found to be 14.2 ± 1.38 MJ kg TS^{-1} (Table 3). Given a 75% TS content, this gives a heating value equal to or above that of municipal household waste of 9-13 MJ/kg (Williams 2005, Avfall Sverige 2014).

The sulphur content is high, 13 g kg^{-1} TS, likely from gypsum $CaSO_4$ $2H_2O$, as the waste also contains Ca. Typically, waste forwarded to waste incineration contains approx. 2 g kg^{-1} TS of sulphur (Williams 2005, Hulgaard, Vehlow 2010). Higher levels might cause problems with corrosion and SO_2 emissions. However, when incinerating alkali and silicate rich wastes such as industrial or municipal solid wastes (MSW), an addition of CaO and SO_x may help to reduce ash related problems and corrosion (Skoglund et al. 2016). As the majority of MSW incinerators are equipped with filters to reduce SO_2 emissions this fraction may be suitable for co-combustion with MSW.

3.3 Field scale experiments

1.25 to 2.5 tons of waste was subjected to sink/float separation. The outputs of the process are shown in Table 4 and Table 5. A considerable difference (up to 30%) was observed in the TS entering and exiting the process, likely due to sampling difficulties with the sink fraction, due to the high free phase water content, which produces erroneous TS measurements. The floating percentage is based on the TS of the raw waste and float fraction. Volatile solids in the float fraction were found to be 90% ± 2%, and 25% ± 7% in the sink fraction.

In addition, a total of 63.9 kg of solids were collected in the geotube, originating from the process water. As this amounts to about 20 kg per batch, this was considered negligible.

TABLE 4: Weights on entry to and exit from the process

	Raw waste	Float	Sink
Unit	Kg	Kg	Kg
Batch 1	2480	1000	2660
Batch 2	1280	540	1440
Batch 3	1220	540	1460

TABLE 5: Mass balance of the field scale test.

	Raw waste TS	Float TS	Sink TS	Floating	Difference In/out
Unit	Kg	Kg	Kg	%	%
Batch 1	1850	514	1127	28%	11%
Batch 2	955	252	401	26%	32%
Batch 3	910	264	520	29%	14%

3.3.1 Differences between lab and field scale tests

The difference in VS found in the sink fraction in lab and field scale tests may have been caused by the experimental procedure. In the lab scale, a more rigorous stirring was performed, including stirring of the whole water mass. Further, the wastes were added using different procedures: In the lab scale, waste was added in increments, whilst in the field scale the waste was added all at once and stirred using a machine. Due to the size of the tractor bucket, it is likely that the whole volume may not have been stirred as rigorously.

Another factor contributing to the difference is the variation in waste itself. With almost three times more material floating in the field scale experiment, and three times more VS in the raw waste, it is evident that the waste tested in the field scale trials contained more wood and organic materials. Using the field scale waste in a lab scale test would have likely produced a high VS sink fraction as well, meaning that the results from the field scale test would be in line with those of the lab scale test. This also implies that a lab scale test would have sufficed. Since the field scale test was carried out as a batch experiment without any special sink-float machinery, no extra information was provided with regard to practical applications. Any practical applications using sink-float should always be performed using a continuous process, as discussed also by Bilitewski (2010).

4. CONCLUSIONS

Density based separation using water was successfully applied to separate an organic material from inorganic. However, the resulting sink fraction may not always be suitable for landfilling, as the organic content may continue to be too high. Nevertheless, the use of analytical assays other than TOC to measure biological activity indicate that the organic content remaining in the sink fraction is not as biologically available as the TOC value may suggest.

In a practical Swedish scenario, sink-float separation fails to reduce the carbon content of the treated material in a reliable manner. In addition, since the material absorbs significant amounts of water, if density is to be used for separation this should be undertaken using a dry method.

4.1 Further research

Further research methods to be applied include the use of dry density separation methods, such as wind sifting, and combination treatments also including sieves or screens. Temporal variations of the waste should also be investigated further to better assess the appropriateness and feasibility of treatment methods. It is clear however that temporal variations may be considerable (up to a factor of three), thus a robust treatment method is needed.

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