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PYROLYSIS OF SOLID RECOVERED FUEL FROM LANDFILLED WASTE: GAS AND OIL PRODUCT COMPOSITION

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Abstract

A study has been conducted to examine the effect of different components in solid recovered fuel (SRF) on the pyrolysis performance and composition of pyrolysis products. The SRF samples were produced from fresh solid waste and excavated landfill waste. Pyrolysis was performed by heating up the sample from ambient temperature to 900°C at a heating rate of 25°C/min by using a nitrogen atmosphere. The results show that the gas product from pyrolysis of SRF landfill waste had significantly lower H₂, CO, and CO₂ as compared to the case of SRF from fresh solid waste. Furthermore, the oil and wax product in the case of SRF from landfill was dominated by hydrocarbon compounds rather than oxygenated compounds as was found in the case of SRF from fresh waste.

Introduction

It is estimated that there are no less than 150,000 to even 500,000 closed and active landfill sites in the EU-28 countries.¹ Unfortunately, nearly 90% of those landfill sites are non-sanitary landfills, which might lead to severe environmental problems.² Hence, the mining of landfills and the remediation of polluted land have been considered as essential measures for environmental protection in Europe.³ Recently, Enhanced Landfill Mining (ELFM) has been considered as a potential solution for landfill remediation, through the adaptation of advanced waste sorting processes and thermochemical treatment processes to recover materials and energy from the landfilled waste.⁴

Municipal solid waste (MSW) originating from landfills has a different composition compared to the fresh MSW. It is reported that landfilled waste contains a higher fraction of fines, which is partially caused by the degradation of waste over time.⁵ Moreover, it is found that the plastics and paper/cardboard fraction from landfills has higher ash content.^{5,6} This might be due to the fact that those fractions have experienced long-term physicochemical reaction processes, which resulted in

significant amounts of impurities sticking to their surface.⁶ Therefore, materials derived from ELFM might have different behaviour during the thermochemical conversion as compared to fresh MSW.

Pyrolysis (alternatively named devolatilisation) has been considered as a fundamental step in all main thermal conversion processes,⁷ including gasification. Consequently, it is essential to understand the pyrolysis characteristics of MSW in adapting a thermochemical-based treatment. In this study, pyrolysis of solid recovered fuel (SRF) produced from MSW was performed to investigate the resulting gas composition and oil yield. The objective of the study was to understand the effect of differing SRF composition (from fresh waste and waste from landfill mining) on the pyrolysis performance and end products, and more particularly the gas and oil/wax composition.

Materials and methods

SRF samples

In this study, two SRF samples, SRF-1 and SRF-2, composing SRF derived from fresh solid waste and an SRF sample, SRF-LW, obtained from the excavation of landfill waste were used in the pyrolysis process. The fresh SRF samples were supplied by a commercial SRF producer (Shanks-Renewi, Belgium). The SRFs were produced through a series of operations including shredding, screening, sorting, and drying of commercial and industrial waste. Table 1 shows the composition of the SRF samples. The composition of SRF-1 and SRF-2 samples was obtained by manual sorting (handpicking). Meanwhile, the landfill waste composition was based on the previous report by Garcia Lopez *et al.*⁸ The SRF-1 samples were obtained in a pelletised condition that consist of plastics, paper, wood, and a small fraction of textiles. On the other hand, SRF-2 samples consisted of a fluffy material that mainly comprises of shredded polyester sponge, paper, plastics, and textiles. The landfill sample was obtained from excavation waste at a landfill site in Halbenrain, Austria. The excavated waste was sorted and screened, which was then followed by size reduction step. The size reduction step consisted of hammer milling, disk milling, and a cryogenic cutting process of which the details can be found in Garcia Lopez *et al.*⁸ The result of the size reduction process was a powder fraction, which consisted of mostly inert materials, and the SRF fraction (SRF-LW). Only the SRF fraction was used for the pyrolysis process. The amount of the powder fraction was relatively high (69 wt% of the total sample weight) due to the addition of soil that was detached from the waste surface during the milling and cutting process. SRF-LW has additional components to the main component (plastics, wood, paper, and textiles), as it also contains other combustible materials such as sanitary material, rubber, foam, nappies, sandpaper, electronic plates, *etc.*

Table 1: Material composition of SRF samples

	SRF-1	SRF-2	SRF-LW* ⁸
Component, wt%			
Plastics	34.92	23.55	21.46
Wood	15.83	3.03	11.90
Paper and cardboard	40.29	21.60	2.38
Textiles and fibres	8.96	13.02	0.94
Polyester sponge	-	38.80	-
Other combustible fraction	-	-	21.15
Metals			5.49
Inerts (soil, glass, etc.)			36.69

*Composition before the sample was milling and cut, producing a fines and SRF fraction, of which only the SRF fraction was use in the present research.

Pyrolysis experiment

A fixed bed reactor was used to perform the pyrolysis process. The reactor consists of a metal tube, a thermocouple, an electric heater, a cooling bath, and a gas cleaning system as shown in Figure 1. For each experiment, approximately 10 g of sample was inserted in a metal basket and was then placed in the middle of the tube. To measure the temperature inside the tube, a thermocouple was put into the tube until its end was about 1 cm above the sample. Then, the reactor was heated up from a ambient temperature to 900°C, using a heating rate of about 25°C/min and a nitrogen flow of 100 mL/min. The reactor was maintained at the target temperature for 1 h and subsequently cooled to ambient temperature. An on-line measurement of the gas composition was done using a micro gas chromatography (micro-GC) instrument using the procedure described in Evangelopoulos *et al.*⁹ During the pyrolysis, oil and wax were collected through a washing bottle inside the cooling bath which was then analysed using a GC/MS analyser using the procedure described in Sophonrat *et al.*¹⁰

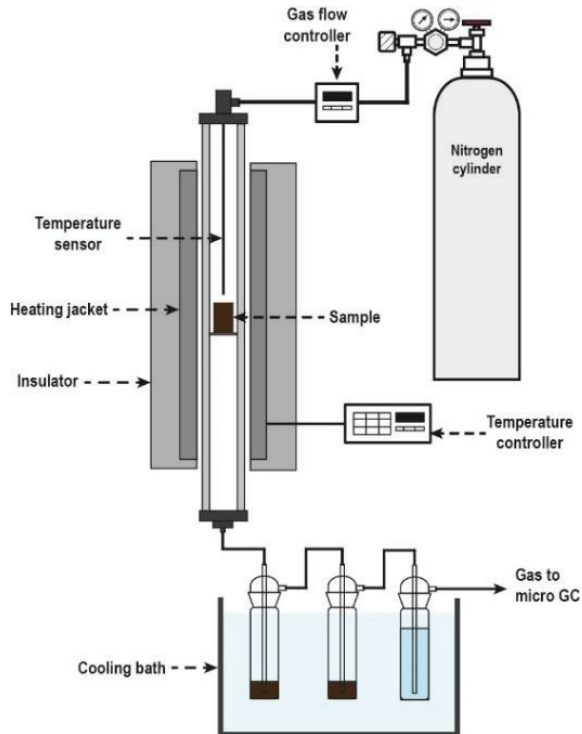


Figure 1: Schematic diagram of the pyrolysis reactor

Results

Product yield distribution

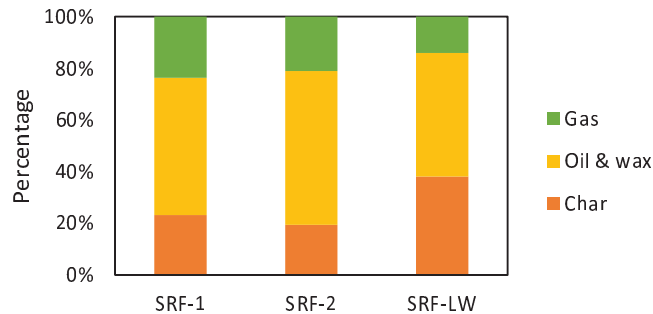


Figure 2: Product yield distribution for all samples

Figure 2 shows the yield of the pyrolysis products for all samples. It can be seen that SRF-1 and SRF-2 samples have a yield of products with the highest fraction composed of the oil-wax mixture, which is common in case of pyrolysis of materials with high contents of plastic. Meanwhile, pyrolysis of SRF-LW produced a higher char fraction, which was mainly caused by high ash content of the SRF-LW sample.

Gas composition

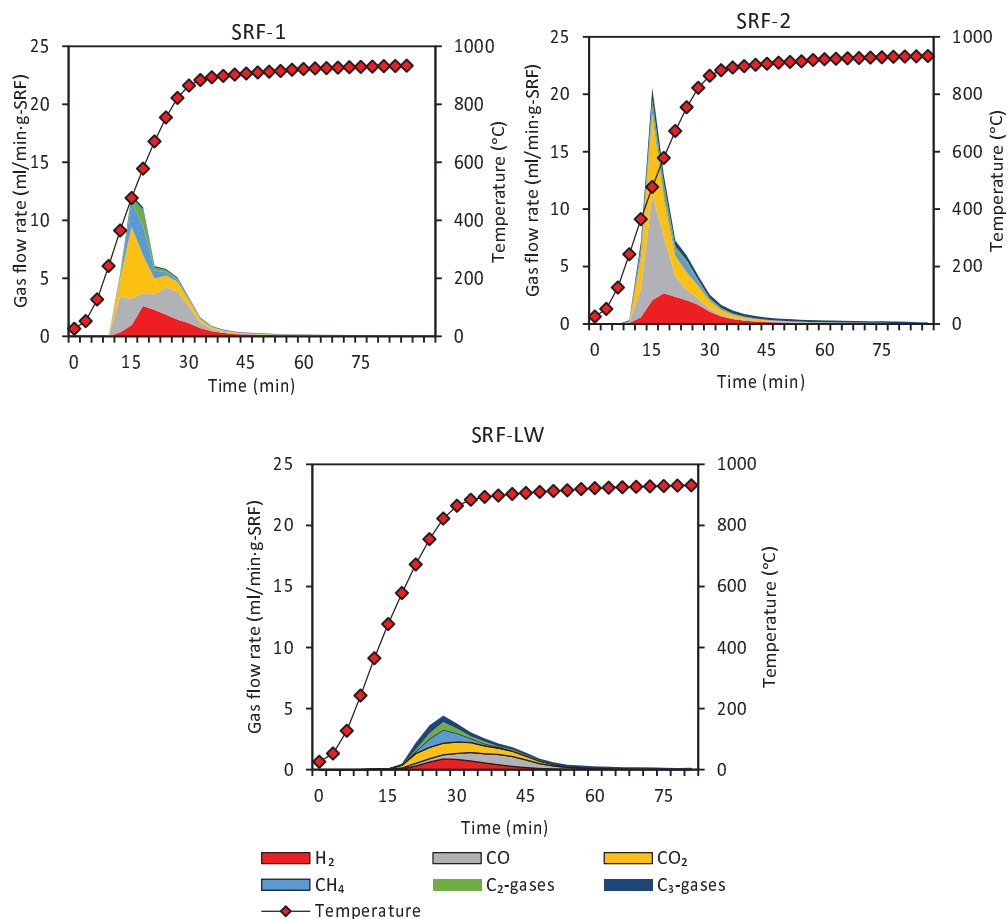


Figure 3: Gas product composition during pyrolysis

Figure 3 shows the gas composition during pyrolysis of the SRF samples. In the case of SRF-1, the total amount of the gas product was 165 mL/g-SRF being composed of 26 vol% H₂, 13 vol% CH₄, 31 vol% CO, and 30 vol% CO₂. The CO production was observed to peak at two different temperatures, 365 and 820°C. The pelletisation of SRF-1 might be one of the reasons for the different peaks of CO. As a result of pelletisation, some materials trapped inside the pellets started to decompose and release gas in the later stage of pyrolysis. In the case of SRF-2, the total amount of the gas product was 206 ml/g-SRF being composed of 21 vol% H₂, 5 vol% CH₄, 30 vol% CO, and 28 vol% CO₂. However, in contrast with the SRF-1 sample, there was only one peak for the CO production which occurred at the temperature of about 440°C. For both SRF-1 and SRF-2, the production of C₂- and C₃-hydrocarbon gases was significantly low. The gas produced from SRF-1 contained 5 vol% of C₂-hydrocarbon and 3 vol% of C₃-hydrocarbon gases, while the SRF-2 gas contained 5 vol% of C₂-hydrocarbon and 11 vol% of C₃-hydrocarbon gases.

In contrast with SRF from fresh waste, the pyrolysis of SRF-LW started to produce gas at a higher temperature. As can be seen in the figure, SRF-LW released the pyrolysis gas at around 450°C and peaked at approximately 800°C. In general, pyrolysis of SRF-LW produced significantly lower amounts of gas compared to SRF-1 and SRF-2 especially in terms of H₂, CO, and CO₂. This trend might be due to the lower content of light volatiles, *i.e.* volatiles which decompose in the temperature range of 250-350°C in the SRF-LW sample as a result of the devolatilisation occurring in the landfill site.¹¹ As a result, in percentage, the heavier gases (the C₂-hydrocarbon and C₃-hydrocarbon gas) were higher in concentration in case of SRF-LW (11 vol% and 23 vol% respectively).

Oil-wax mixture composition

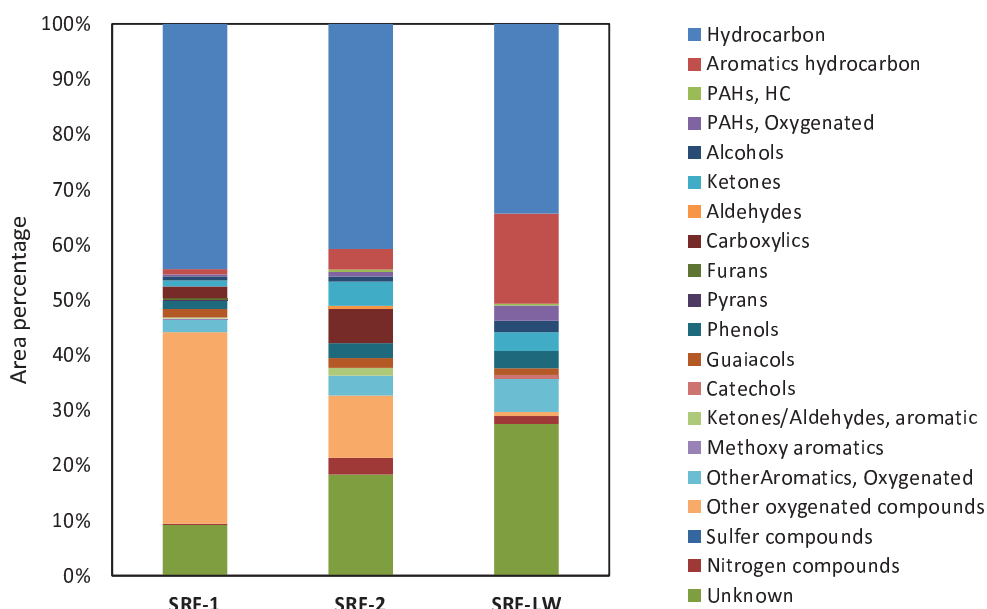


Figure 4: Composition of oil-wax mixture product from pyrolysis process

During the pyrolysis of SRF samples, the volatile content of the SRF was mostly converted into wax with a small fraction of heavy oil. This product is typically produced in a pyrolysis process of plastic-dominated feedstock when no catalysts are used. The composition of the oil-wax product from the pyrolysis of three SRF samples is shown in Figure 4. In the case of SRF-1, the oil-wax mixture composition is dominated by oxygenated compounds. This is because SRF-1 had a significant amount of wood, paper, and textiles which for the main source of oxygenated compounds in pyrolysis products. On the other hand, SRF-2 produce less oxygenated compounds as the hydrocarbon compounds dominate the oil-wax composition.

Furthermore, the oil-wax product from pyrolysis of RDF-LW consists of mainly hydrocarbon compounds (50.6 vol%), in which one third are aromatic hydrocarbons. The oxygenated compounds in the oil-wax mixture were significantly lower compared to other compounds.

Conclusion

The results of this study show that the performance of pyrolysis was greatly affected by the SRF material composition. The gas product from pyrolysis of SRF derived from excavated landfill waste had significantly lower H₂, CO, and CO₂ content compared to the SRF from fresh solid waste. This might be partly caused by the low light volatile content in landfilled waste. As a result, the volume percentage of C₂- and C₃-hydrocarbon gases in the gas product were relatively higher. In addition, the pyrolysis of landfilled waste produced gas at a higher temperature compared to the one from fresh waste. Furthermore, the oil and wax product in the case of SRF from landfill was dominated by hydrocarbon compounds rather than oxygenated compounds as was found in the case of SRFs from fresh waste. The phenomenon was due to the higher plastic and low biomass content in the landfill waste as compared to the SRF from fresh waste.

Acknowledgments

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References

1. J. Krook, N. Svensson and M. Eklund, "Landfill mining : A critical review of two decades of research", *Waste Manage*, **32** 513-520 (2012).
2. EURELCO. Data launched on the landfill situation in the EU-28. (2015).
3. W. Hogland, M. Marques and S. Nimmermark, "Landfill mining and waste characterization : a strategy for remediation of contaminated areas", *J Mater Cycles Waste*, **6** (2) 119-124 (2004).
4. A. Bosmans, I. Vanderreydt, D. Geysen, and L. Helsen, "The crucial role of Waste-to-Energy technologies in enhanced landfill mining: A technology review", *J Clean Prod*, **55** 10-23 (2013).
5. A. Bosmans, C. Dobbelaere and L. Helsen, "Pyrolysis characteristics of excavated waste material processed into refuse derived fuel", *Fuel*, **122** 198-205 (2014).
6. C. Zhou, W. Fang, W. Xu, A. Cao and R. Wang, "Characteristics and the recovery potential of plastic wastes obtained from landfill mining", *J Clean Prod*, **80** 80-86 (2014).

7. A. O. Aboyade, J. F. Görgens, M. Carrier, E. L. Meyer, and J. H. Knoetze, "Thermogravimetric study of the pyrolysis characteristics and kinetics of coal blends with corn and sugarcane residues", *Fuel Process Technol*, **106** 310-320 (2013).
8. C. G. Garcia Lopez, A. Clausen, and T. Pretz, "Landfill mining: A case study on sampling, processing, and characterization of excavated waste from an Austrian landfill", in *16th International Waste Management and Landfill Symposium* 1-24, Sardinia, 2017.
9. P. Evangelopoulos, E. Kantarelis and W. Yang, "Experimental investigation of the influence of reaction atmosphere on the pyrolysis of printed circuit boards", *Appl Energ*, **204** 1065-1073 (2017).
10. N. Sophonrat, L. Sandstro, A. Johansson and W. Yang, "Co-pyrolysis of Mixed Plastics and Cellulose : An Interaction Study by Py-GC × GC / MS, *Energy Fuels*, **31** (10) 11078-11090 (2017).
11. M. Rotheut and P. Quicker, "Energetic utilisation of refuse derived fuels from landfill mining", *Waste Manage*, **62** 101-117 (2017)