proceedings

MDPI

Proceedings

Effect of the Incorporation of Biomass in the Carbonization of Waste Electrical and Electronic Equipment †

Roberta Mota-Panizio [1,2,*], Luis F. Carmo-Calado [1], Octávio Alves [1], Catarina Nobre [2], J. L. Silveira [3] and Paulo Sérgio Duque de Brito [1] and Margarida Gonçalves [1,2]

1 VALORIZA—Research Center for Endogenous Resource Valorisation, Polytechnic Institute of Portalegre, 7300-555 Portalegre, Portugal; rpanizio@ipportalegre.pt (R.M.P); luis.calado@ipportalegre.pt (L.F.C.C.); octavio.alves@ipportalegre.pt (O.A.); pbrito@ipportalegre.pt (P.B.); mmpg@fct.unl.pt (M.M.G.)

2 MEtRICs—Mechanical Engineering and Resource Sustainability Center, Department of Science and Technology of Biomass, Faculty of Science and Technology, Universidade NOVA de Lisboa, 1099-085 Lisboa, Portugal; cp.nobre@campus.fct.unl.pt

3 LOSE Laboratory, IPBEN-UNESP—Institute of Bioenergy Research, Faculty of Engineering of Guaratinguetá, São Paulo State University, São Paulo 13500-230, Brazil; j.luz@unesp.br

* Correspondence: rpanizio@ipportalegre.pt

† Presented at the Bioenergy International Conference, Portalegre, Portugal, 11–13 September 2019.

Published: 6 April 2021

Abstract: The behavior of chars from the carbonization process were studied when the lignocellulosic biomass was incorporated into the waste of electrical and electronic equipment for chlorine removal. Tests were performed at 300°C with a heating rate of 15°C/min and residence time of 60 min. Compositions studied had 100, 75, 50, 25 and 0% of waste electrical and electronic equipment (WEEE) in the mixtures. The composition of 50% WEEE with 50% lignocellulosic biomass presented the best char properties, having an increment of the calorific value in 5.5% relative to the initial value, and chlorine removal of 23.4% when compared to the forestry biomass.

Keywords: co-carbonization; lignocellulosic biomass; WEEE and chlorine removal

1. Introduction

Global development and economic growth drive technological advancement in industries, resulting in increased production of electrical and electronic equipment (EEE), which is one of the fastest growing and still developing products. New technologies developed are being replaced by new devices, and the resulting waste is sent to landfills without consideration of possible adverse impacts on the environment [1].

In 2016, for example, the amount of electrical and electronic equipment waste (WEEE) increased by 8% worldwide compared to in 2014. In the European Union, around 12.3 million ton of WEEE is generated annually, constituting one type of waste with recovery potential [2,3].

EEE includes a wide range of products. Directive 2012/19/EU defines EEE as equipment that relies on an electrical current or electromagnetic field to function properly. This type of waste includes large and small appliances and information technology equipment [4]. This waste contains various toxic substances that can be released into the environment during landfilling deposition and improper processing [5].

2. Literature Review

WEEE contains heavy metals, brominated flame retardants (BFRs) and other toxic and hazardous substances, such as chlorine. Landfilling may lead to soil and groundwater pollution caused by BFRs and heavy metals.

WEEE pyrolysis allows it to recover its carbon content in the form of bio-oils and bio-carbons. However, the valuation of these products generally requires additional processes which presents a disadvantage [6].

Combustion of this material may cause formation of polybrominated dibenzodioxins and dibenzofurans. The carbonization of WEEE allows the decomposition of the molecular structures of these materials at 300–500 °C in an inert atmosphere, thus eliminating the amount of chlorine and plasticizing elements. The char obtained has better properties to be used as fuel [7], for example in gasification processes. Low temperature carbonization (≈300 °C) can be used as a pretreatment for solid biomass processing, providing an alternative to the standard use of biomass as a raw material for the thermal gasification process. This effect is due to the reduction in the amount of harmful gaseous emissions and decreases the amount of ashes and tars [8].

The gasification process thus emerges as a technology that allows the integration of various processes and the production of synthesis gas, ensuring a more complete separation between the organic and inorganic components of these wastes [5]. Direct thermal gasification of WEEE causes HCl emissions, encrustation and corrosion in equipment due to Cl and heavy metals present in such wastes [9]. Therefore, a pretreatment like carbonization may be required to avoid such problems.

In the present work, carbonization tests with mixtures containing WEEE and a lignocellulosic biomass in various proportions were performed with the aim of evaluating process behavior and to analyze the properties of resulting chars for further use as fuels in a gasification process.

3. Experimental

Tests were performed with 100, 75, 50, 25 and 0% WEEE to study the effect of increased biomass incorporation and its benefits for the energy recovery of waste.

The parameter of most interest is related to chlorine removal, which, as discussed, is one of the biggest problems for the WEEE energy recovery process.

The carbonization tests were performed in an oven at 300 °C for 60 min with a heating and cooling rate of 15 °C/min. The heating rate is an important factor for increasing the dechlorination rate and the ratio between HCl and volatiles.

4. Results and Discussions

The initial mixtures and chars obtained in the test are shown in Figure 1. In the chars derived from the carbonization processes, it is possible to observe that the greater the amount of WEEE, the greater the formation of agglomerations, while the initial biomass becomes clustered.

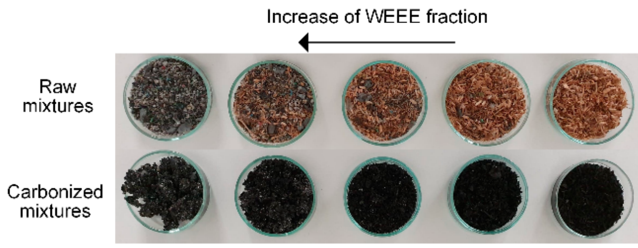

Figure 1. Biomass and carbonization chars.

Table 1 presents the characterization of the raw mixtures with biomass and WEEE. As the percentage of lignocellulosic biomass in the residue increases, the amount of chlorine decreases, which constitutes an advantage for the energy recovery process since HCl emissions may be attenuated.

Table 1. Analysis of the different raw mixtures.

		100% WEEE	75% WEEE	50% WEEE	25% WEEE	0% WEEE
Proximate (%)	**Moisture**	0.71	2.45	2.12	2.94	6.17
	Volatiles	62.71	62.38	61.84	58.7	57.25
	Fixed Carbon	8.24	11.84	18.08	24.67	30.32
	Ashes	28.33	23.34	17.96	13.73	6.26
Ultimate (%)	**Nitrogen**	0.76	1.14	1.37	1.27	1.99
	Carbon	41.85	36.95	39.5	30.38	29.41
	Hydrogen	7.47	6.23	6.67	4.89	4.67
	Sulphur	0.23	0.27	0.2	0.13	0.22
	Oxygen	21.36	32.07	34.29	49.6	57.45
Chlorine (%)		26.83	22.95	22.71	16.79	4
Higher Heating Value (MJ/kg)		22.7	21.22	21.18	19.3	17.59

In Table 1, it can be observed that the greater the incorporation of lignocellulosic biomass, the lower the amount of ash, which has an advantage, as the high amount of ash can cause equipment malfunctions and slagging problems. Increased biomass amounts in the mixture reduces the amount of chlorine present that will go to the reactor. On the other hand, because lignocellulosic biomass has a relatively low calorific value, WEEE incorporation increases the calorific value of the mixture. Table 2 presents the char characterization obtained from the carbonization process.

Increased biomass amounts in the mixture reduces the amount of chlorine present that will go to the reactor. On the other hand, because lignocellulosic biomass has a relatively low calorific value, WEEE incorporation increases the calorific value of the mixture.

Table 2. Char characterization obtained from the carbonization process.

		100% WEEE	75% WEEE	50% WEEE	25% WEEE	0% WEEE
Proximate (%)	**Moisture**	1.21	3.7	1.02	0.34	0
	Volatiles	47.55	47.45	54.47	52.09	50.01
	Fixed Carbon	17.27	13.88	16.53	16.67	21.05
	Ashes	33.97	34.97	27.98	30.90	28.94
Ultimate (%)	**Nitrogen**	0.82	0.89	1.21	1.8	1.91
	Carbon	44.59	37.06	40.01	61.07	54.84
	Hydrogen	7.61	5.32	6.56	7.4	6.28
	Sulphur	0.57	0.48	0.37	0.28	0.15
	Oxygen	46.41	56.78	43.85	29.45	36.82
Chlorine (%)		24.09	21.98	17.4	8.34	1.34
HHV (MJ/kg)		21.74	21.18	22.42	19.88	20.79

Generally, it is possible to verify that, according to the data compiled in the proximate analysis, the carbonization process reduced the humidity and volatile matter in all chars. The char obtained from the mixture with 50% WEEE exhibited the highest higher heating value (HHV).

As expected, the carbon content of all chars were higher than in the samples prior to the carbonization process. The amount of carbon and calorific value demonstrated that the samples had an optimal incorporation value of lignocellulosic biomass of 50%, with a chlorine reduction of 23.5% compared to the initial biomass. In the composition considered ideal, the amount of ash was lower in relation to the others, contributing to the increase of the calorific value.

The incorporation of lignocellulosic biomass in the mixtures for carbonization increases the amount of inert present in it, which results in a reduction in the concentration of plastic components. With the addition of biomass, it is possible to increase the carbonization mass yield. Forest biomass represents a reduction in the amount of hydrogen in the mixture. However, when charred, the char properties are improved, and this difference is minimized, thus improving the physicochemical properties of WEEE.

5. Conclusions

The aim of this paper was to show that carbonization is an adequate pretreatment for the removal of chlorine from biomass-incorporated WEEE residues. It can be seen that the low temperature carbonization process can be considered as a good pretreatment. It is necessary to use catalysts and to define studies related to hydrocarbonization that show it is possible to remove more chlorine from polymeric wastes, being an alternative to be studied for WEEE, which have a relevant amount of polymers in its composition.

Based on the conditions studied, the composition of 50% WEEE generated a reduction in the amount of chlorine by 23.4%, an increase in calorific value of 5.8% and mass and energy yields between 70 and 75%, demonstrating that it is the best mixture for a possible subsequent process of gasification for energy recovery.

Acknowledgments: The authors are grateful for the financial support given to the project by 0330_IDERCEXA_4_E—RENEWABLE investment, development and energy for the improvement of the entrepreneurial fabric in the region CENTRO, ESTREMADURA and ALENTEJO, co-financed by the European Regional Development Fund (ERDF) through the INTERRREG. Support from the MEtRICs research unit, financed by national funds from FCT/MCTES (UID/EMS/04077/2019), is also appreciated.

References

1. Kiddee, P.; Naidu, R.; Wong, M.H. Electronic waste management approaches: An overview. *Waste Manag.* **2013**, *33*, 1237–1250.
2. Baldé, C.P.; Forti, V.; Gray, V.; Kuehr, R.; Stegmann, P. *The Global E-Waste Monitor 2017*; United Nations University: Macao, China, 2017.
3. Balde, C.P.; Wang, F.; Kuehr, R.; Huisman, J. *The Global E-Waste Monitor 2014*; United Nations University: Macao, China, 2015.
4. Diretiva 2012/19/UE do Parlamento Europeu e do Conselho. DIRETIVA 2012/19/UE DO PARLAMENTO EUROPEU E DO CONSELHO de 4 de julho de 2012. relativa aos resíduos de equipamentos elétricos e eletrónicos (REEE). *J. Of. União Eur.* **2012**, *6*, 38–71.
5. Gurgul, A.; Szczepaniak, W.; Zabłocka-Malicka, M. Incineration and pyrolysis vs. steam gasification of electronic waste. *Psychol. Bull.* **2018**, *624*, 1119–1124, .
6. Luda, M.P. Pyrolysis of WEEE plastics. In *Waste Electrical and Electronic Equipment (WEEE) Handbook*; Woodhead Publishing: Cambridge, UK, 2012; pp. 239–263.
7. Üner, O.; Bayrak, Y. The effect of carbonization temperature, carbonization time and impregnation ratio on the properties of activated carbon produced from Arundo donax. *Microporous Mesoporous Mater.* **2018**, *268*, 225–234.
8. Umeda, K.; Nakamura, S.; Lu, D.; Yoshikawa, K. Biomass and Bioenergy Biomass gasification employing low-temperature carbonization pretreatment for tar reduction. *Biomass Bioenergy* **2019**, *126*, 142–149.
9. Kasper, A.C.; Berselli, G.B.T.; Freitas, B.D.; Tenório, J.A.S.; Bernardes, A.M.; Veit, H.M. Printed wiring boards for mobile phones: Characterization and recycling of copper. *Waste Manag.* **2011**, *31*, 2536–2545.

© 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).