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Refuse Derived Fuel from Municipal Solid Waste rejected fractions- a Case Study

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Abstract

Portuguese legislation enforces adequate alternatives to municipal waste landfilling of organic wastes as well as others susceptible of valorisation. In the present work, the energetic valorisation of final municipal solid wastes rejected fractions is studied through the production of Refuse Derived Fuel (RDF). To accomplish this purpose several sampling campaigns were performed. Physical, chemical and energetic characterization of the rejected streams was done. Preliminary data allows us to conclude that studied materials have interesting potential to be used as RDF, particularly if blended with higher heating value materials in order to obtain RDF pellets with good combustion behavior, consistency and storage characteristics.

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1. Introduction

European legal framework emphasizes measures for waste valorisation and the utilization of endogenous resources in order to minimize the amount of wastes send to landfill, namely enhancing the valorisation of the rejected streams from the multi-municipal waste management systems with RDF production [1]. In Portugal, as in

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other countries, it is expected the application of RDF in direct combustion or co-combustion systems, namely in the cement manufacturing, paper and pulp mills or in thermoelectric power plants, keeping in mind the principle of proximity manufactures-users. The legal framework is governed by the Integrated Pollution Prevention and Control Directive (2010/75/UE, 2010) [2]. The recovery of energy from these fuels is also possible through the syngas production by gasification, but even in this process, ways to reduce moisture and increase the heating value should be followed [3, 4, 5, 6].

The region under investigation, located in Central Portugal, has an integrated municipal waste management system serving 19 municipalities and 350 000 inhabitants, where municipal and industrial non-hazardous solid wastes are mainly landfilled. A scheme of the operations done in the waste management system under study is shown in Figure 1. Unit operations are mechanical and biological treatment and selective materials collection. These processes lead themselves to final rejected wastes, traditionally send to landfill, considered the rejected fraction in Figure 1.

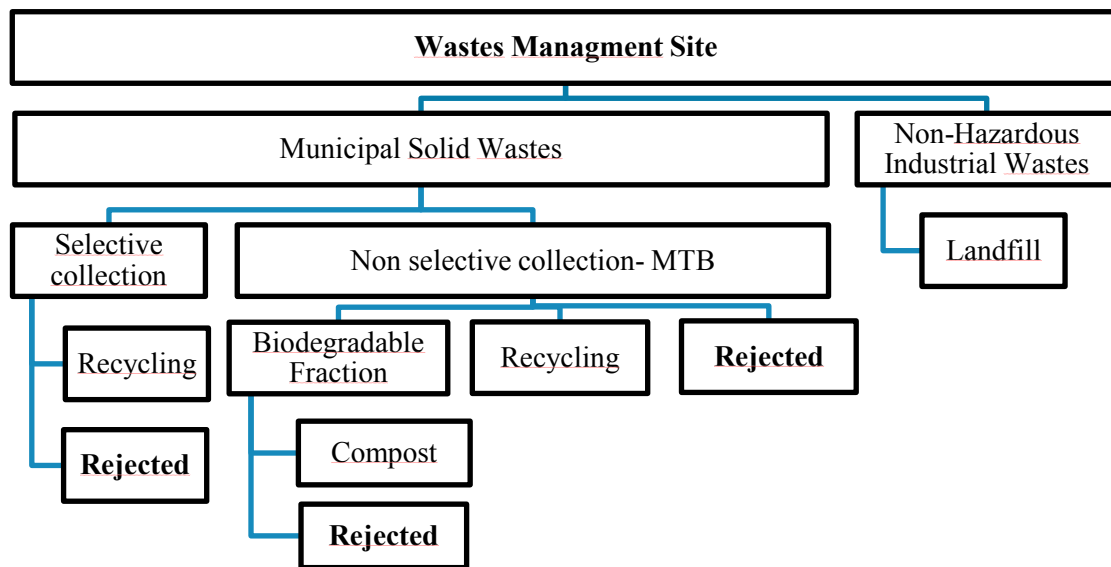


Fig. 1. Materials flow from the management operations within the Wastes Management plant.

Municipal Solid Wastes (MSW) that contain mixtures of paper, wood, green wastes, food wastes, plastics, leather, and rubber can have energy characteristics similar to wood. Use of MSW as a fuel can be accomplished by burning the as-received material, called mass burning, but processing is often required before it can be burned effectively. The purpose is to reduce size and remove materials, valuable materials or non-combustible materials in order to be reclaimed and used as alternative fuel for sustainable disposal and converted into green and clean energy. The impact of burning these heterogeneous materials in traditional boiling systems, as primary or supplemental fuel, needs to be assessed: the physical and chemical characterization of raw materials should be performed. According to Portuguese Standard NP 4486:2008, based in the technical specifications CEN/TC 343 “Solid Recovered Fuels” a classification system is used based on RDF main parameters: lower heating value, chlorine and mercury content.

The ideal composition of RDF is high content in plastics, paper/cardboard, polymeric containers textiles, wood and other organic matter [7, 8]. Higher heating value is in fact associated with paper/card, plastics, wood and textiles content and, once these materials have in their composition biogenic compounds (40-80% w/w), they become an interesting alternative fuel to accomplish the reduction of CO₂ emissions. Moreover, meaningful advantages of RDF are its low production costs and significant calorific value [9]. The drawback associated to these fuels is their heterogeneity, moisture and high ash, chlorine or sulphur content associated with energetic density,

ignition, combustion and corrosion problems in boilers [10]. Several benefits of using RDF in the cement industry blended with other fuels are expected, namely ecological, with the reduction of the non-renewable fossil fuels and its environmental extraction impacts, the reduction of greenhouse gases emissions. It is also important to notice that the wastes would otherwise have to be disposed of on waste disposal sites. The technical benefits enclose the organics destruction at high furnace temperatures and residence times and the reduction of non-combustible parts of raw materials. The energy recovery from wastes can be achieved by direct combustion, gasification or pyrolysis, with the first being more generally allocated. Nevertheless, pelletization should be implemented once it is the potential way for mass and energy densification of these energetic materials. In the economic standpoint, in the cement industry, as fuel consumption decreases the production costs also reduce [10].

The purpose of this study is to characterize the rejected streams from the mechanical treatment of unsorted municipal solid waste, from the rejected residual fraction from plastic municipal selective collection and from the rejected fraction from the composting treatment, in order to evaluate their potential of valorisation as RDF.

2. Material and Methods

The study was carried out in Associação de Municípios da Região do Planalto Beirão Area, between March 2014 and May 2016, only with spring campaigns. Six collecting campaigns were performed at MSW Treatment Plant in the spring of 2014 (one campaign), 2015 (two campaigns) and 2016 (three campaigns). The sampling methodology was performed according to EN 15442 and EN 15443 methods for sampling and for the laboratory sample preparation, respectively. The samples were taken from the mechanical biological treatment, the selected collection and compost rejected streams, defined as MBTR, SCR and CR respectively.

Original sample portions of about 15 kg of MBTR and 10 kg of SCR rejected streams were used. For the CR analysis, 10 kg of sample was taken. In this case, it was taken only one sampling because the biological treatment was recently started up and the sample corresponds to the first rejected streams from the composting process. The laboratory work started with the physical characterization of rejected streams, evaluating the mass content of the food wastes, green wastes, wood, paper/cardboard, plastics (several plastic polymers), textiles, glass, iron materials, aluminium, non magnetic metals, inerts, electric and electronics, and a final class of others (not classified above). Then samples were cut and prepared by quartering and afterwards hammer-milled and pressed. The proximate analysis was accomplished by the analysis of the moisture, volatile matter (VM), fixed carbon (FC) and ashes. An automatic bomb calorimetry was used to obtain the higher heating value (HHV). The lower heating value (LHV) was calculated in accordance to CEN / TS 15400, based on the theoretical elemental analysis of the different fractions, obtained from the physical characterization [2]. For the total chlorine content determination, a KOH absorption solution (0.2 M) was introduced in the calorimetric bomb and Mohr's method was used for quantification.

3. Results and Discussion

The energetic valorisation of wastes has an important role in the waste management strategies with legislation and technical notes arising in order to classify and normalize alternative fuels in the electric power plants. Moreover, the biodegradable part of municipal solid waste used in energy production can contribute to achieve EU 20-20-20 energy goals, including the increase of renewable energy use and the reduction of CO₂ emissions. Therefore, RDF potential of three rejected streams generated in the MSW plant was studied. As expected, the three streams have different compositions and are characterized by their heterogeneity and variability. Table 1 has the data from the physical characterization of the rejected from packaging selective container, while Table 2 represents the data from the MBTR rejected. The MBTR has an important fraction of bio-wastes (food and green wastes) – around 43%, while SCR has mainly plastics, cardboard and textiles. Average values for SCR comprise 88% of plastics, paper and textiles, while in the MTBR these materials represent 36%. The inert fraction, namely glass, metals, rocks and bones, is also representative - around 8% of the MTBR.

Although the characterization was done with tighter classes (food and green wastes or different kinds of plastics), here broader classes are presented. For this reason it is possible to identify the higher content of biogenic carbon in

the MBTR. Similar percentages were found in municipalities with no specific strategies of selective bio-waste collection [6, 11, 12]. According with Kara et al. [12], cities where specific programs for organic wastes collection are in practice, the percentages of this fraction in global wastes stream are far below, between 23 and 32%.

Table 1. Physical characterization of the rejected of the packaging selective container (SCR), in percentage (%).

Type of waste	Sampling campaign						Avg	s
	1	2	3	4	5	6		
Food/green wastes		2.67			2.40		2.53	0.19
Plastics	21.37	29.64	50.24	19.32	22.39	63.41	34.40	18.20
Paper/cardboard	48.10	48.90	21.79	42.41	19.64	28.60	34.91	13.20
Textile	5.98	6.10	11.57	28.86	39.24		18.35	14.97
Tinfoil				0.77	0.19		0.48	0.41
Cork/Wood				0.32	0.42	1.07	0.60	0.41
Inerts		4.78	4.50	4.61	6.38		5.07	0.88
Metal						4.35	4.35	-
Others	24.35	7.92	11.90	3.71	9.53	2.57	10.00	7.86

Avg – average; s – standard deviation

Table 2. Physical characterization of the mechanical-biological treatment rejected (MBTR), in percentage (%).

Type of waste	Sampling campaign					Avg	s
	1	2	3	4	5		
Food/green wastes	49.90	39.10	43.10	38.00	42.50	42.52	4.66
Plastics	12.40	12.90	10.70	13.60	10.60	12.04	1.34
Paper/cardboard	17.60	22.00	3.90	18.20	11.70	14.68	7.06
Textile		4.70	9.20	10.20	12.00	9.03	3.11
Tinfoil							
Cork/Wood			1.80	1.30		1.55	0.35
Inerts	20.10	21.20	8.60	4.20	6.30	12.08	7.99
Metal			1.60	2.50	1.30	1.80	0.62
Others			19.20	12.00	15.60	15.60	3.60

Avg – average; s – standard deviation

The rejected fraction from the composting process (CR) was also characterized. The main fraction was wood (58%) followed by plastics (22%), inerts (19%) and some metals (1%). The higher percentage of the wood is due to the fact that this material is the bulking agent in the composting process and is recovered, along with other fractions, after the compost refining. Although it has a high amount of easily burning material it has an important fraction of inerts (metals and glass). The inert fraction was rejected for analysis. The scattering of results is due to the fact that the quality of MSW changes with time (seasonal characteristics), cultural differences, separation at source level, recycling and waste processing.

The proximate analysis results show the variability between streams, calculated with the average of the campaigns done (Figure 2).

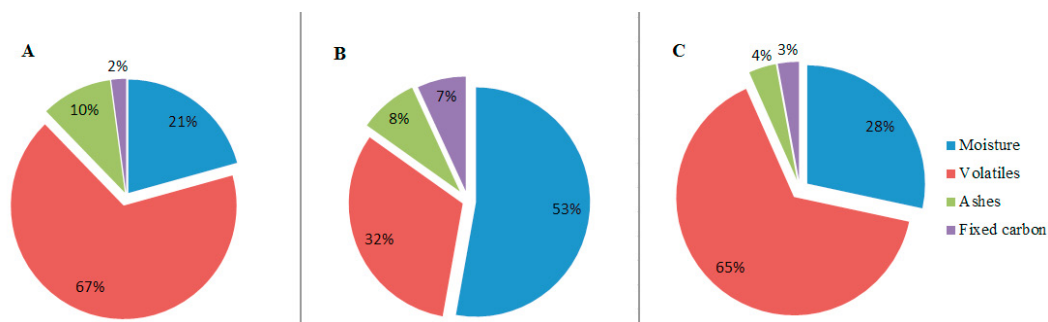


Fig. 2. Proximate analysis of rejected streams: A – SCR; B- MBTR; C - CR

Overall, the CR and SCR showed similar proximate analysis, excepted for the ashes content. This fact may be related with the higher plastic content and lower wood content of SCR comparing with CR. The MBTR has the highest moisture content, 53%, and the lowest volatile matter, 32%, while the SCR has the lowest moisture, around 20% in average and almost 70% of volatile matter. The rejected from the composting process has a moisture content around 29%, but a high volatile fraction. According to Mokrzycki and Uliasz – Bochenczyk [13], RDFs with moisture content below 20%, are desirable in the cement industry, and can be valued as an alternative fuel. A high moisture content has a negative influence on the value of lower heating value (LHV) and consequently a reduction in the combustion efficiency as well as influence the emission of gases such as carbon monoxide, sulfur dioxide, nitrogen oxide and nitrogen dioxide. Nevertheless, in this industrial process, high incineration temperatures, the furnace area, the mean length of the oven and the alkaline environment within the furnace allow the use of this fuel very favorably both in environmental or economic perspectives. In order to use the rejected from MBTR and CR to produce RDF a drying system is necessary. The CR stream has a high volatile matter and low ashes content, which may indicate that this material has an interesting potential to energetic valorization.

According to Portuguese Standard NP 4486:2008, a classification system is used based on RDF main parameters: lower heating value, chlorine and mercury content. In Table 3 the data allows to classify the potential RDF produced from SCR as class 1, while the MBTR would be class 2. Once CR presented a chlorine content of 0.16 ± 0.02 % it is also classified as potentially class 1.

Table 3. Chlorine content of mechanical-biological treatment (MBTR) and selective collection (SCR) rejected samples (%)

	Samples						Avg	s
	1	2	3	4	5	6		
MBTR	0.41	0.13	0.56	0.16	1.19		0.49	0.10
SCR	0.07	0.22	0.19	0.25	0.37	0.19	0.22	0.06

Avg – average; s – standard deviation

The main problem regarding the use of RDF by cement kilns is the chlorine content. When chlorine content is high, it weakens the concrete in terms of 2, 7 and 28 days compressive strength. But although problems of chlorine corrosion and emissions are mentioned in the literature, adequate effluents treatment should minimize its impacts. Ma et al. showed that the most important output of chlorine were the fly ash, with lower percentages found in the bottom ash, semi-dry scrubber and bag filter ash. Therefore, efficient processes of fly ash removal would minimize the chlorine emission through the smokestacks [14]. The NP 4486:2008 considers in the worst class a chlorine concentration of 3% (dry basis) and some authors suggest as acceptable for the cement industry values less than 1.5% [8]. The chlorine concentrations obtained in the present work are below these values suggesting the absence of difficulties in cement kilns combustion and afterwards in produced cement quality. Although these materials result

from a complex mix, when comparing the addition of RDF with coal in boilers feeding in the cement unit plants, it is not expected to increase chlorine output [9].

Overall, the HHVs found were greater than 10 MJ/kg (Figure 3). The SCR stream presented the highest HHV showing potential for RDF production.

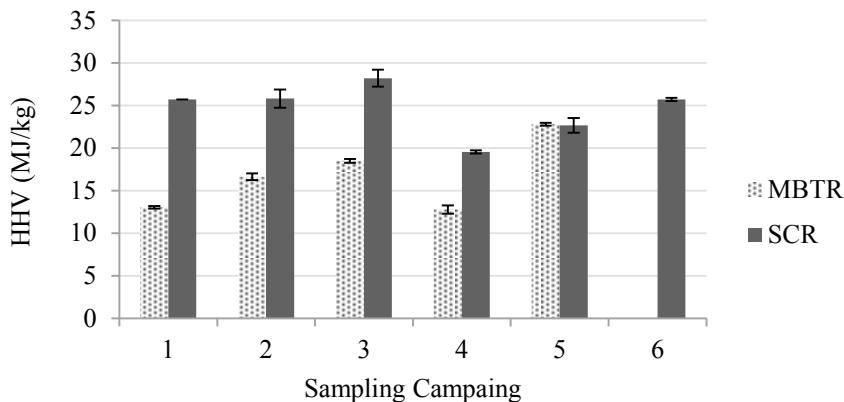


Fig. 3. Higher heating value of mechanical-biological treatment (MBTR) and the selective collection (SCR) rejected samples (MJ/kg)

CR had a higher heating value of 24.22 ± 0.06 MJ/kg. Considering the hydrogen content of the wastes streams, taken by its physical characterization, it is possible to evaluate the lower heating value (LHV), according with the standard NP 4486:2008. In average, the LHV for each stream under evaluation is 23.06, 22.88 and 15.53 MJ/kg for SCR, CR and MBTR, respectively. Fractions rejected from selective collection and from composting have LHV not very different from coal 25.8 MJ/kg but superior to wood or waste from wood, 13.8 — 15.6 MJ/kg [15]. Then, it may be considered that the MSW rejected fractions can be, in fact, an important resource advantageously replacing fossil fuels primary energy sources. The cement industry estimates that up to 20% of the heat load of a cement kiln could be produced by RDF but the moisture should be 10–15% before feeding into rotary cement kiln [12]. Others studies formulate optimum RDF with 42% plastics, 41% paper/cardboard, 7% textile and 10% horticultural waste, based on the existing Singapore waste composition. This RDF had a LHV of 23.7 MJ kg^{-1} , which was less than mineral fuel but it could meet the fuel requirements given in the European standards [16]. Fuels prepared from waste but only with paper, plastic, textile and wood, with 58%, 22%, 15% and 5%, respectively, contained less chlorine and mercury than bituminous coal and RDF resulting from a MSW mechanical treatment plant [17]. This strengthens the fact that the preparation of RDF is very important and dependent on MSW composition and type/performance of specific unit operations employed for preparing fuel from waste. Considering the conversion factors for power plants with the calorific values achieved with the rejected streams, and considering efficiencies of 25% for energy recovery, with the wastes production data from 2015, the energy that could be produced from SCR, MBTR and CR could be 588, 1154 and 1699 MWh/year, respectively.

The MBTR stream shows a biodegradable fraction (high percentage of food and green wastes), concentrating the biogenic carbon fraction and minimizing the CO_2 emissions, while in the SCR stream, carbon concentrates in the synthetic fraction, namely plastics, and textiles. Therefore, concerning neutral carbon emission, MBTR material presents more favorable conditions for combustion although having higher moisture and chlorine contents. In average, MBTR has 41% of carbon with 35% of this value representing the fossil carbon, while in CR the fossil carbon represents 39% of 49% and in SRC 70% of 54% is fossil carbon. According to IPCC guidelines [18], taking into account the wastes physical and chemical composition, it is expected that the CO_2 emissions are around 0.247, 0.545 and $0.993 \text{ kg CO}_2\text{-eq.kg}^{-1}$ for RDF prepared with MBTR, CR and SCR, respectively. Such values are lower than the reported by Nutongkaew et al. for emissions from RDF prepared with municipal waste and palm kernel,

mixed or straight (only RDF). They reached to emission amounts of 1.696 kg CO₂-eq.kg⁻¹ and 1.423 kg CO₂-eq.kg⁻¹, for RDF prepared with mixes and only MSW, respectively [19].

4. Conclusion

Results obtained in the present work show that the refused stream from mechanical treatment (MBTR), the rejected from selective collection (SCR) and from composting (CR) are, as expected, rather different in water content, energetic matter and ashes, as well as in terms of heating value and chlorine content.

Concerning chlorine content, although MBTR presented higher values than SCR and CR, found concentrations suggest the absence of difficulties in using RDF in cement kilns combustion and afterwards in produced cement quality.

The lower heating value (LHV) is 23.06 MJ/kg for SCR and 22.88 MJ/kg for CR, both not very different from coal but higher than wood, while for MBTR the LHV was 15.53 MJ/kg. Considering adequate power plant conversion factors, with 2015 wastes production data, the energy potential from SCR, MBTR and CR could be 588, 1154 and 1699 MWh/year, respectively.

The RDF has an important role as additive of fossil fuels, allowing economical savings but moreover the reduction of CO₂ and other greenhouse effect gases emissions. Taking in account the wastes physical and chemical composition, it is expected that the CO₂ emissions are around 0.247, 0.545 and 0.993 kg CO₂-eq.kg⁻¹ for RDF prepared with MBTR, CR and SCR, respectively. It is also important to emphasize the production of green energy and the decrease of landfill deposition, in a perspective of “Zero Carbon Landfill” and the increase of landfill lifetime.

Studied MSW rejected fractions characteristics are compatible with a production of high quality RDF, thus being an important resource advantageously replacing fossil fuels primary energy.

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