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Characterization of input and output streams at material recovery facilities of São Paulo city for thermal treatments applications

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ABSTRACT

In São Paulo city, the large volume of waste generated and the scarcity of areas for new landfills are two factors for the study of the implementation of new treatment technologies. The present study aims to evaluate the technical feasibility of the incineration of municipal solid waste (MSW) from the door-to-door selective collection from São Paulo city and its rejects. The methodology involved sampling at the input and output of the Loga and Ecourbis Material Recovery Facilities (MRFs) and laboratory tests to determine moisture content, organic matter, ash content and volatile material content to estimate the thermogravimetric curves. Input samples of the MRF-Ecourbis and MRF-Loga showed an average total mass reduction equal to 54.7 % and 58.8 %, respectively, with emphasis between 200 °C and 375 °C. These weight losses reflect materials such as Tetra Pak, textiles, rejects, papers and plastics. Output samples from MRF-Ecourbis presented a 52.5% reduction compared to 69.5% from MRF-Loga, and both had higher mass loss between 200 °C and 275 °C, characteristic of rejects, papers and plastics. Using secondary data, it was possible to estimate the lower calorific value (LCV) of the samples analysed, which was revealed to be higher than that necessary for the technical feasibility of incineration. Considering the composition of the samples and the amount of degradation, incineration is seen as a good alternative for the integrated treatment of MSW, as well as encouraging the energy use of refuse-derived fuel (RDF) from the local MSW.

Keywords: Municipal Solid Waste; Selective Collection; Thermal treatment; Incineration.

1 INTRODUCTION

Aiming to protect the environment from inadequate or incomplete integrated management of solid waste, Brazil has the National Solid Waste Policy (NSWP), Law nº. 12.305/2010. This instrument sanctioned concepts that were previously little known and practiced, established new tools for solid waste legislation and defined a hierarchy of actions before the final disposal of solid waste, aiming to reduce the amount of them sent to landfills: no generation, reduction, reuse, recycling, treatment, and final disposal (Brazil, 2020). The NSWP defines reject as solid waste that, after exhausting all treatment and recovery possibilities through available and economically viable technological processes, did not present any other alternative than the environmentally appropriate final disposal.

To ensure the integrated management of MSW, with the elaboration of a collection route, use of the recyclable fraction and implementation of available technologies for treat these materials is fundamental to carry out studies about the MSW characteristics. This type of procedure is important for decision-making regarding their valorisation and develop the local management systems (Andrade, 2017).

Incineration is a process of controlled combustion, with temperatures higher than 850 °C and presenting the potential to reduce the volume of waste by up to 90%, transforming it into inert ash, reducing its dangerousness, in addition to having the potential to generate energy (Soares, 2011). This technology allows energy recovery, which contributes to the reduction of costs. However, in Brazil they do not exist on a commercial scale. When dealing with MSW through incineration the condition of technical feasibility is lower calorific value (LCV) higher than 2,000 kcal/kg (Brazil, 2014). Incineration has an advantage over landfills because it can be installed close to large centres, reducing logistical costs, and allowing the use of the land for any activities at the end of its useful life, unlike landfills that must be monitored for up to 100 years after closure.

According to Table 1, the LCV of MSW from São Paulo city is 2824.38 kcal/kg, which makes the incineration process with energy recovery feasible. The amount of metal-free MSW is used to reduce the total daily mass of waste, which is feasible to use in the energy generation process through incineration. Plastics play an important role in the process because they have the highest amount of energy among the materials presented.

Table 1. *Percentage composition in mass and energy of MSW in the city of São Paulo (Oliveira et al. (2018).*

Material	MSW Composition (%)	Metal-free MSW fraction (%)	LCV (kcal/kg)	MSW energy (kcal/kg)
Organic matter	57,80	58,93	1310	772,00
Plastic	16,77	17,10	6300	1077,2
Paper / cardboard	11,08	11,30	4030	455,26
Metals	2,18	-	-	-
Others	12,43	12,67	4102,5	519,92

In 2016, the international generation of waste had 44 % of food and green origin, 38 % of recyclables, 12 % of others, 2 % of wood and 2 % of rubber and leather. The composition of waste varies a lot depending on income levels of each country. Recyclable materials had more participation in higher-income countries composition than in lower-income countries, which generated more food and greens, proportionally (Kaza et al., 2018).

Regarding the waste disposal scenario, around 33 % of MSW destined to open dumps, 40 % undergoing to landfills, 11 % in incinerators and 19 % for composting and recycling. This factor also varies significantly by region and income level. Higher-income countries had diverse treatment systems, with 2 % disposed in open dumps, 39 % in sanitary landfills, 6 % sent to composting, 29 % for recycling, 22 % destined to incineration and 2 % for other advanced methods. However, lower-income countries had significantly worst treatment systems, which can reach up to 93 % disposed in open dumps, 3 % in landfills, 0,3 % for composting and 3,7 % for recycling (Kaza et al., 2018).

It is essential to attack the root cause of the MSW generation and disposal problem, and for that, the regional and seasonal characterization of these materials is indispensable, aiming to understand and adopt the best possible alternatives for the current scenario. The objective of this paper is to characterize in the laboratory the MSW from door-to-door selective collection in São Paulo city and its rejects, regarding the application of incineration, to reduce the volume of waste aiming the extension of the useful life of the sanitary landfills serving the municipality.

2 MATERIAL AND METHODS

In São Paulo city, data from the Municipal Authority for Urban Cleaning (AMLURB) reveal that the public administration managed 20.1 thousand tons per day of solid waste in 2012, in the following proportion: 67% domestics, 19% rubble, 2% selective, 1% fairs, 1% health, and 10% others (City Hall of São Paulo, 2018).

In the case of household waste in São Paulo, 89.7% is disposed of in landfills, but only 14.3% are rejects (City Hall of São Paulo, 2014). The 67% of domestics is equivalent to approximately 12,000 t/day (City Hall of São Paulo, 2020). Of this amount, only 1.6% is recycled and the remainder is transported to two landfills: one located in the municipality of São Paulo (CTL – East Treatment Center) and another, located in the municipality of Caieiras (City Hall of São Paulo, 2014). This scenario is a wide field for the implementation of techniques to reduce the waste generation.

In Brazil, the use of technologies for treatment of large amounts of MSW is incipient. Despite the Integrated Solid Waste Management Plan of the municipality of São Paulo, approved in 2014, the construction of Mechanical-Biological Treatment Units (MBTs), large composting plants, and mechanized sorting centres were previewed, but only these the latter was partially implemented (City Hall of São Paulo, 2014).

The MSW sampling sites were the Material Recovery Facilities Ponte Pequena (MRF – LOGA) and Carolina Maria de Jesus (MRF – Ecourbis), according to the plan carried out by Oliveira (2019) and Jacinto (2019).

Fourteen sampling campaigns were carried out between May 2017 and May 2018. This period was chosen because it considers seasonality with climate and cultural changes in the population, which influences the characteristics of MSW in one year. The collection carried out during different days of the week and times was proposed, thus including diverse neighbourhoods and types of waste, generated in more representative exhibitions. During the sampling, MRF – LOGA received dry MSW from the selective collection of 10 submunicipalities located in the West, Northwest and Middle zones of São Paulo city. MRF - Ecourbis received MSW from the selective collection of 13 submunicipalities located in the South Zone of the city. The recyclable waste collected by the companies is taken as a priority to 25 recycling cooperatives qualified in the Socio-environmental Program for Selective Collection of the City Hall. The remaining waste is sent to the MRFs, which receive dry household waste, which is collected at predetermined locations (Ecopoints) or door-to-door. Each MRF has a processing capacity of 250 t/day of waste, but at the time of the study, they received about 90 t/day. In addition, the door-to-door selective collection is responsible for approximately three-quarters of the total selective collection in the municipality.

In the laboratory, samples were shredded in a knife mill with a final sieve of 6 mm opening, homogenized, and stored at 4 °C. Several different analyses and geo-environmental characterization tests were carried out, as published by Mondelli et al. (2022). Therefore, the output samples used during the present work presented a very high initial moisture content, no longer this characteristic coming from the original samples from the MRFs.

2.1 Combustion loss tests

Characterization of waste is extremely important for the execution of solid waste management, because in São Paulo city there are no strategies effectively considered for the treatment of undifferentiated MSW. Aiming to deep understand the problem of waste generation and alternatives that contribute with the reduction and management of them, it was necessary to adopt other methods capable of characterizing the samples regarding moisture content, organic matter, ash content, calorific value, and volatile material content, as well as the elaboration of the thermogravimetric curve. The methodology adopted for the experiments was based on the following standards for solid waste: ASTM D2974–20, ASTM D586–19, ASTM E711–87, ASTM E872–82, UNE-EN 15402 and UNE-EN 15403.

When dealing with gravimetric analysis for MSW, it has an important role in sizing the energy generation potential in incineration plants, considering that it classifies each fraction of waste concerning its weight and volume, in addition, to revealing which part of the samples are biodegradable (Soares, 2011).

Input and output samples from both MRFs were tested for evaluation of the potential for energy, totalling 56 analyses, considering the duplicates. Around 3 g of each sample was burned in an oven and measured when reached 65, 105, 150, and 200 ºC and, subsequently, the burning continued in a muffle with weigh measurements in 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500, 550, 600, 650, 700, 750, 800, 850, 900 e 950 °C. Once the samples were removed from the burning equipment to perform the mass measurement, they were stored in the desiccator. Measurements were made until the mass variation was less than 0.2% of the initial value. Mass measurements were carried out considering the points determined by the standards, thus allowing the obtaining of each parameter, because they are obtained from the mass difference measured between certain temperatures.

2.2 Estimate of the energy potential for incineration

From the secondary data presented by Oliveira et al. (2018), Jacinto (2019) and Oliveira (2019), the energy potential for incineration of waste from the regular and selective collection in the municipality of São Paulo was estimated. To simulate scenarios where incineration is viable, Table 1 were analysed to understand the amount of organic material, plastic, paper/cardboard and others that must be treated by this technology to attend to the condition of technical feasibility. The results were obtained using Equation 1.

$$LCV = E_{OM} * P_1 + E_{PLASTIC} * P_2 + E_{PAPER} * P_3 + E_{OTHERS} * P_4 \quad (1)$$

Where E_{OM}, $E_{PLASTIC}$, E_{PAPER} and E_{OTHERS} represent the energy released by each fraction of MSW in kcal/kg, and P represents the percentage of waste burned.

Samples from the MRFs were reclassified to match the data in Table 1, and for that, the percentage of each residue fraction was calculated according to Equation 2. Materials with lower degree of processing obtained from living beings, occasional household waste that may have been carried with the collected samples, and recyclables that have lost recycling capacity were classified as organic.

$$C_{Xn} = C_{Xm} / (C_{OM} + C_{PLASTIC} + C_{PAPER} + C_{OTHERS}) \qquad (2)$$

Where C_{Xn} represents the adjusted percentage composition of the type of waste for the scenario without metals, C_{Xm} refers to the percentage of the waste of interest in the MSW composition considering metals, and C_{OM}, $C_{PLASTIC}$, C_{PAPER} and C_{OTHERS} represent the percentage of each type of residue in the MSW composition considering the metallic fraction. Matrices of theoretically released energy were elaborated considering different percentages of burning for each class of waste.

3 RESULTS AND DISCUSSION

Visual analysis of each of the samples was carried out, aiming to understand the likely behavior of each of them, as well as to carry out the comparison between the expected and actual results. After the process of burning, the figures below were obtained, expressed in Figures 1 and 2, presenting the total mass loss in percentage, for input and output samples, for both study MRFs. Figures 3 and 4 show the behavior of mass loss in percentage for each sample, only for the degraded fraction of each one, i.e., the amount of ash at the end of the burning process was disregarded.

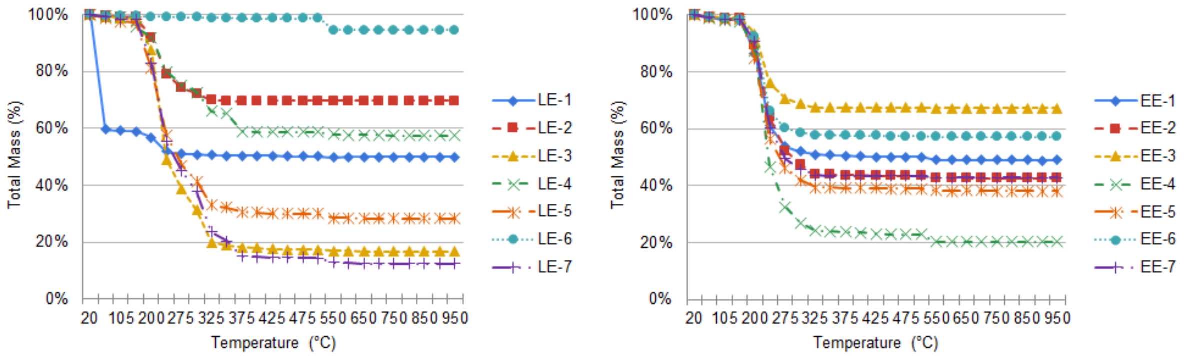

Figure 1. *Average mass loss of the MRF-LOGA-LE input samples. Average mass loss of the MRF-ECOURBIS – EE input samples.*

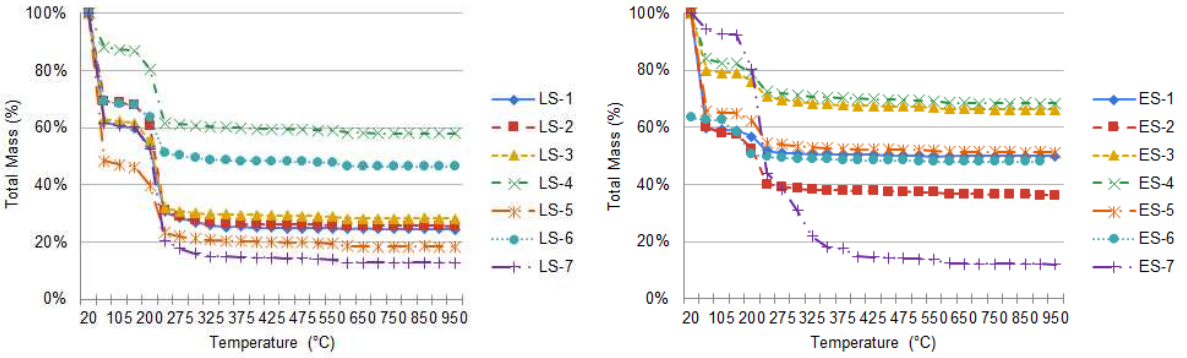

Figure 2. *Average mass loss of the* MRF*-LOGA - LS output samples. Average mass loss of the* MRF*-ECOURBIS - ES output samples.*

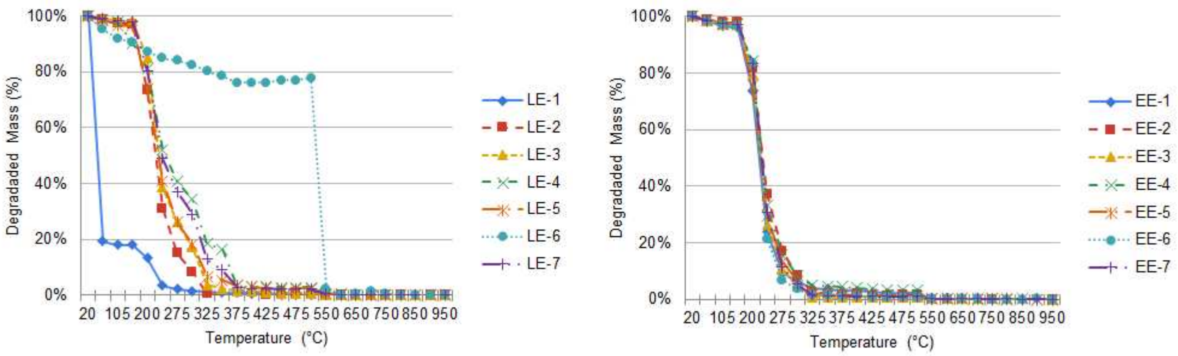

Figure 3. *Average degraded mass loss of the MRF – LOGA – LE input samples. Average degraded mass loss of the MRF – ECOURBIS - EE input samples.*

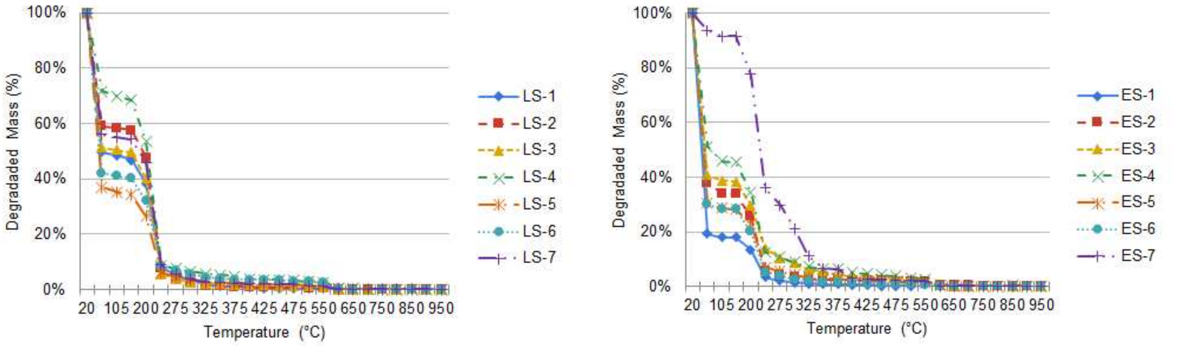

Figure 4. *Loss of average degraded mass of the MRF– LOGA - LS output samples. Average degraded mass loss of the MRF - ECOURBIS - ES output samples.*

To simulate the curve derived from mass loss, Figures 5 and 6 were constructed based on the ratio between the mass difference at the temperature of interest and the immediately previous temperature (Equation 3), and the mass of the temperature of interest, as follows:

$$Tx = (Xj - Xi) / Xi \qquad (3)$$

Where, Tx is the mass loss rate, Xi is the mass at the temperature of interest and Xj is the mass at the temperature before Xi.

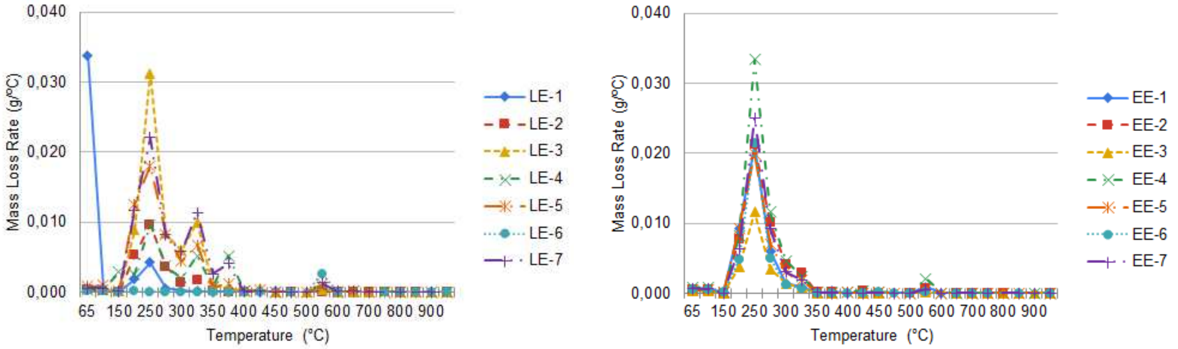

Figure 5. *Average mass loss rate of the MRF – LOGA - LE input samples. Average mass loss rate of the MRF – ECOURBIS - EE input samples.*

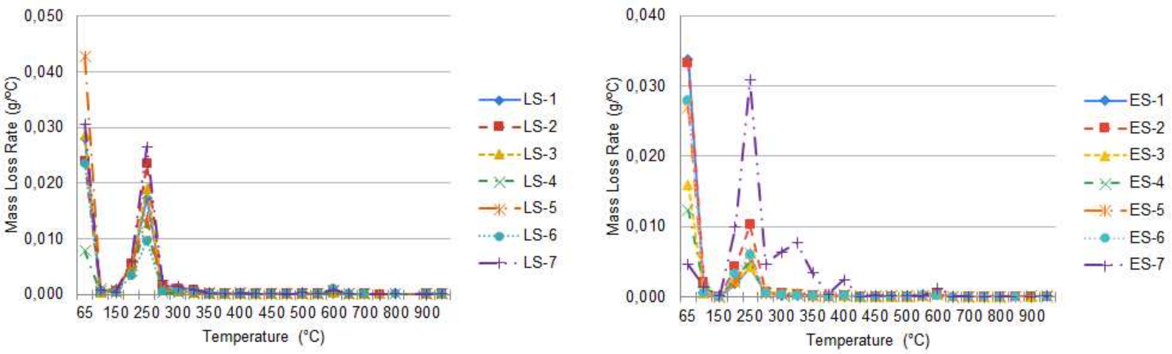

Figure 6. *Average mass loss rate of the MRF– LOGA - LS output samples. Average mass loss rate of the MRF – ECOURBIS - ES output samples.*

The input samples, presented closer average values when compared to each other, reflecting 1.5% of moisture content, 53.1% of organic materials, 46.9% of ash content and 49.6% for volatile materials for MRF – Ecourbis-EE, compared to 1.3%, 57.1%, 42.9% and 54.5% for MRF – Loga-LE, respectively. The output samples presented higher moisture content, due to laboratory tests carried out before the execution of this work. The average values for the MRF-Ecourbis-ES were 45.5% for moisture content, 29.8% for organic material, 70.2% for ash content and 55.0% for volatile material. Such numbers show a considerable difference when compared to those obtained for MRF-Loga-LS, 61.4%, 53.7%, 46.4% and 49.3%, respectively. The higher amount of organic materials present in input and output samples reveals great potential for degradation and agrees with the literature (Soares, 2011). The amount of degraded mass is in accordance with the gravimetric compositions of the tested samples, as there is an important participation of inorganic materials, such as glass and metals, as well as the mass reduction limit for each type of material present in them and the uncertainty associated with the composition of the rejects.

3.1 Energy potential for MSW

According to Filho (2008), the determination of the theoretical energy potential (P_{et}) of energy generation from MSW can be calculated through Equation 4:

$$P_{et} = 0{,}001163 * LCV * \eta * m_{MSW} \quad (4)$$

Considering the overall electromechanical efficiency (η) of an incinerator of around 28% (Filho, 2008), LCV equal to 2824.38 kcal/kg (Oliveira et al., 2018.) and daily production of MSW from the household origin (m_{MSW}) equal to 12000 t/day (City Hall of São Paulo, 2020), the theoretical potential for energy generation is 11036.8 MWh/day.

To investigate the potential for the energy use of recyclable samples collected in the MRFs, the gravimetric classes obtained for them by Mondelli et al. (2022) were reclassified in percentage for organic material, plastic, paper/cardboard and others, as shown in Table 2. So, a database normalization was made for the same input and output data from both MRFs to investigate the theoretical behavior of MSW.

Table 2. *Potential energy use for São Paulo city MRFs without metallic fraction.*

	Input			**Output**		
MRF	**Ecourbis (%)**	**Loga (%)**	**Average**	**Ecourbis (%)**	**Loga (%)**	**Average**
Organic Matter	8.4	10.9	9.6	45.2	30.1	37.7
Plastic	31.6	25.8	28.7	20.8	30.4	25.6
Paper / Cardboard	34.3	50.1	42.2	7.4	23.9	15.7
Metals	-	-	-	-	-	-
Others	25.7	13.2	19.4	26.6	15.5	21.0
Energy (kcal/kg)	4537.2	4329.5	4433.3	3291.8	3912.5	3602.1

Table 2 reveals that the average composition of the input and output samples from both MRFs, satisfy the condition of technical feasibility for incineration with a good operating margin, due to many recyclables' presence. The main difference is the greater amount of paper and the smaller number of organics in the input samples. The opposite behavior is observed for the output samples, which reflects in the lower LCV value for the latter.

During the sorting process, materials with the potential for recovery are separated and sold. During the study, both MRFs commercialized paper, cardboard, Tetra Pak, aluminum, ferrous metals, PET, HDPE, and LDPE fractions, but only the MRF Loga sold glass, PVC, and PP. The presence of glass in the selective collection in São Paulo tends to disrupt the sorting process, as this material has a low market value and have high-density material, affecting the final composition of the rejects from the MRFs. An MRF properly operated, supported by effective educational programs and public outreach, tends to have rejects percentage of less than 10% of the total weight of the facility. However, these numbers are underestimated because of the post-consuming plastics in the selective collection are very high and without treatment technology (Correa et al., 2022).

Table 3 presents a summary of the input and output MSW composition of the MRFs samples, which were calculated to find the minimum amount of each fraction that must be burned in each scenario to meet the condition of technical feasibility for incineration. These data were treated using the LCV values presented in the Table 2 and matrices constructed with the aid of the PROCX function of the Microsoft Excel software.

Table 3. *Minimum dry MSW amounts scenarios for technical incineration feasibility.*

Input MRFs Samples				
Scenario	**Organic**	**Plastic**	**Paper**	**Others**
1	49%	49%	49%	49%
2	100%	47%	47%	47%
3	13%	100%	13%	13%
4	38%	38%	100%	38%
5	17%	17%	17%	100%
6	100%	100%	35%	35%
7	100%	9%	100%	9%
8	100%	13%	13%	100%
9	0%	100%	100%	0%
10	0%	100%	0%	100%
11	0%	0%	100%	100%
12	0%	100%	100%	100%
13	100%	0%	100%	100%
14	100%	100%	0%	100%
15	100%	100%	100%	0%

Output MRFs Samples				
Scenario	**Organic**	**Plastic**	**Paper**	**Others**
16	57%	57%	57%	57%
17	100%	50%	50%	50%
18	22%	100%	22%	22%
19	44%	44%	100%	44%
20	48%	48%	48%	100%
21	100%	100%	31%	31%
22	100%	0%	100%	0%
23	100%	38%	38%	100%
24	0%	100%	100%	0%
25	0%	100%	0%	100%
26	27%	27%	100%	100%
27	0%	100%	100%	100%
28	100%	4%	100%	100%
29	100%	100%	0%	100%
30	100%	100%	100%	0%

Table 3 reveals that it is possible to use dry MSW and its rejects from São Paulo city for incineration and as refuse-derived fuel (RDF). The RDF is an innovation in the form of waste energy recovery because it presents market potential with focus on the post-segregation waste that would become reject. In addition, RDF production proved to be viable, meeting the economic, technical, environmental, and regulatory pillars, and being capable of integration with other complementary technological solutions (Levi, 2021).

RDF obtained from a mechanical and biological treatment (MBT) plant have high LCV, with low ash and moisture contents, although its composition and quality depend on the characteristics of the feed residues, the specificities of the plant and the efficiency of its operations. The RDF takes advantage of the energy potential present in the non-recyclable fraction of MSW and non-hazardous industrial solid waste as an alternative, being a viable environmental and economical source of energy. This fits into the treatment section of non-recyclable MSW before final disposal in landfills, and once processed, it acquires an attractive market value compared to petroleum coke. The implementation of RDF along with recycling becomes interesting, because the production of RDF, as well as its use in energy recovery systems, becomes more viable as waste segregation increases (Levi, 2021).

In general, the MRFs are schematized for a sequence of manual pre-sorting, crushing, sieving, classification and separation into four recoverable fractions: organic, recyclable, waste and RDF. The production of this type of fuel is seen favorably, mainly because the municipality of São Paulo already has MRFs with technologies that help segregate materials, which implies less need for adaptation and investment. Currently, about three-quarters of the samples studied for selective door-to-door collection in the municipality have the physical and chemical potential for transformation into RDF and almost half of these are already segregated at the end of the MRF plant process, just processing them for commercialization (Levi, 2021).

Rodrigues and Mondelli (2021) found that the most economically, socially, and technically viable way to manage MSW in the Southeast region of the São Paulo city is the implementation of MBT plants with the capacity to process 1275 t/day of MSW each. In these, there will be a mechanized separation of materials, allowing an increase in the recovery rate of recyclable materials from 2% to 7.44% in the municipality, extending the same data to the northwest region. The dry fraction could be commercially used as RDF or as recovered products, such as plastic and cardboard. The organic fraction should be destined for anaerobic digestion and the digestate will be composted. Furthermore, for every 5,000 tons of MSW destined to MBT plants, around 3,300 tons would be destined for anaerobic digestion, which would result in approximately 2,000 tons of compost.

The energy generation potential presented by Rodrigues and Mondelli (2021) is 1650 MWh/day, compared to the value of 11036.8 MWh/day calculated from Equation 4. This difference is due to the amount of waste destined for energy generation by each model, the calculation method used and the segregation of recyclable materials in the model that provides Mechanical-Biological Treatment and selective collection increasing.

4 CONCLUSIONS

The laboratory tests method developed proved to be efficient for the characterization of MSW by burning, approaching what would be the TGA and DTG curves. Through data analysis and comparison with the literature, the complexity of the analysed samples was verified. In general, the profile of the obtained curves and the degradable fraction are similar when compared to the respective duplicates.

The data obtained by burning tests and energy potential analysis promote the discussion of the application of MSW heat treatment by incineration in the Metropolitan Region of São Paulo (MRSP). To verify the technical viability of this methodology, it is necessary to determine the calorific value of the samples, to provide greater reliability and precision for decision-making, in addition to verifying whether there is a need to use additional fuel to reach the condition of technical feasibility.

The incineration of MSW in São Paulo with energy recovery proved to be viable for municipal gravimetry values of regular collection in the city and the compositions of the studied samples, coming from the selective collection and their rejects. The use of this treatment method can be integrated with other technologies, to enable a more complete waste management model for the city of São Paulo.

In the current scenario, incineration is an alternative for the reduction of the MSW generation, since there is scarcity of new areas to construct new landfills in the MRSP, low recycling rate, and to increase the useful life of the landfills currently used. The possibility of using the RDF is a good solution to enable the advance of selective collection in the municipality and to follow the hierarchy proposed by the NSWP.

However, the use of incineration as MSW treatment is present in the municipal waste management plan and should be accepted along with other alternatives for the treatment of the wet and dry fractions of the local MSW, and if necessary, moving towards circular economies and the hierarchy established by the NSWP, foreseeing the recycling increasement.

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