Management of urban solid waste in the city of Manaus-AM. Thermal characterization for power generation

https://doi.org/10.56238/sevened2024.004-024

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ABSTRACT

With a population of two million inhabitants, Manaus – AM has undergone a considered industrial development and consequent urban development, resulting in a significant increase in the need for urban energy and in the control of waste generated. All municipal solid waste (MSW) is currently deposited in landfills, causing health problems to the population, contamination of soils, rivers, and groundwater. This article proposes the use of incineration to recover energy from urban solid waste to produce electricity in the metropolitan region of Manaus - AM. Energy characterization tests were carried out on MSW collected from various neighborhoods of the city, such as: gravimetry, thermogravimetry (TGA), immediate analysis, elemental analysis and superior calorific value (PCS) tests. Finally, the lower calorific value (PCI) was determined. The high percentages of recyclable materials, above 50%, combined with PCI values, presenting values between 15,000 and 19,000 kJ/kg on dry days, calorific value equivalent to the fuels cataloged in the bibliography such as lignite, kiln-dried firewood and coconut shells (17,000 kJ/kg), Coal, (15,000 KJ/Kg), showed promise in a future decision-making for the treatment of MSW by incineration.

Keywords: Municipal solid waste, Waste incineration, Energy recovery, Sustainable energy generation, Energy potential of solid waste.

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INTRODUCTION

Nowadays, controlled dumps and landfills occupy large areas in large urban centers, contaminating soils and groundwater, attracting animals and insects, increasing the risks to the health of the population and increasing the emission of greenhouse gases. A considerable portion of this MSW ends up in the beds of rivers and streams, clogging rainwater systems and causing flooding. These social and environmental benefits alone justify the need to solve this problem. Federal Law No. 12,305/10, which instituted the National Solid Waste Policy (PNRS), gave a period of 10 years for the problems arising from MSW to be extinguished. By the end of the deadline, approximately 60% of the country's cities had not yet achieved this goal.

Between 2010 and 2022, MSW generation in Brazil registered a considerable increase of 20.90% (from 67 million to 82 million tons per year), three times the population growth rate of 6.46% in the same period. In turn, per capita generation increased from 348 kg/year to 381 kg/year (ABRELPE, 2022). On the other hand, there would be economic and sustainable benefits if there were energy recovery through the thermal treatment of MSW, since there is a viable and attractive possibility of integration with other processes, such as recycling and composting, as well as with the reduction of waste disposal in landfills and dumps and its consequences (ABREN, 2020).

In the city of Manaus, capital of the state of Amazonas, the largest state in Brazil, with its ecological and environmental riches, there is no thermal treatment of solid waste. 2,800 tons of MSW collected every day are landfilled at the site. The city has no area or interest in building another landfill, and must hire these services from private companies. In addition, the IBGE classified Manaus as the fourth worst city in Brazil with garbage accumulation in public places. Approximately 6.2% of the surroundings of the households have accumulated garbage. Just near the creeks there are 108,000 residents affected by unpleasant odor, diseases and a lot of dirt. A total of 345,000 families are affected by the dirt in the streams of Manaus (SEMULSP MANAUS, 2021).

Currently, the situation of MSW management in Manaus - AM Almost all MSW is paid to be filled in (98%), occupying an area of 66 hectares that has been in operation since 1985 and is due in 2024. The technology for solid waste management was only used in 2006, that is, for more than 20 years it operated as an open-air dump, which resulted in contamination of some streams such as the Bolivia and Conceição bridge, and the Alta do Tarumã waterfall. The landfill also generates greenhouse gas emissions and a bad smell at the site. The low recycling rate (1.68%) negatively impacts the income expectations of collectors' cooperatives and other related activities (ABRELPE, 2022).

Abren (2019) reveals that the waste sector is responsible for 11% of the total greenhouse gases emitted into the atmosphere. The methane (CH_4) emitted is 25 times more harmful than carbon dioxide (CO_2). And the construction of landfills is continuous, every ten years a sanitary landfill is increased in the world. Landfills are still used all over the world as a waste destination. The global overview of MSW destination can be shown in Figure 1. It can be seen that adding up all the existing types of landfills results in a total of 70% and the composting, recycling and incineration processes add up to 30% (ABREN, 2019).

Figure 1. Destination of MSW in the world. Adapted from ABREN, 2019.

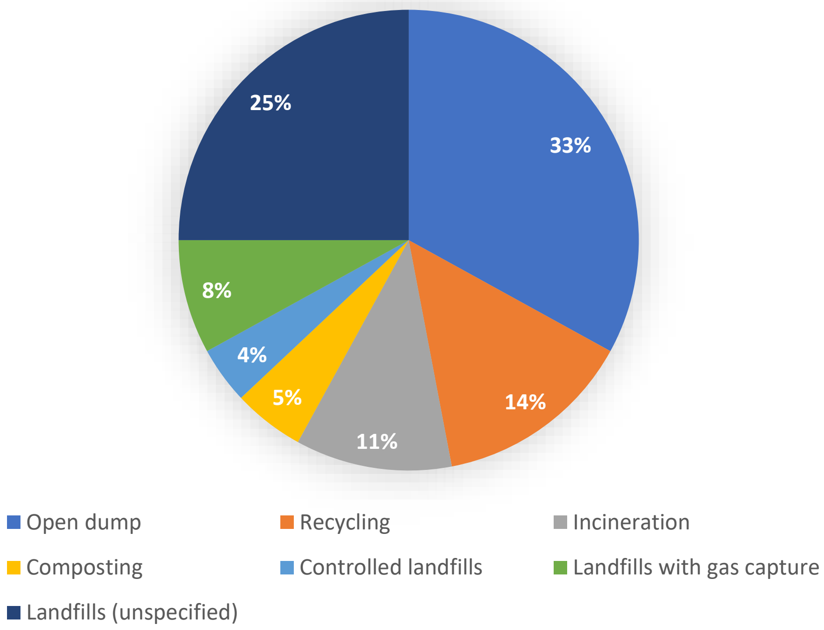
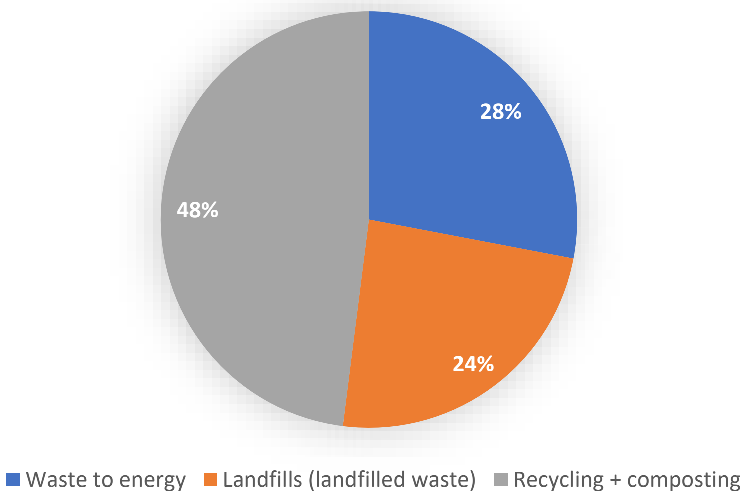


Figure 2 illustrates the European Union's overview of MSW destination. In several countries there are laws prohibiting the construction of landfills. In places where they still exist, the tendency is to decrease (ABREN, 2019).

Figure 2. Overview of the European Union destination of MSW – EU28.



Source: Adapted from CEWEP. 2018.

Research has been carried out in recent years, such as Lino and Ismail (2017, 2018), Lino

(2014), Rada (2014), Jones (2010), Maize (2016), Fonseca (2017), Kuhl (2015), Paulo, Dalbosco & Leites (2013), Andrade (2019) and many others have published the MSW treatment technique for energy production and as a mechanism for social inclusion. Menezes (2000), Morgado & Ferreira (2017) conducted studies on incineration as a heat treatment for MSW. Brietzke (2016) studied the feasibility of composting in the treatment of MSW. Poli (2014) and Queiroz (2014) recorded research on the PCI of USW.

ENERGY USE OF URBAN SOLID WASTE.

In recent years, the term circular economy has been widely used, an alternative to the traditional linear economy based on production-use-disposal, whose objective is to reduce the use of new resources through the reuse and valorization of end-of-life products and materials, and thus avoid the generation of waste, pollution and greenhouse gas emissions (ABREN, 2020).

According to Abren (2020), there are more than 2,430 plants worldwide, but Brazil still does not have any ERU, revealing that our country is still far below what is desirable in terms of MSW management, allocating 96% to landfills and dumps, and the vast majority of landfills would not be licensed with international standards. However, several actions have been taken to make this a reality. The new sanitation framework brings the obligation of bidding through public-private partnerships (PPPs) and allows the collection of tariffs on the consumption bill, such as the water bill, for example. The Ministry of Mines and Energy recently announced that it will hold a regulated auction for the contracting of electricity from URE (ABREN, 2020).

A new WTE plant currently produces an average of 600 kWh of electricity per ton of MSW, while landfills with biogas collectors produce an average of 65 kWh per ton, i.e., a WTE plant is almost ten times more energy efficient, not to mention that the electricity generated from waste in a landfill environment is, in this case, it is extracted slowly over time, while in WTE energy is generated immediately (ABREN, 2019).

Thus, Waste-to-Energy (WTE) can be defined as the generation of electricity from biodigestion or heat treatment of waste, whether organic or inorganic, through the use of several existing technologies. The implementation of these WTE plants has been the solution found in some countries for the final destination of MSW that was not used in the recycling or composting process, that is, MSW that would be sent to landfills, and these, even sanitary ones, bring risks of irreversible contamination to the environment. Member countries of the European Union, the United States, China, India, among others, have included WTE as a priority in the treatment of this waste, which, in addition to obtaining a sustainable destination, contributes to the generation of clean, renewable and firm electricity, attributing greater reliability and stability to the electrical system. The number of WTE heat treatment plants in operation in Europe reaches 522, not including incineration of hazardous waste (medical, radioactive, etc.), the amount of heat treated waste in millions of tons, which represents a total of 522 plants in operation and 263,314 tons/day (tons per day) processed in 2016 (ABREN, 2019).

In Brazil there are no WTE plants in operation, only the CS Bioenergia biodigestion plant in Curitiba, some small R&D plants, and some landfill gas capture plants. However, the country has the potential to generate up to 5.4% of the national demand through MSW heat treatment plants, with 106 units generating 236,520 GWh/year and a total installed capacity of 3,176 MW. There is also the potential to generate 1.5% of the national demand through accelerated anaerobic biodigestion, with a total installed capacity of 868 MW, generating 6,701 GWh/year. In total, it is estimated that MSW can generate up to 7% of national demand. It is estimated that the country will be able to receive the approximate amount of R$ 28 billion in investments and, thus, result in the generation of employment and income, and by 2031, R$ 11.6 billion/year in infrastructure investments will be necessary to ensure the universality of sustainable solid waste management in Brazil (ABREN, 2019).

HEAT TREATMENT

Heat treatment is one in which the waste receives a certain amount of heat for a certain time, they are called respectively reaction temperature and reaction time The objective is the reduction of volume with the physicochemical processes. Currently, in relation to the thermal treatment system of municipal solid waste, different techniques are applied: drying, pyrolysis, gasification, microwave treatment, plasma and incineration (LINO & ISMAIL. 2018). In many parts of the world, a combination of two or more techniques is applied, mainly to obtain thermal energy and electrical energy.

Energy recovery consists of the technologies and industrial processes that make it possible to recover part of the energy contained in MSW. Among the existing methods, the most commonly used use incineration by combustion process. The composition of MSW also influences the efficiency of the energy recovery system, depending on the location and how they are generated, especially on the composition, whether it has more or less organic residue, calorific value, humidity, etc.

INCINERATION

An MSW incineration plant operates on a similar operating principle to a typical thermal power plant, with the main difference being the combustion of MSW, or a combination of MSW and another fuel, serving as the primary heat source for the boiler. (ADNAN ET AL., 2021)

Waste incineration reduces the large volume of waste generated and consequently increases the useful life of the landfill. This waste treatment technique occurs very quickly and enables the generation of energy (VG RESIDUALS, 2020).

Incineration can be a form of technology to solve this problem of MSW, as this treatment reduces the volume of waste by up to 90% and the weight to a range of 20 to 30%, also highlighting the two types of ashes produced in this process, namely: solid ash and light suspended ash. The light suspended ash is treated and removed from the exhaust gases. Solid ash is usually inert and typically reused in the manufacture of concrete artifacts, building material, ceramics, etc. (LINO & ISMAIL, 2018).

First, the MSW was burned in the primary chamber (T = 500 to 900 °C). Waste turns into gases and small particles. This prevents volatilization of metals. The second process takes place in the secondary chamber: the gases and small particles formed are burned at higher temperatures (750 to 1250 °C) until complete combustion. Usually the time is 30 min in the first phase and three seconds in the second. After incineration, the solid part is removed from the grate. The amount of this solid material after the incineration process varies from 12 to 30% by mass (from 4 to 10% by volume) of the original material and has the appearance of gray, being a clean, inert material suitable for application to civil construction in the manufacture of bricks, sidewalks, pavements, etc. (MENEZES, GERLACH & MENEZES. 2000).

Morgado & Ferreira (2017) surveyed the possibility of the existence of an incinerator with cogeneration of energy in the city of Goiânia. There, the population was 1,897,957 people, who generated 1,583.50 t/day of MSW, of which 92.50% are disposed of in landfills. They estimate that if they were incinerated, there would be a 90% reduction in volume and a 15% reduction in weight. It would also be possible to generate up to 791.75 KWH, or 289 MW per year.

Lino & Ismail (2018) recorded that solid waste is a renewable energy resource, with the capacity to generate energy in the range of 8 to 11 MJ/kg, while Waste Derived Fuel (RDF) composed of dry MSW has a calorific value ranging from 12 to 17 MJ/kg. From this they concluded that one ton of MSW and one barrel of oil both release almost the same amount of heat, about 7 GJ.

One of the countries that manufactures and uses incinerators for solid waste treatment is Japan. The country incinerates about 80% of MSW in about 1172 incinerators, where 24.5% of them have energy recovery, reaching 1770 MW. On average, the energy conversion rate of these incinerators is about 200 kWh/t MSW. In Tokyo, the electricity conversion rate is about 390 kWh/t of MSW, in Osaka, 320 kWh/t of MSW, while Kobe has a production rate of about 300 kWh/t of MSW. In the latter, incineration supplies 16.2% of the electricity demand and 25% of the hot water demand. Singapore has four incineration plants to handle a load of 1700 t/day. Treated MSW is sourced from households and industry with lower calorific value (PCI) around 6 MJ/kg. Each boiler generates 42 t/h of steam and generates 30 MW (LINO & ISMAIL, 2018).

PYROLYSIS

Pyrolysis is a form of thermochemical treatment of organic material developed entirely without the presence of oxygen, with the possibility of oxidation of a small fraction of residue due to the presence of some oxygen contained in the reactor. This technology is used to destroy volatile organic compounds, fuels, and pesticides in the soil. This is an old technology, but for heat treatment of biomass and MSW it is an innovative technique. The products resulting from pyrolysis can be in liquid, solid, or gaseous states, depending on the composition of the residue and parameters such as temperature, pressure, and burning time. During processing, the organic material is transformed into syngas or syngas (a mixture of flammable gases such as CO, H2, CH4) and other volatile organic compounds (VOCs) with a calorific value ranging from 10 to 20 MJ/Nm^3. A part of these volatiles can be condensed, producing oil, wax and tar, collected in the cooling phase of the syngas and used as liquid fuel. The remaining residue is a type of ash and charcoal. Each ton of solid waste contains 11 kg of ammonium sulfate, 12 liters of tar, 9.5 liters of oil, among others (LINO, 2014). The gas fraction can also be distilled to obtain various hydrocarbons (gasoline, kerosene, and diesel) either burned in boilers or to generate electricity, or partially oxidized to obtain syngas, as occurs in gasification (ABREN, 2019).

The problem is that the syngas generated needs to be purified, for example, through a washing process, only then, without contaminants, this gas can be used, both for electrical and thermal generation, in gas generator sets, or even use it in thermal processes to generate heat (steam, hot water, hot air. For the pyrolysis process to occur, energy from an external source is required, which many consider unfeasible and has not been applied on an industrial scale for MSW processing (ABREN, 2019). The operation of this technology takes place at temperatures ranging from 300ºC to 1600ºC. Therefore, it is observed that any thermal process at temperatures above 300ºC and in the absence of oxygen are considered pyrolysis methods. The advantage is that pyrolysis has proven to be an energy-, economically, socially and environmentally viable technology, being a highly sustainable system, due to the energy generated from 500 kWh/t of MSW, and low levels of atmospheric emissions. (KÜHL, et al. 2015).

GASIFICATION

Gasification is the process of converting organic material into combustible gas in the presence of air in a controlled quantity and high temperature. It also results in syngas gas and has combustible characteristics. It is an endothermic thermal conversion technology for energy extraction from different types of organic materials (LINO, 2014). The principle of this energy conversion process is based on the use of a raw material, called pre-treated biomass, that is, with a low moisture content, converting it into gas, through gasification reactions, consequently this gas is cooled and purified (KÜHL, et al. 2015).

In general, in both processes, gasification as in pyrolysis, the MSW undergo a pre-treatment, in order to create a more homogeneous and dry mass. Subsequently, they are subjected to heat treatment at high temperatures and in an oxygen-poor environment, a situation in which the gases generated in the combustion process also need environmental control systems to eliminate pollutants. In terms of energy, gasification has a lower net energy use (ABREN, 2019).

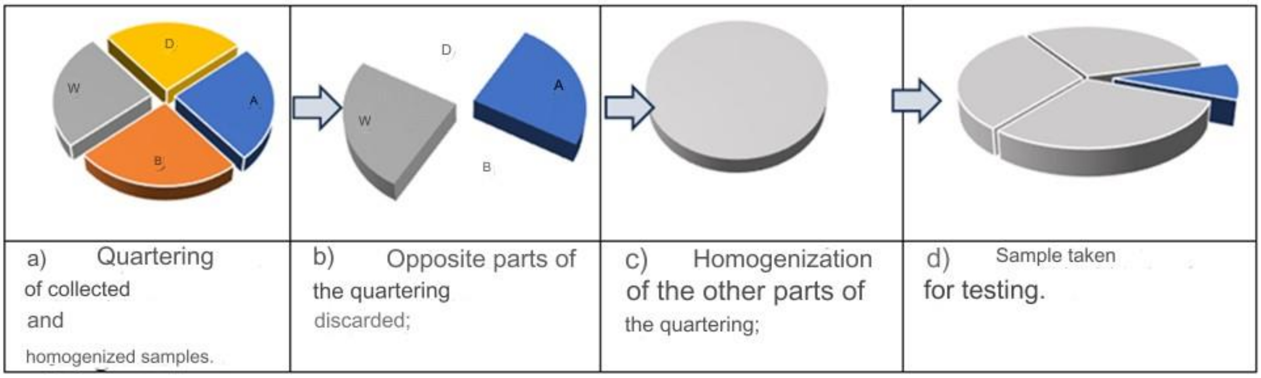
Several gasification processes for heat treatment of solid waste are being developed as an alternative to incineration. The biggest challenge of this technology is to obtain acceptable efficiency due to the high energy consumption in the pre-processing of waste, consumption of large amounts of pure oxygen and cleaning of the syngas. These are the factors that affect the efficiency of converting syngas to electrical energy. Several MSW gasification processes have been proposed, but very little has been built and tested (LINO, 2014).

METHODOLOGY

GRAVIMETRIC COMPOSITION OF MSW

MSW were collected from 18 neighborhoods of the city for gravimetry. The activities developed are carried out in three stages: quartering, identification and weighing of the categories of each type of waste. It is regulated by ABNT - NBR 10.007/2004. The quartering is explained in figure 3.

Figure 3. Stages of the quartering according to NBR 10.007/2004.



With these data, the percentages of each type of existing material were determined, according to Equation 1, by dividing the percentage of the mass of each material by the total mass of the sample, as well as the calculation of the apparent specific weight - direct division of the total mass by the total volume. After the total weighing of the sample, the waste was sorted on the plastic tarpaulin as follows: Paper/cardboard, wood, metals, glass, hard plastic (HDPE), soft plastic (LDPE), PET plastic, PP plastic, Styrofoam, rejects and organic material. Again, each type of material was properly weighed separately to obtain the representativeness in weight of each one. The percentages of each type of material in that 1000-liter sample were then determined, according to Equation 1.

Equation 1. It allows you to calculate the percentage of each type of material after sorting.

$$\text{Percentual de cada categoria (\%)} = 100 * \frac{\text{peso de cada fração (kg)}}{(\text{peso total da amostra (Kg)})} \quad (1)$$

Where:

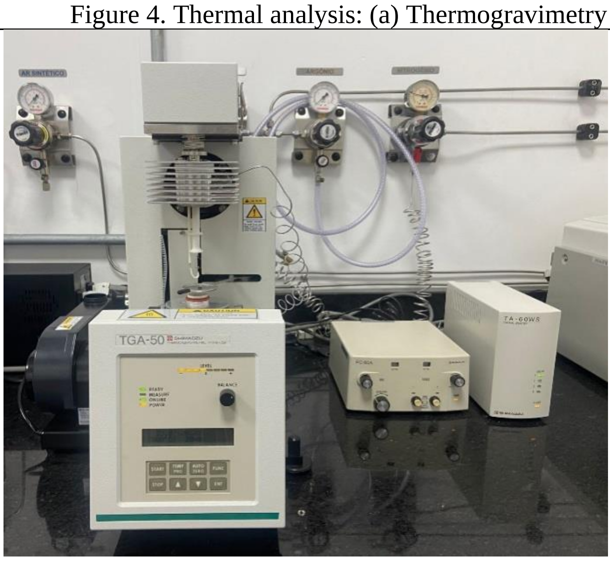
Percentage of each category = percentage of each class/type of waste present in the sample;

Weight of each fraction = weight of each class/type of waste after sorting.

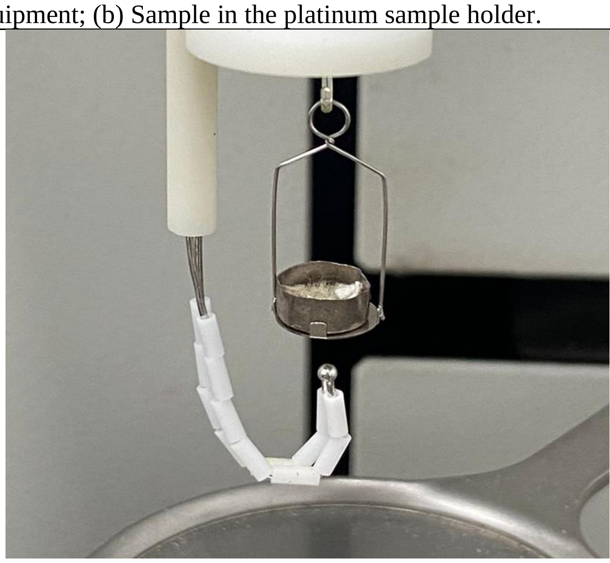
TGA/DTG THERMAL ANALYSIS

The thermal behavior of MSW was evaluated by Thermogravimetry Analysis (TGA) and Thermogravimetry Derivative (DTG). The analyses were carried out at the Laboratory of Synthesis and Characterization of Nanomaterials, of the Federal Institute of Amazonas (LSCN/IFAM), with the aid of the Shimadzu thermogravimetry analyzer, model TGA-50, shown in Figure 4. To perform the analyses, 1.0 mg were deposited in a platinum crucible, without a cap. This sample holder was inserted into the equipment, which in turn operated at a heating rate of 10 °C per minute, until it reached a temperature of 1000 °C, with a nitrogen gas flow of 50 milliliters per minute.

Figure 4. Thermal analysis: (a) Thermogravimetry equipment; (b) Sample in the platinum sample holder.



a)



b)

IMMEDIATE ANALYSIS: MOISTURE, ASH, VOLATILE MATERIAL AND FIXED CARBON.

The values of moisture, volatile material and fixed carbon, determined by heating in muffle to 950 ± 10°C for the samples collected in the summer period and in the Amazonian winter period and were performed in duplicates. The humidity corresponds to the amount of water present in the sample, the volatile material is that substance that evaporates more easily and the ashes correspond to the inorganic fraction of the MSW sample, aggregating in its constitution the chemical elements that are inert to combustion reactions, among them are phosphorus, potassium and calcium. The amount of carbon that does not volatilize is called fixed carbon.

ELEMENTAL ANALYSIS: CARBON, HYDROGEN, AND NITROGEN.

CHN Elemental Analysis is a technique for determining the percentages of Carbon (C), Hydrogen (H) and Nitrogen (N) in a sample, and is generally performed for organic materials. Its operation is based on the Pregl-Dumas method, in which samples are subjected to combustion in an atmosphere of pure oxygen, and the gases resulting from this combustion are quantified in a TCD detector (thermal conductivity detector). Its main applications involve the study of liquid and solid samples, resulting from organic synthesis and formation of complexes, synthesis of polymers, geological and environmental samples and petroleum derivatives, among others. They are indispensable in the calculation of the lower calorific value of a sample.

CALORIFIC VALUE - PC

The study of the calorific value of MSW allows the analysis of the feasibility of using this material as an energy source, which will serve as a strong argument for a possible decision by the authorities for the development of projects and execution of one or more plants for the transformation of MSW into energy, which will result in the reduction of landfills and dumps. and will result in the various benefits generated by an energy matrix (QUEIROZ, 2014).

Superior Calorific Value - PCS

The equipment that measures the superior calorific value of a sample is the calorimetric pump. It is able to measure the amount of heat released or absorbed in a chemical or physical reaction. It is basically composed of a combustion chamber, isolated by cold water, where the reaction of oxygen at high pressure with the sample to be analyzed occurs. Combustion begins with the heating of the sample by means of an electric current that burns the ignition wire in contact with the electric current conductor and the sample in the metal crucible.

The residue sample pressed in the form of a tablet or tablet is placed in a metal crucible mounted inside a pressure vessel, with a volume of 350 ml, equipped with an ignition device through electric current. The mass of the sample is approximately 1.0 g. After the sample is placed, the pump is hermetically sealed and pressurized with pure oxygen at about 30 bar, as detailed in Figure 5.

Figure 5. Determination of PCS: (a) Analytical balance; (b) decomposition vessel or pressure vessel; (c) sample press; (d) metallic crucible; (e) combustion calorimeter; (f) Sample in the form of pressed inserts.

	
(a)	(b)
	
(c)	(d)
	
(e)	(f)

Soon after, the pressure vessel is carefully placed inside the equipment, which is filled with water and has an agitator so that the temperature of the set is homogenized and a thermometer that measures the temperature variation throughout the process. At the beginning, the aim is to balance the temperature of the set between 20°C and 23°C. The calorimeter is configured by entering the mass of the sample. Then an electrical pulse is emitted to the ignition wire which causes the sample to combust, raising the temperature of the system. The equipment's high-precision thermometer measures temperature variation, which is accurate to +/- 0.0001 K (Kelvin) and is recorded minute by minute. At the end of 15 minutes or 16 minutes, the gain in the upper calorific value of the sample is also recorded, in j/g. This is only achieved due to the previous calibrations carried out automatically by the equipment and the various corrections due to the water masses, the calorimeter, ignition energy, etc., as well as the energy gain in the entire process in relation to the mass of the sample measured and typed in the initial phase, on an analytical balance with an accuracy of 0.0001 g. results in Higher Calorific Value.

After muffle drying at 105 °C, the moisture content of each sample was determined and it was possible to determine the value of the dry PCS according to Eq. 2:

Equation 2. It allows you to calculate the upper calorific value of each sample in the dry state.

$$PCS_{seco} = \frac{PCS_w}{1-w} \quad (3)$$

Where:

PCS_{seco} : Calorific value of fully dried sample (Joules/Kg);

PCS_w : Superior calorific value of MSW, in the humidity condition "w" (Joules/Kg);

w : Moisture content at the time of the laboratory test (% by mass).

According to Poli, et al (2014) most fuels have hydrogen in their composition, which, during combustion, reacts with oxygen, generating an additional amount of water. If this hydrogen generates water, then it should be considered in a more precise relationship between PCI and PCS. Assuming that all Hydrogen converts into water and that each gram of Hydrogen in the fuel generates 9.0 g of water stoichiometrically, the ratio is as described in Eq. 3:

Equation 3. It allows you to calculate the lower calorific value of each MSW sample.

$$\mathrm{PCI}_w = (1-\mathrm{w}) * \mathrm{PCS}_{\mathrm{seco}} - [(1-\mathrm{w}) * 9 * \mathrm{H} + w] * 2449{,}38 \quad (4)$$

Where:

PCIw: Lower calorific value of MSW, at the time of humidity w (joules/Kg);

PCSdry: Calorific value of fully dry sample (Joules/Kg);

w : Moisture content at the time of the laboratory test (% by mass).

H : Hydrogen content, on a dry basis (% by mass, expressed between 0 and 1);

2449.38: Enthalpy of vaporization of water at 22°C (joules/Kg).

RESULTS

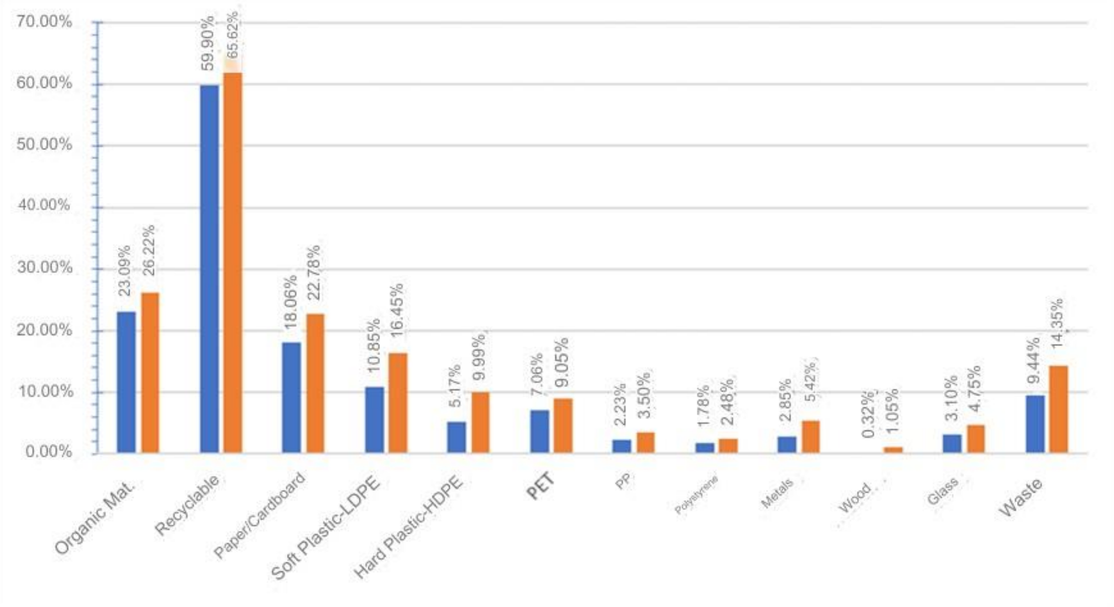
GRAVIMETRIC COMPOSITION OF MSW

Detailed samplings of the gravimetric profile of urban solid waste from each of the neighborhoods were performed. The mean and standard deviation of the sample were calculated. The results indicated a partial variation in certain materials when compared to the national average. The waste profile differs in that it presents a higher amount of recyclable materials such as paper, cardboard and plastics, in relation to the national average, while organic waste is shown in a higher percentage. This is due to the separation carried out in this work between tailings and organic material whose destination can easily be biodigestion or composting, as summarized in Table 1 and summarized in Figure 6.

Table 1. Percentage fractions by administrative area and weighted average of each material comprising the MSW.

COMPONENTS	PERCENTAGE FRACTION						AVERAGE	WEIGHTED AVERAGE
	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST		
Organic Mat.	23,25%	24,5%	24,3%	28,1%	25,3%	24,3%	24,96%	24,66%
Total recyclables	64,24%	58,47%	65,81%	58,61%	62,55%	64,15%	62,31%	62,76%
Paper/Cardboard	20,92%	20,7%	18,6%	18,3%	23,4%	24,5%	21,04%	20,42%
Soft Plastic:LDPE	10,61%	14,3%	18,5%	13,5%	11,0%	11,1%	13,16%	13,65%
Hard Plastic:HDPE	10,60%	3,7%	5,3%	7,9%	9,3%	9,2%	7,69%	7,58%
PET	9,70%	6,9%	7,7%	6,8%	8,3%	7,8%	7,86%	8,05%
PP	2,00%	2,7%	3,3%	3,1%	3,3%	4,0%	3,06%	2,87%
Polystyrene	2,44%	2,1%	2,4%	1,5%	1,7%	2,0%	2,02%	2,13%
Metals	4,36%	3,1%	6,1%	3,1%	3,1%	2,5%	a)	b)
Wood	1,20%	0,0%	0,6%	0,5%	0,8%	0,8%	0,64%	0,69%
Glass	3,60%	5,0%	4,0%	4,4%	2,6%	3,1%	(a)	(b)
Waste	11,31%	(c)	(d)	12,8%	11,4%	(e)	(f)	11,90%
TOTAL	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Weighting factor	0,2799	0,1600	0,2502	0,1417	0,0853	0,0829	-	-

Figure 6. Final gravimetry of the city of Manaus -AM.



In the research, it was evidenced that the greater representativeness of recyclable waste (59% to 65%) and the small proportional reduction of organic waste (23% to 26%) and waste (10% to 14%), while the national average these values are 28%, 50% and 22% respectively, are possibly consequences of the excessive use of packaging, due to the number of people who start to live in the vicinity of the Manaus Industrial Pole and the commercial and service area existing in the urban area of the city. In the field analysis, it was found that at least 50% of this plastic material comes from recyclable packaging (or with easy commercial value in the market), evidencing the possibility of selective collection if a sorting plant is installed before the waste is landfilled. Such characteristics may possibly be a consequence of the increasing use of packaging, evidencing the need for local public policies of post-consumption responsibility, product life cycle analysis and priority marketing of products with sustainable packaging.

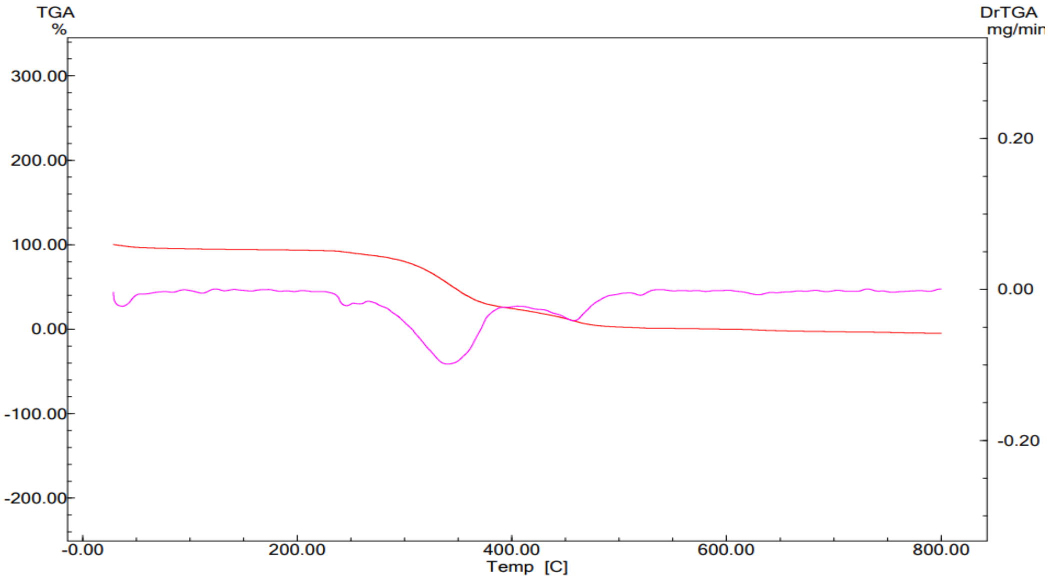
One of the consequences of the presence of a high percentage of packaging and recyclable materials is the average value of apparent specific weight, 73.68 Kg/m³, approximately one third of the national average, confirming the large amount of light materials containing air inside, such as packaging and enabling a high degree of compaction when dimensioning the route and the number of waste compactor collection trucks.

The studies carried out in these neighborhoods were fundamental for the collection of initial and updated data, which enabled the gravimetric characterization of solid waste in the city of Manaus, state of Amazonas, and will enable other studies. For the time being, there has been a large amount of material with the capacity to be recycled (62% + 2%), despite the publicity campaigns of the public authorities, with a low apparent specific weight, confirming little organic matter and a lot of light material that can be recycled, leading to the thought of installing a sorting plant as an alternative to reduce the waste destined to the city's landfill. increasing its useful life and the reuse of recyclable materials, bringing economic, social and environmental benefits to the city and its inhabitants.

TGA/DTG THERMAL ANALYSIS

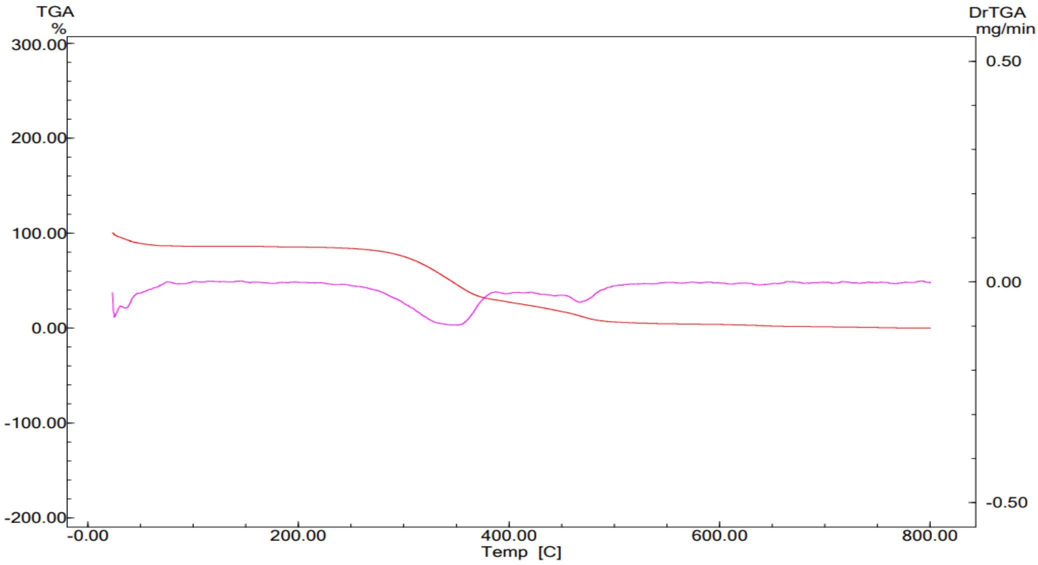
To verify the thermal behavior of the MSW sample, Thermogravimetry (TGA) and Thermogravimetry Derivative (DTG) analyses were performed. Three of these TGA curves are shown in Figures 7, 8 and 9.

Figure 7. Thermogravimetry analysis of MSW.



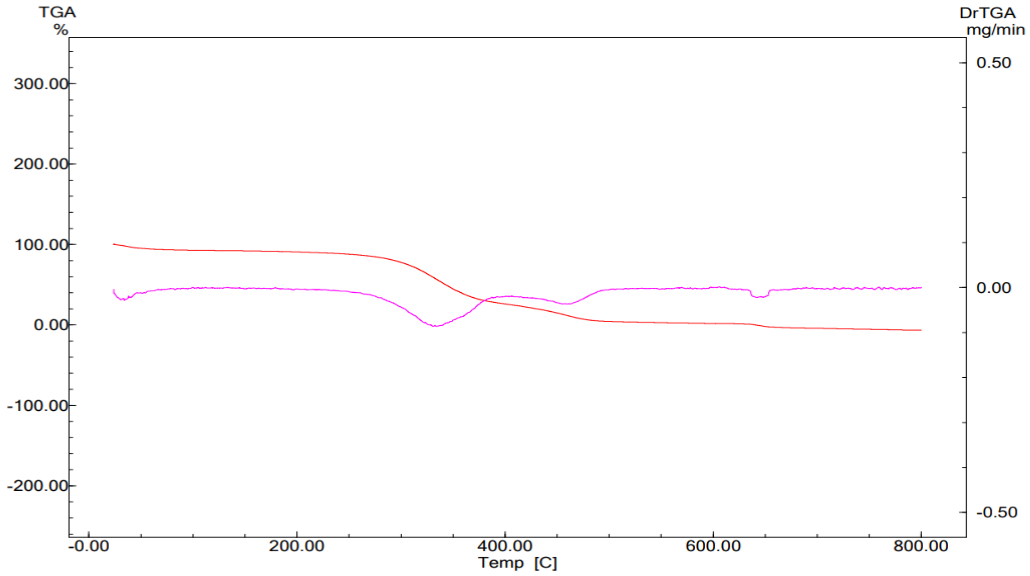
Source: Author.

Figure 8. Thermogravimetry analysis of MSW.



Source: Author.

Figure 9. Thermogravimetry analysis of MSW.



Source: Author.

It is verified that the MSW samples submitted to the tests remain constant until approximately 250 ºC, where it began its deterioration process that was up to approximately 500 ºC and from that point on the degradation of the polymeric chains or the process of rupture of primary bonds due to thermal energy occurs, where practically all the material has already been consumed.

IMMEDIATE ANALYSIS: MOISTURE, ASH, VOLATILE MATERIAL AND FIXED CARBON.

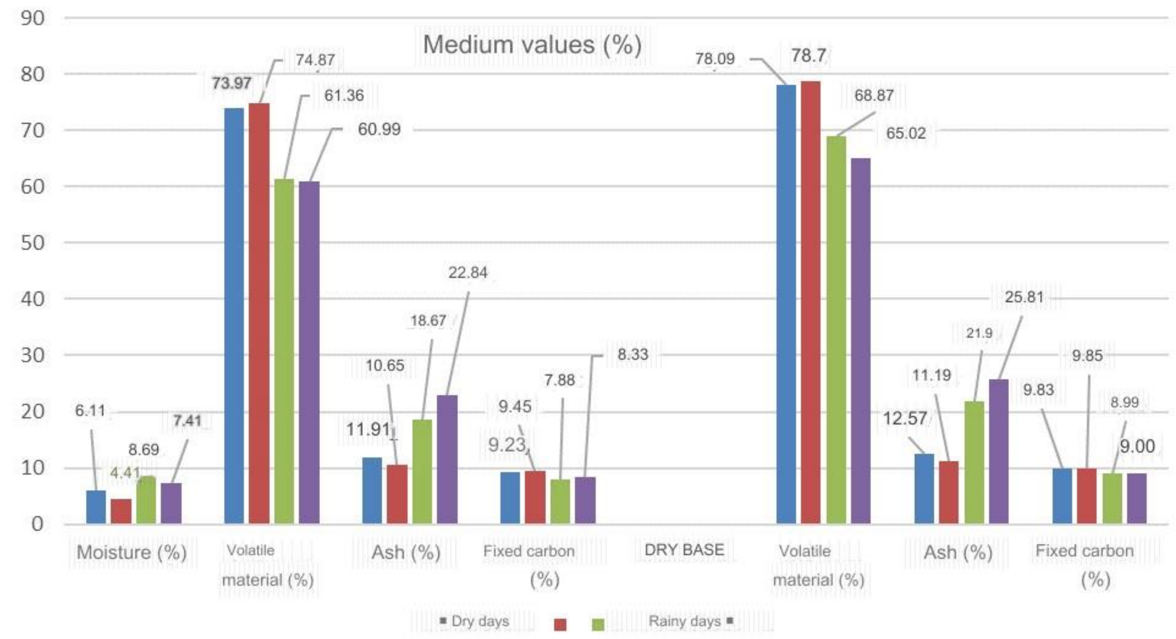
The values of moisture, volatile material and fixed carbon can be seen in Table 2 for the samples collected in the summer period and in Table 3 for the samples collected in the Amazonian winter period and duplicate tests were performed. Figure 10 shows the mean values of these properties.

Table 2. Immediate analysis of MSW in administrative regions on dry days

Experiment 1							
Dry Days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	6,03	6,18	6,23	4,39	5,92	8,12
Volatile material (%)	v	76,31	72,65	71,73	75,29	77,76	55,90
Ash (%)	c	8,36	11,07	12,78	12,75	7,12	29,31
Fixed carbon (%)	FC	9,30	10,09	9,26	7,57	9,20	6,67
Total		100,00	100,00	100,00	100,00	100,00	100,00
DRY BASE							
Volatile material (%)	vs	81,21	77,44	76,50	78,75	82,65	60,84
	cs	9,90	10,75	9,87	7,92	9,78	7,26
Fixed carbon (%)	FCs	8,89	11,80	13,63	13,33	7,57	31,90
Total		100,00	100,00	100,00	100,00	100,00	100,00
Experiment 2							
Dry Days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	4,17	3,78	5,55	3,98	4,66	6,61
Volatile material (%)	v	75,49	62,82	74,26	76,46	78,64	58,45
Ash (%)	c	10,91	23,72	10,39	10,10	8,05	27,64
Fixed carbon (%)	FC	9,44	9,68	9,80	9,46	8,65	7,30
Total		100,00	100,00	100,00	100,00	100,00	100,00
BASE SECA							
Volatile material (%)	vs	78,77	65,29	78,63	79,63	82,48	62,59
Fixed carbon (%)	FC	9,85	10,06	10,37	9,86	9,08	7,81
Ash (%)	cs	11,38	24,65	11,00	10,52	8,44	29,60
Total		100,00	100,00	100,00	100,00	100,00	100,00
Experiment 1							
Rainy days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	6,54	10,97	18,13	8,84	7,72	8,54
Volatile material (%)	v	60,13	62,50	55,29	65,58	69,99	60,21
Ash (%)	c	25,02	18,44	18,90	17,01	15,19	24,07
Fixed carbon (%)	FC	8,30	8,09	7,68	8,58	7,10	7,18
Total		100,00	100,00	100,00	100,00	100,00	100,00
DRY BASE							
Volatile material (%)	vs	64,34	70,20	67,54	71,93	75,85	65,83
Fixed carbon (%)	FC	8,88	9,09	9,38	9,41	7,69	7,85
Ash (%)	cs	26,78	20,71	23,08	18,66	16,46	26,32
Total		100,00	100,00	100,00	100,00	100,00	100,00
Experiment 2							
Rainy days	ZONE	NORTH	SOUTH	EAST	WEST	SOUTH CENTER	MIDWEST
WET BASE							
Moisture (%)	w	4,93%	7,56%	15,47%	7,39%	5,48%	7,43%

Volatile material (%)	v	61,26%	57,96%	53,70%	67,90%	70,61%	60,73%
Ash (%)	c	25,13%	27,56%	22,23%	16,45%	17,85%	23,45%
Fixed carbon (%)	FC	8,68%	6,92%	8,61%	8,26%	6,06%	8,40%
Total		100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
DRY BASE							
Volatile material (%)	vs	64,43%	62,70%	63,52%	73,32%	74,70%	65,60%
Ash (%)	cs	26,43%	29,81%	26,29%	17,77%	18,89%	25,33%
Fixed carbon (%)	FCs	9,13%	7,49%	10,19%	8,92%	6,41%	9,07%
Total		100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Figure 10. Mean of the values obtained in the immediate analysis on dry and rainy days



The lower moisture and ash contents of the MSW samples are concentrated in those collected on dry days, while the volatile material contents are in those samples collected on dry days, an indication that MSW on dry days have advantageous characteristics for the production of thermal energy in relation to those of rainy days. The samples have similar fixed carbon contents, with a tendency to be slightly higher on dry days. However, the fixed carbon/volatile materials ratio was higher for materials collected on rainy days, possibly due to lower volatile material contents on rainy days.

According to Pereira (2014), the lower the moisture content, the lower the amount of energy spent in the carbonization process of the material and the higher the calorific value of the material. Some biomasses such as rice husks, sugarcane bagasse and soybean meal have 64.10%, 80.42% and 80.00% of volatile materials, respectively, which when compared with the MSW samples analyzed make it possible to classify them as alternatives for energy use based on the averages found, especially on dry days that present less amount of substances to be released as gases during the carbonization process. and, therefore, it has a lower ash content than the MSW on rainy days. The volatile and fixed carbon materials had their values very approximate, with their FC/Volatiles ratios being very close, indicating a good capacity of both types of materials to be destined for combustion processes. Thus, the materials collected on dry days have a higher proportion of minerals in their composition with greater ease of burning and burning, but for the material collected on rainy days, in a possible work of sorting on conveyor belts and with consequent decrease in humidity, it also becomes of good combustion and thus the first a possible source of energy use.

ELEMENTAL ANALYSIS: CARBON, HYDROGEN, AND NITROGEN.

The elemental analyses of the samples were performed in duplicates at the Analytical Center of the Institute of Chemistry of the University of São Paulo (IQ-USP), using the equipment Elemental Analyzer - Perkin Elmer 2400 series II. These values will be used together with those obtained by the upper calorific value test in the methodology to determine the value of the lower calorific value of each of the samples

Table 4. CHN elemental analysis of MSW samples from Manaus. Medium values

	DRY	ZONE	H (%)	C (%)	N (%)
AVERAGE	1	WEST	6,405	43,31	0,35
	3	SOUTH	6,035	41,79	0,235
	6	NORTH	4,475	35,04	1,34
	RAINY				
	1	NORTH	6,135	38,78	1,685
	2	EAST	5,745	38,33	1,825
	3	MIDWEST	5,645	39,62	1,245

CALORIFIC VALUE – PC

Table 5 shows some PCI values, in joules and calories per kilogram of material.

Table 5. Calorific value of some fuels. Source: ANDRADE. 2019.

FUEL	PCS (KJ/Kg)	PCI (Kcal/Kg)
Paraffin	39.000	9.321
Fuel oil	35.000	8.365
Charcoal	31.000	7.409
Agricultural waste charcoal	26.000	6.214
coconut shells	17.000	4.063
Kiln-dried firewood	17.000	4.063
Lignite	17.000	4.063
Mineral coal	15.000	3.585
Biomass 50% humidity	8.326	1.990
Biomass 10% humidity	17.029	4.070

Superior Calorific Value - PCS

The calorific value analyses were carried out at the Thermal Laboratory of the Faculty of Mechanical Engineering of the State University of Campinas (UNICAMP), with the aid of the IKA C-200 Calorimetric Pump, which performs analyses of gross calorific values of liquid and solid samples. To perform the analyses, each sample should be weighed between 0.5 and 0.7g in a porcelain crucible, without a lid. The analytical balance used was PIONEER OHAUS.

The analyses of the upper calorific value carried out at the Thermal Laboratory of the Faculty of Mechanical Engineering of the State University of Campinas (UNICAMP), with the aid of the IKA C-200 Calorimetric Pump, resulted in the values described in Table 6 for rainy days and in Table 7 for samples collected in the administrative zones of Manaus on dry days.

Table 6. Determination of MSW PCS in administrative regions on rainy days.

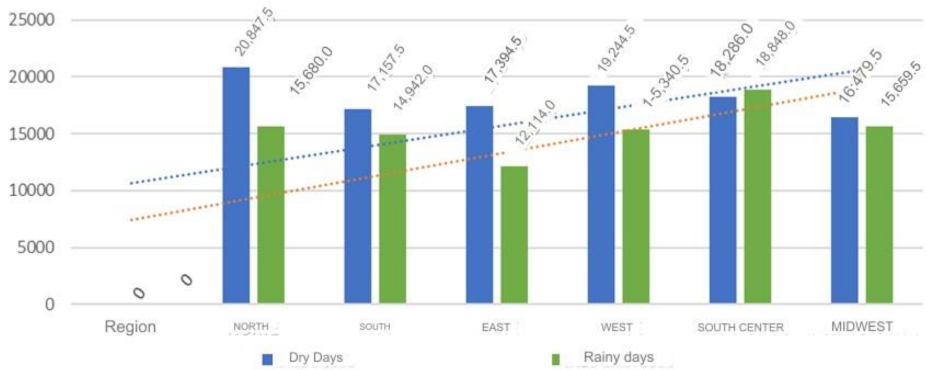
Sample	PCS-1	PCS-2	Average	Standard deviation	Minimum	Maximum
RSU-M07	15.243,0	15.438,0	15.340,5	2001,95	13.339	17.342
RSU-M08	15.147,0	14.737,0	14.942,0		12.940	16.944
RSU-M09	15.690,0	15.670,0	15.680,0		13.678	17.682
RSU-M10	11.994,0	12.234,0	12.114,0		10.112	14.116
RSU-M11	17.885,0	19.811,0	18.848,0		16.846	20.850
RSU-M12	15.543,0	15.776,0	15.659,5		13.658	17.661

Table 7. Determination of MSW PCS in administrative regions on dry days

Sample	PCS-1	PCS-2	Average	Standard deviation	Minimum	Maximum
RSU-M01	20.086,0	21.609,0	20.847,5	1547,66	19.300	22.395
RSU-M02	16.925,0	17.390,0	17.157,5		15.610	18.705
RSU-M03	16.955,0	17.834,0	17.394,5		15.847	18.942
RSU-M04	18.672,0	19.817,0	19.244,5		17.697	20.792
RSU-M05	17.685,0	18.887,0	18.286,0		16.738	19.834
RSU-M06	16.236,0	16.723,0	16.479,5		14.932	18.027

Figure 11 shows the mean values of the PCS of the MSW samples from the six zones on the city's summer and winter days. Possibly due to the naturally increased humidity due to the exposure of the residues to the rains that occurred on rainy days, the values will naturally be lower than on dry days, with the exception of the central-south zone where probably on the day of collection there was no rainfall, making the average value similar to the average value resulting from dry days.

Figure 11. Average PCS of MSW in Manaus-AM on dry and rainy days



Dry Upper Calorific Value - PCSseco

In the previous item, the sample was in thermal equilibrium with the environment and exposed to the humidity of the place, and the amount of additional water formed by the hydrogen in the fuel, as well as the water in the relative humidity of the combustion air, were not considered. In this case, it was necessary to obtain the dry PCS values, in joules/Kg, using equation 2 and obtaining the values in Table 8:

Table 8. Dry PCS of Manaus MSW samples on dry and rainy days

ADMINIST REGION.	Dry		Rainy		Dry	Rainy	Dry		Rainy	
Region	PCS-1	PCS-2	PCS-1	PCS-2	w	w	PCS_{seco} 1	PCS_{seco} 2	PCS_{seco} 1	PCS_{seco} 2
NORTH	20.086,0	21.609,0	15.690,0	15.670,0	6,02	6,54	21.372,63	22.993,19	16.787,93	16.766,53
SOUTH	16.925,0	17.390,0	15.147,0	14.737,0	6,18	10,97	18.039,86	18.535,49	17.013,37	16.552,85
EAST	16.955,0	17.834,0	11.994,0	12.234,0	6,23	18,13	18.081,48	19.018,88	14.650,05	14.943,20
WEST	18.672,0	19.817,0	15.243,0	15.438,0	4,38	8,84	19.527,30	20.724,74	16.721,15	16.935,06
SOUTH CENTER	17.685,0	18.887,0	17.885,0	19.811,0	5,92	7,72	18.797,83	20.075,47	19.381,23	21.468,36
MIDWEST	16.236,0	16.723,0	15.543,0	15.776,0	8,12	8,54	17.670,88	18.200,91	16.994,31	17.249,07

Lower Calorific Value - PCI

After the calculation of the dry PCS, it was possible to determine the values for PCI, using Equation 3 and considering the hydrogen content extracted from the CHN elemental analyses performed on the samples of municipal solid waste. The values calculated for PCI, in joules/kg, are described in Table 9. Mean PCI and standard deviation values are also presented.

Table 9. PCI of Manaus MSW samples on dry and rainy days.

Region	Dry Days			Rainy days			DP		Weighting	Weighted PCI – by region	
	H (%)	PCI-1	PCI-2	H (%)	PCI-1	PCI-2	Dry	Rainy	%	Dry Days	Rainy days
N	6,405	18.611,60	20.134,60	6,135	14.265,83	14.245,83	761,5	10	0,2799	5.422,53	3.990,21
S	6,035	15.448,94	15.913,94	6,135	13.674,24	13.264,24	232,5	205	0,16	2.509,03	2.155,08
L	6,405	15.478,42	16.357,42	5,745	10.442,70	10.682,70	439,5	120	0,2502	3.982,66	2.642,79
O	6,405	17.214,62	18.359,62	6,135	13.793,60	13.988,60	572,5	97,5	0,1417	2.520,43	1.968,37
C-S	6,405	16.211,64	17.413,64	6,135	16.447,89	18.373,89	601	963	0,0953	1.602,24	1.659,26
C-O	6,405	14.739,82	15.226,82	5,645	14.096,89	14.329,89	243,5	116,5	0,0829	1.242,12	1.178,29
									Média	17.279,02	13.593,99

The calorific value of MSW is immediately influenced by the increase in the moisture content of the material, and any variation of this property in any sample changes the result. This is because the higher the moisture content, the greater the energy expenditure to evaporate the water present in the sample and the more water, the smaller the other components, reducing the calorific value of the material present as fuel. Figure 12 explains the above.

Figure 12. Average PCI of MSW in the administrative areas of Manaus-AM.

CONCLUSION AND FUTURE WORK

The characterization of a city's waste is of paramount importance for government decision-making on the type of treatment to be carried out at that site. Knowing that there is Law 12.305 (PNRS) in the country, which requires a form of waste treatment before final disposal, and knowing the thermal treatments, whose techniques are safer and more innovative, increase the range of options available in the market. The values obtained in the tests, such as apparent specific weight, 73.68 Kg/m³, indicate the presence in a high percentage of packaging and recyclable materials, approximately one third of the national average, confirming the large amount of light materials and containing air inside, allowing a high degree of compaction when dimensioning the route and the number of waste compactor collection trucks. The gravimetry studies will enable other studies. For the time being, a large amount of material with the capacity to be recycled (62% + 2%) has been found, despite the publicity campaigns of the public authorities, indicating little organic matter and a lot of material that can be recycled, leading to the thought of installing a sorting plant as an alternative to reduce waste destined to the city's landfill, increasing its useful life and the reuse of recyclable materials. bringing economic, social and environmental benefits to the city and its inhabitants. The high percentages of recyclable materials, combined with lower calorific value (PCI) values, presenting values between 15,000 and 19,000 KJ/Kg on dry days, calorific value equivalent to the fuels cataloged in the bibliography such as lignite, kiln-dried firewood and coconut shells (17,000 KJ/Kg), Coal, (15,000 KJ/Kg), showed promise in future decision-making for MSW treatment by incineration. Currently, approximately 83 thousand tons of MSW are generated per month in the city of Manaus. Most of these wastes (98%) are landfilled, occupying a large area and causing environmental impacts. The researches show the feasibility of increasing recycling, composting a part of these and the rest going through thermal treatment by incineration and consequently the generation of electricity.

FUTURE WORK

The proposed management plan for the city of Manaus-AM aims at adequate treatment and final disposal of MSW to reduce dependence on landfill and electricity generation. An economic analysis should be presented in the future, taking into account some scenarios of recycling percentages, the amount and cost of fuel spent in incineration, the energy consumed in the process, as well as the gas emissions and financial impacts that may be caused. Finally, the calculation of the actual mass to be deposited in landfills, which includes the solid ash from incineration and the possible use of this in the composition of cementitious material to be used in civil construction.

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