

Evaluation of the Feasibility of using the Incineration of Urban Solid Waste for Electric Power Generation in Itacoatiara, AM

Layrton Marinho Fernandes¹, Fabiana Rocha Pinto²

¹Undergraduate Student of the Electrical Engineering Bachelor of the University Center FAMETRO, Amazonas, Brazil

²PhD, Teacher and Advisor of the Bachelor Degree Course in Environmental Engineering and Renewable Energy of the University Center FAMETRO, Amazonas, Brazil.

Abstract - In Brazil, 92% of urban solid waste is disposed in controlled landfills, but a significant portion is still sent to inadequate open-air sites. Most of sites used for this purpose are saturated and the problem of making new sites available for this practice only delays the problem without solving it completely. The option that most countries have used to solve is the usage of this waste as fuel for thermoelectric plants. Therefore, this work aims to evaluate the feasibility of solid urban waste incineration for power electric generation in Itacoatiara, AM. The proposal is based on a literature search. The results obtained show that the studied alternative is possible and that the amount of solid urban waste collected in the referred city allows the generation of 18.06 GW year⁻¹ of electricity and obtaining a turnover of R\$ 26.024x10⁶ year⁻¹.

Key Words: alternative sources; incineration; urban solid waste; power generation; calorific value; carbon credits; sustainable development.

1. INTRODUCTION

In Brazil, the main power sources used are: hydroelectric and thermal energy (via fossil fuels), coal and biofuels, in addition to other sources used on a small scale, such as natural gas and nuclear power. However, fossil sources are non-renewable and are increasingly scarce for use, as well as the water source which has a limited and poorly managed conditions. Therefore, the insertion of alternative sources has become evident, given technological initiatives for power utilization (EPE, 2014; MIRANDA et al. 2017).

The city of Manaus, AM was the first to implement an incinerator in 1896 and that was deactivated it in 1958 because it no longer meets local needs. In Belém (Pará), at the beginning of the 19th century, an incinerator similar to the Manaus, was also installed, and then deactivated in 1978 due to maintenance problems. In São Paulo, in 1913, an incinerator was installed with the capacity to process 40 tons of garbage per day for which was provided with a power recovery system, which consisted of a boiler and alternator.

However, incineration is a technology poorly used in the country, being restricted to just a portion of hospital waste, pesticide packaging and some hazardous industrial waste, where none of these incinerated were designed for power utilization. The technologies available for power generation process are exploited in the international context. In contrast

to Brazil, where there is not much investment in the usage of incineration as alternative (MACHADO, 2015; MARANHO, 2008).

For Machado (2015); Maranhão (2008), the gas cleaning systems used in these facilities are basic, limited only to simple methods of collecting particulate material, without any filter for finer particulate material, such as acid gases and dangerous metals. The selective waste collection service is carried out by private bodies in most cities through concessions or bids.

Brazil has adopted the option of sanitary landfills and controlled landfills for waste disposal, due to lower operating costs and area availability. However, they are still mainly disposed of in controlled landfills, but most of them are still sent to open-air sites (EPE, 2014).

According to the Brazilian Constitution (1988), specifically in article 30, items I, II and V guides that it is the responsibility of the municipality to legislate on matters of local interest, supplement the state and federal legislation when necessary to organize and provide, directly or under the regime of concession or authorization, the public services of local interest. Therefore, USW are property and responsibility of the municipal government, with the mission of ensuring their collection and final disposal.

Barsano; Barbosa (2013) highlights that the National Solid Waste Policy – NSWP (Law 12.305, of August 2, 2010), combines a set of objectives, instruments, guidelines, goals and actions that should be adopted, alone or in cooperation with other states, Federal District, municipalities or private entities, aiming at an integrated management and environmentally appropriate management in relation to SW.

According to the Institute of Technological Research - IPT (2018), the definition of procedure that will be adopted should be in accordance with the situation of the city, where one requisite is a diagnosis that considers the type, origin and amount of waste produced, and thus analyze the most appropriate type of available treatment and site for its conditioning.

In the main Brazilian cities, the waste conditioning process is saturated, so the problem of making new areas available for this practice only postpones the problem,

without actually solving it. Thus, is extremely important the conduction of studies that aimed to find solutions for reduction of waste amount deposited and, also for the power utilization of these wastes for generation of electric and thermal power, biofuels, recyclables usage, natural fertilizers and ashes used in civil construction (EPE, 2014; OLIVEIRA et al. 2017).

On April 26, 2002, the Brazilian government created the Incentive Program for Alternative Sources of Electric Power (PROINFA), through Law No. 10.438, revised by Law No. 10.762 of November 11, 2003, which aimed to the usage of alternative sources. By this way, alternative sources such as solar, wind and biomass are seen as an advantageous and profitable investment in the power generation market.

According to the Brazilian Association of Public Cleaning Companies (ABRELPE, 2016), every time the GDP grows, consumption increases, generating more waste. The year of 2016 was an example, when the generation of waste grew by 1.07% and the GDP decreased by 3.8% a fact that can be explained considering that the crisis did not stop the consumption of disposable products, but made those consumers opt for products with lower costs. Lenharo (2016) comments that the increase in USW generation, an increase of 29% in the last 11 years, is greater than the 6 % of population growth, where not even the economic downturn in 2014 caused the reduction of USW generation.

According to ABRELPE (2017), USW generation in Brazil was 78.4×10^6 t ($377,775$ kg in $\text{hab}^{-1} \text{ year}^{-1}$), pointing to an increase of 1% over the previous year, compared to the population growth of 0.75%, exceeding this variation.

Regarding collection, there was an increase of 1.25% and an advance in the collection services reaching a total of 71.6×10^6 t in 2017, covering 91.2% of the country, or 6.9×10^6 t of waste not collected and with inadequate destination (ABRELPE, 2017).

In all areas where occurs the USW packaging, liquid and gases waste requiring control and appropriate treatments are produced (EPE, 2014). In addition to the visual impact and soil disuse of the area, it is estimated the zone return to be chemically inert within 50 years after termination of activities (REZENDE, 2015; BENDITO et al. 2017).

Bendito et al. (2017), states that the most aggravating factor that causes impacts on the environment is the pollution of the USW deposit site. Its inadequate management can bring undesirable consequences, causing public health problems and damage to the environment, as well as consequences under the social, aesthetic, economic and administrative aspects involved. The regions close to the areas used are devalued for commercial and residential use, causing discomfort to the surrounding low-income population.

According to the US Environmental Protection Agency, there are at least four ways to associate USW with the

greenhouse effect (EPA, 2017): 1) emission of carbon dioxide (CO_2) through the use of energy for the extraction and production of goods and services, the use in the treatment of fuels and their consumption; 2) emission of CO_2 from the use of fuels for purposes other than burning, such as the production of asphalt, solvents for paints, lubricants and others; 3) emission of methane (CH_4) resulting from the decomposition of organic components of waste in landfills; and 4) carbon retention in parts of materials that do not decompose in sanitary landfills.

The gases produced by the anaerobic decomposition of organic waste in landfills are composed of 45 to 60% methane (CH_4), 40 to 60% carbon dioxide (CO_2), 25% nitrogen and, small amounts less than 1%, organic and inorganic impurities, also listed by the acronym NMOC (*non-methane organic compounds*), which comprise benzene, toluene, organochlorines, mercury, and organometallic (EPE, 2008; REZENDE, 2015).

According to Rezende (2015), worldwide landfills produce about 20×10^6 t year⁻¹ to 60×10^6 t year⁻¹ of methane (CH_4) as a direct consequence of the anaerobic decomposition of waste components, noting that even landfills are a solution for USW, the greenhouse gases emission are very high, especially in the first years of operation.

According to Gasques (2013), USW can be characterized by: specific weight, generated volume, chemical composition, humidity and calorific power (CP). This characterization is important to dimension the collection system, where the specific weight is important to dimension the characteristics of collection vehicle fleet, the number of transshipment stations and incinerators; the volume generated is determinant to forecast the number of collector vehicles, their capacity and technical characteristics, as well as the personnel.

The chemical composition provides information on the content of O₂, H, C and S, thus determining the amount of air required in incinerators, chambers, and other system components. Among the power generation processes is the calorific value of the waste, which is the energy released by total combustion at the constant pressure of one kilogram of fuel and its subdivisions as the upper CP, which is the amount of heat released by burning completely one kilogram of fuel, resulting in carbon dioxide and water in the liquid state; and lower PC, that is the result of combustion such as carbon dioxide and water vapor.

As of the elementary analysis (mass % of C, H, O, S and humidity) we use valid empirical equations in International System of units

The composition of USW in Brazil is an important parameter, since the amount of each component and humidity has a direct influence on the USW's CP and can be influenced by several factors: number of inhabitants,

purchasing power, educational level, habits and customs of the population, climatic and seasonal conditions, and changes in the country economic policy.

According to a report from the National Sanitation Information System (BRAZIL, 2009), in 2009 the mass collected from USW ranged from 0.77 kg per day⁻¹ to 1.19 kg per day⁻¹, with an average of 0.96 kg per day⁻¹ being important the verification of % of USW components (Table 1).

Table -1: Percentage of dry mass of Components found in USW

Waste	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food	48.0	6.4	37.6	2.6	0.4	5.0
Cardboard	43.0	5.9	44.8	0.3	0.2	5.0
Plastic	60.0	7.2	22.8	-	-	10.0
Polyethylene	85.2	14.2	-	< 0.1	< 0.1	0.4
PVC	45.2	5.6	1.6	0.1	0.1	2.0
Textiles	48.0	6.4	40.0	2.2	0.2	3.2
Rubbers	69.7	8.7	-	-	1.6	20.0

Adapted from KENJI IWAI, 2005

The most widely used technology today for power generation from USW is the combustion of organic components in boilers, because it has a low deployment cost and is simple compared to other technologies. The simplest furnace was implemented by a company called Martin GmbH in Munich (Germany), which has the capacity to process about 59×10^6 t year⁻¹ of waste. One of the newest plants installed by Martin GmbH is in Brescia (Italy).

According to Themelis; Keufman (2004b), most US states produce approximately 28.5×10^6 t year⁻¹ of USW, which can be incinerated and used for power generation. According to the International Solid Waste Association (IWSA), the installed capacity for USW treatment in US plants was 29.4×10^6 t year⁻¹, whereas in European plants it was 40×10^6 t year⁻¹. Therefore, 41×10^6 GJ of electrical power and 110 GJ of thermal power were generated in Europe (IWSA, 2013).

It was noted that, in contrast to Europe, the USA makes very little use of the exhaust steam potential of power turbines for residential or industrial heating (IWSA, 2013). On the other hand, Japan converts 314 kg per capita of USW into electricity, Singapore 252 kg and the USA 105 kg (IWSA, 2013).

According to Machado (2015), Europe is the one that most invests in technologies for the power generation from USW, thus has a good part of the facilities, with an installed capacity of 3051 MW; the USA has 1541 MW of installed

capacity and the other countries do not exceed 727 MW. It is also worth noting the average capacity of incineration plants is about 1500 tons per day⁻¹ of USW, where the largest is installed in China, with capacity to process about 3000 tons per day⁻¹.

In Brazil, according to the same author, only large industrial companies have incinerators in order to contribute with mitigation of solid waste in urban areas and cogeneration of power. They are responsible for processing approximately 80,750 tons of waste year⁻¹, with a capacity between 7.5 tons day⁻¹ and 50 tons day⁻¹. All incinerators have gas filters and most of ashes produced are sent to their own industrial landfills.

The objective of this study is to characterize the amount and composition of USW for power generation, analyzing its estimated calorific power of USW from the combustion process, its lower calorific power - LCP, highlighting the environmental, economic and social advantages.

2. METHODOLOGY

For the development of this work, the method used is based on an exploratory research of literature, including the relevant legislation and survey of data about production and characterization of USW in the municipality. Subsequently, the technique of thermal treatment of USW with power recovery was evaluated, using incinerators and steam generators of Itacoatiara, AM.

2.1 Data Collection

Data about USW composition were obtained from information available on website of the Environment State Secretariat, IBGE and ABRELPE.

As previously mentioned, the determination of quantity and composition of USW produced in a city for power generation purposes depends on a number of factors, such as: the number of inhabitants, the quality of life in a population, the collection type and even the local atmospheric conditions. In this case, the chosen city has an estimated population of 95,714 inhabitants, of which 64,101 inhabitants are in the urban area, which represents 2.75% of the municipalities in the state of Amazonas and 0.05% in Brazil, generating approximately 76,921 t day⁻¹ of garbage (IBGE, 2010; PERS-AM, 2014).

For the analysis of the estimated CP, a software was used to analyze the combustion process, including the mass balance, composition of gases released, the required air amount, the energy balance and calorific value of fuel, where the mass fraction of each fuel constituent should be known in advance (% mass of C, H, S, O, N, H₂O, ash) . Another important parameter is the amount of water used for calculation of LCP (wet USW).

Based on Themelis (2013), one of the ways to verify the LCP in kcal kg⁻¹, of organic fuels can be calculated by eq. 1,

where: Y_{fuel} , Y_{H_2O} , Y_{glass} and Y_{metals} , represent the proportion of each material in 1 kg of USW.

$$LCP = \frac{18,500 \cdot Y_{combustible} - 2,636 \cdot Y_{H_2O} - 628 \cdot Y_{glass} - 544 \cdot Y_{Metals}}{4,185} \text{ eq. 1}$$

The portion of water found in organic material (leaves, wood, decomposing material, etc.) should not be taken into account because it is already expressed in the variable Y_{H_2O} . In the absence of data, the typical value of 60% can be considered as the standard value of humidity content (THEMELIS; KAUMAN, 2004 b).

For analysis of LCP of USW, the work of Themelis; Kauman (2004 b) (Table 2) was used.

Table -2: Calorific power of materials found in USW

Waste	LCP (kcal kg ⁻¹)
Plastic	6.300
Rubber	6.780
Leather	3.630
Textiles	3.480
Wood	2.520
Food	1.310
Paper	4.030

Adapted from Nogueira (2015); EPE (2014).

Based on the EPE (2014); the work of Nogueira (2015) was used, although the classification based on the LCP cannot be taken into account to establish the appropriate destination of the USW, it was considered:

- For $LCP < 1.675 \text{ kcal kg}^{-1}$: unfeasible, because in addition to technical difficulties, it is necessary to add auxiliary fuel;
- For $1.675 \text{ kcal kg}^{-1} < LCP < 2.000 \text{ kcal kg}^{-1}$: partially viable, because USW still depends on some kind of pre-treatment to increase its calorific value;
- For $LCP > 2.000 \text{ kcal kg}^{-1}$: feasible, the incineration of raw material is technically feasible and incineration plants can generate 450-700 kWh t⁻¹ of USW.

3. RESULTS AND DISCUSSION

To observe the environmental, economic and social advantages of this research, the basis will be the data from GIRAÇOL et al. (2011); PASSARINI et al. (2014):

- The incineration of USW prevents such waste from being sent to landfills and sanitary landfills; the combustion of USW generates power and from it, incomes are receipt from its commercialization. According to ANEEL (2019), the power generation costs in Amazonas is 679.00 R\$ MWh⁻¹;

from the methane not emitted, carbon credits are obtained, which can also be sold. According to Miranda et al (2017), each carbon credit can be sold at €6.0 (1€\$ = R\$3.42).

Thus, the mitigation of greenhouse gas emissions brings benefits to the environment, human health and company image in the market. (GIRAÇOL et al. 2011; PASSARINI et al. 2014), aiming the improvement of power production.

Several materials can be used for power generation. In Itacoatiara, 30% of its power comes from the BK power industry, which burns wood waste and forest management waste. Table 3 presents the percentage composition of USW in the city of Itacoatiara and the power amount that can be generated by its incineration.

Table -3: Percentage composition in mass and power of the USW of Itacoatiara, AM

	Organic Material	Plastic	Paper	Other (1)
USW Composition (2)	52,50	8,80	11,70	24,30
USW fraction without metal	0,5360	0,0897	0,1194	0,2481
LCP (kcal kg ⁻¹) (3)	1310	6300	4030	4102,5
Power (kcal kg ⁻¹)	702,16	565,11	481,18	1.017,83
Non-metallic USW (%)	97,9	Total LCP (kcal/kg RSU)		2.766,28

Note: (1) the other item corresponded to the junction of the following components: tissue, leather, rubber, hospital waste, styrofoam and wood.

Adapted from ABRELPE (2014); (2) ANDRADE, (2007); (3) THEMELIS; KAUMAN (2004.b)

The metallic components are separated by electromagnets installed on the furnace feed conveyors; the percentage that represents the total metal-free waste is 97.9%, a variable that will be used later as a total mass reducer of USW produced per day and in the incineration for power generation. It is observed that the largest amount of power produced from the combustion of USW comes from the junction of various components such as remnants of fabrics, leather, rubber, hospital waste, Styrofoam, wood and others, which even having 3 times less mass, generates approximately 35% more power than organic waste.

The estimated value for LCP of USW collected in the city of Itacoatiara is 2,766.28 kcal kg⁻¹; then its incineration for electric power production is feasible (EPE, 2014; Nogueira, 2015). According to PERS-AM (2014), the city of Itacoatiara generates approximately 76.92 tons of USW day⁻¹.

Considering that 97.9% of this total is organic waste, it is possible to install two small plants with average capacity to process 50 tons of USW each.

The power generation from SW presents as a possible alternative, contributing to sustainable development. In this context, due to the attractiveness of projects for the private sector, the use for power generation can encourage the development of more appropriate sanitary practices such as the implementation of sanitary landfills, sorting sectors, selective collection and incinerators.

With the power utilization of USW, other significant advantages can be cited as jobs generation, technology transfer, and consequently the replacement of fossil fuels and reduction of greenhouse gases in the environment.

Assuming an efficiency, according to EPE (2014), in the burning of USW for cogeneration of electrical power of 20%, and stable conditions of USW generation and operation of a thermoelectric system, based on Queiroz (2014) the eq. 2 was used to determine the power potential (P_e) of USW where K is a factor of conversion of kcal to kWh and is worth 0.001163:

$$P_e = m_{USW} * LCP * K \quad \text{eq. 2}$$

Thus, considering an estimated USW production of around 38.46 t day⁻¹ (m_{USW}) in each plant.

$$P_e = 38.46 \text{ kg} * \text{day}^{-1} * 2,766.28 \text{ kcal} * \text{kg}^{-1} * 0,001163 \rightarrow P_e = 123.732,88 \text{ kW.h} * \text{day}^{-1}$$

$$\eta = \frac{E_{\text{electric}}}{E_{\text{thermal}}} \quad \text{eq. 3}$$

And from eq. 3 where η is the performance, E_{electric} is the amount of power that can be generated and E_{thermal} is the amount of thermal power by burning the USW, they have:

$$0,2 = \frac{E_{\text{el\u00e9tric}}}{123.732,88 \text{ kw.h} * \text{day}^{-1}} \rightarrow E_{\text{el\u00e9tric}} = 24.746,57 \text{ kw.h} * \text{day}^{-1}$$

or
 $E_{\text{el\u00e9tric}} = 24,75 \text{ MW.h} * \text{dav}^{-1}$

The theoretical potential for power generation is shown in Table 4, which presents a summary of electrical power production from the total incineration of USW per incinerator unit and the sales obtained. For the calculation of revenues for electricity generation in the state and carbon credits were considered the values of 679.00 R\$ MWh⁻¹ and R\$ 20.52 respectively (ANEEL, 2019; MIRANDA et al. 2017).

According to the Integrated Solid Waste Management Manual (BRASIL, 2017), the average CP of household waste is in the range of 5,000 kcal kg⁻¹, and the average composition of waste generated in Brazil is: organic matter: 65%; glass: 3.0%; metal: 4.0%; plastic: 3.0%; paper: 25.0%; of these, 10% are destined to sanitary landfills; 13% controlled landfills; 75% to landfills and only 2% to recycling.

Although the global industrial USW power generation has grown significantly in the last decade, hundreds of millions of municipal waste streams are dumped in landfills. And for every ton of SW discharged into these landfills, greenhouse gas emissions increase by about 1.3 t (THEMELIS; KEUFMAN, 2004 a).

Table -4: Summary of power production and revenues obtained.

USW (t day ⁻¹)	Capacity (t day ⁻¹)	Number of plants	
76,921	50	02	
POWER GENERATION			
USW per plant (t day ⁻¹)	Daily (MW)	Annual (GW)	Revenue (×10 ⁶ R\$)
38,46	24,75	9,03	6,132
CARBON CREDITS			
CC conversion (CO ₂ eq.)	Journal (eq.)	Annual (eq.)	Revenue (×10 ⁶ R\$)
1,3	50	18.250	0,374
Annual revenue per unit (×10 ⁶ R\$)			6,506
Total annual revenue (×10 ⁶ R\$)			13,012

Note: Price of power generation = 679.00 R\$ MWh⁻¹ (ANEEL, 2019); 1 CC = 6 €\$ or R\$ 20.52.

It is observed the amount of power generated was 24.75 MW day⁻¹, which corresponds to 9.03 GW year⁻¹ and a turnover of up to R\$ 6.5×10⁶ year⁻¹ with power generation. It is also observed that the incineration unit is capable of producing 50 tons of CO₂ equivalent daily, which corresponds to 18,250 annual carbon credits and a turnover of up to R\$ 0.374×10⁶ with its sale on the stock exchange.

Thus, each unit can generate sales of up to R\$ 13,012×10⁶ year⁻¹. In addition to the revenues that can be obtained from the generation of electricity produced, other benefits can be highlighted such as:

The mitigation of greenhouse gas emissions from landfills; the ashes generated by the burning of USW can be used for fertilizer production, soil recovery and ceramic manufacturing; it occupies an insignificant area when compared to sanitary landfills; it would not be necessary to provide areas for the construction of these landfills; it avoids the destruction of native forest areas and their desertification; it reduces the presence of animals and insects that vector diseases;

Although constant throughout the year in relation to the chemical composition, as a consequence of climate change and also by the way in which these wastes are stored and

their composition, the emissions vary both in the speed of production and in the amount produced over the time of deposition (EPE, 2008; REZENDE, 2015).

Gas emissions that contribute to the greenhouse effect are related to the exposure time to the environment converted to carbon dioxide (CO₂), taking into account the way as they are discarded.

4. CONCLUSIONS

The LCP of the USW collected in the city of Itacoatiara is greater than 2000 kcal kg⁻¹, and this value is viable for using as fuel for electric power generation.

The amount of USW generated of 76.92 t day⁻¹ allows the installation of two small plants with daily installed capacity of 24.75 MW.

In total the plants can generate 18.06 GW and 36,500 tons of carbon equivalent per year, with the possibility of providing a turnover of up to R\$ 26.024×10⁶ year⁻¹.

The use of USW from the city of Itacoatiara, AM as fuel for thermoelectric plants is a viable and a long-term sustainable alternative. In addition to the revenues that can be obtained, the use of this alternative contributes significantly to the mitigation of: greenhouse gas emissions from landfills and dumps, degradation and contamination of the areas of these areas.

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