

ENCIT2018-0015 PELLETIZED BIOMASS FROM MUNICIPAL SOLID WASTES FOR USE AS SOLID FUEL

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Abstract. *Municipal Solid Wastes (MSW) from the city of Boa Esperança, Minas Gerais, Brazil, were used to produce refuse-derived fuel (RDF). The MSW contain residues of the human society, including product packaging, bottles, batteries, organic wastes, fines, textile, health textile, plastics, glass, metals, among others. The following protocol was performed during the conversion of MSW in RDF: (i) the raw MSW were placed into a silo and conducted to a primary crusher using a metal conveyor belt, which reduced the particles size to 80 mm; (ii) the biomass was conducted to a selective waste collection platform by a rubber conveyor belt, being the recyclable waste, metals and glasses separated manually; (iii) residual metals were removed by a magnetic separator; (iv) the waste was conducted to a secondary crusher which reduces its particles size to 60 mm; (v) the waste passed through an airborne separator to remove materials with high density, such as: glass, stones and organic using a metallic conveyor belt; (vi) the particle size was reduced to 40 mm by a tertiary crusher; (vii) the non-ferrous metals, especially aluminum, from non-metallic materials, such as: plastic, paper, rubber, among others were separated using an Eddy current separator; (viii) the particle size was reduced to 25 mm using a quaternary crusher; (ix) the MSW was introduced into a rotary dryer using a metal conveyor belt, reducing the moisture content below 15 wt%; (x) the RDF was compacted, pelletized and stored for use in thermochemical reactors to produce a combustible gas. In addition, the MSW and RDF were analyzed and the elemental composition and combustion characteristics were determined. On the basis of these results, the protocol evaluated was effective on the conversion of MSW in RDF, which can be used as a source of renewable fuel.*

Keywords: *solid waste, processing, thermal properties, heating value, renewable energy.*

1. INTRODUCTION

Nowadays, the world's economies are driven by consumer-based lifestyles, where producing waste is the most evident and unfavorable resource-intensive by-product. The generation rate of MSW is expected to increase to 2.2 billion tons per year by 2025 worldwide. However, in developing countries, collection, transport and disposing of waste is still challenging while, in developed countries, emerging technologies are used to produce different by-products such as heat, electricity, compost, and biofuels (Moya et. al., 2017).

Table 1 shows the elemental composition and combustion characteristics of some raw solid biofuels (Wang et. al., 2018). The ash contents varied between 2.9 and 18.4%. Although lower values were obtained to wood pellets and logs, no significant difference was observed between MSW and charcoal, a commercial product. Regarding the calorific values, the same profile was observed between the bio-waste solid fuels, with exception of the charcoals. Therefore, the solid biofuels can be used as potential fuels for energy production.

Table 1. Elemental composition and combustion characteristics of different solid biofuels.
Adapted from Wang et. al. (2018).

Solid biofuels	C (%)	H (%)	O (%)	N (%)	Total Moisture (%)	Ash (%)	HHV* (MJ/kg)	LHV** (MJ/kg)	Reference
Sugarcane bagasse	47.8	5.9	45.7	0.5	9.24	2.9	16.4	14.9	Horst (2013)
Rice husk	37.4	5.43	33.2	0.38	9.19	18.4	14.4	-	Souza (2012)
Municipal solid waste	51.2	6.2	40.1	0.1	-	4.4	-	17.2	Edo et al. (2016)
Wood pellets	50.2	5.9	43.2	0.08	7.6	0.5	-	19.0	Johansson et al. (2004)
Wood logs	50.6	6.4	42.7	0.05	15/26/38	0.3	-	19.0	Johansson et al. (2004)
Charcoal	72.2	2.9	23.6	1.3	4.6	4.7	26.0	-	Motghare et al. (2016)

*High Heating Value (HHV)

**Low Heating Value (LHV)

1.1 Context of the Proposed Project

The Brazilian National Solid Waste Policy, Law 12,305/10, in force since August 2, 2010, defined several granted objectives and goals to be achieved for a better future of the country in terms of solid waste management in all administrative levels. In particular, the following stand out:

- A systemic vision, in solid waste management, that considers the environmental, social, cultural, economic, technological and public health variables;
- Sustainable development;
- The eco-efficiency (Lehni et al, 2000) of qualified goods and services that meet human needs and bring quality of life and reduce the environmental impact and consumption of natural resources to a level at least equivalent to the estimated carrying capacity of the planet;
- The recognition of reusable and recyclable solid waste as an economic good with social value, which generates work and income and promotes citizenship;

In view of the above items, it is necessary to establish systems that promote the safe disposal of waste, as well as the reuse of available resources whenever possible. In contrast, the common scenario and culture found in Brazil in view of our large land area is uncontrolled disposal, with the dumps being the common destination of MSW.

The municipality of Boa Esperança, in the Southwest of the State of Minas Gerais, was the city proposed to receive the research and development project described in this document. This is an emblematic case of the systems and customs installed.

With an approximate population of 40,000 inhabitants (IBGE, 2018), the municipality of Boa Esperança, located in the Lake Furnas region, allocates most of its MSW in a dump located 3.5 km south of its urban area.

According to a sanitation study carried out by Furnas in the Lake region in 2003, there were about 1,120,323 inhabitants, of these 949,040 lived in municipalities, 27,801 in districts and 171,282 in rural areas. The same study indicated a total waste generation at that time of 600 tons/day, and projections indicate that generation may have exceeded 800 tons/day today.

Using data from Furnas study and IBGE projections, it was estimated that the daily production of MSW from Boa Esperança is currently 30 tons/day that are destined to the dump.

Within this scenario, it is important to invest public and private capital to investigate alternative technologies and methodologies for reuse and disposal of domestic waste with minimal social, environmental and economic impact.

Therefore, the present project intends to bring a solution to convert MSW to RDF using national and international technology with functionality verified by Environmental State Company of São Paulo (CETESB).

The objective of this work is to produce and store pelletized RDF to a Gasification Power Plant (GPP).

The GPP is being built in the city of Boa Esperança, under Research & Development operational and economic feasibility verification purposes. In this sense, the system will not be connected to the grid for energy export. The

construction of GPP began in 2017 and is expected to be completed in 2019. A second work will be written to present the GPP with the capacity to process up to 30 tons of RDF per day, resulting in 1.5 MWh of electricity.

The waste processing line and the GPP were located 3.5 km south of the urban area, next to the dump used for MSW disposal. This location is strategically important since it does not demand a significant modification waste transport routine, facilitating the transition between the use of the dump and the use of the new disposal system.

Local people living from the collection of recyclable waste were also involved in the project. A cooperative type system will be implemented so that materials with economic value (metals and glasses), separated during MSW treatment, will be properly destined, generating social value to the project.

2. MATERIALS AND METHODS

2.1 Acquisition and preparation of the raw materials

This work consisted in the design of a Solid Waste Processing Line (SWPL), with class II waste processing, for co-processing through thermochemical reactions, in accordance with the Brazilian Resolution CONAMA 316/02 (CONAMA, 2002).

2.2 The waste processing line

Figure 1 presents the waste processing line which has the following characteristics:

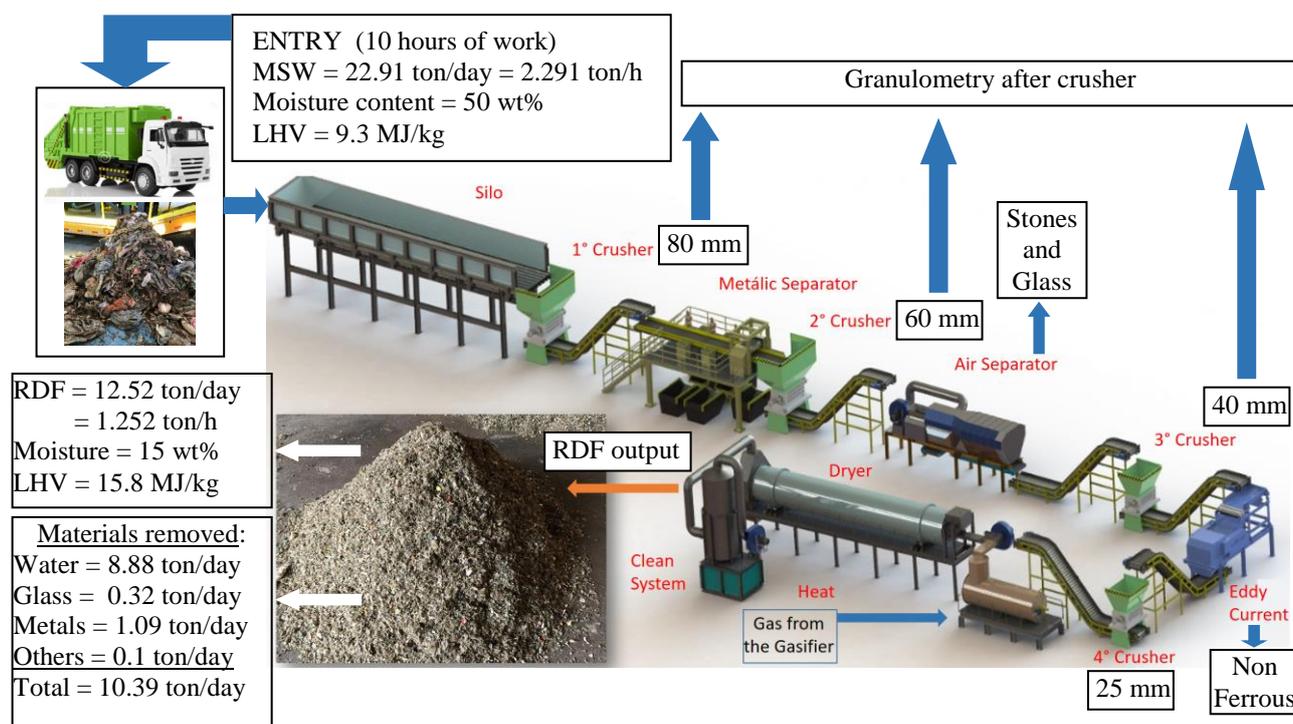


Figure 1. Solid Waste Processing Line (SWPL)

According to Technical Standard ABNT NBR 10.004: 2004, the Class II-A - Non-inert - MSW have the following properties: biodegradability, combustibility or solubility in water.

In order to meet environmental safety, treatment and industrialization, the MSW are processed in a covered and closed shed, with the waterproofed floor, negative pressure system, and odor control. The waste processing line operates daily for 10 hours and processes 2.291 ton/h of MSW "in natura".

Trucks authorized to enter in the SWPL initially move to the weighing site to control the amount of MSW. After weighing, the trucks go to the silo to be unloaded by tipping. The silo was built on the ground and it has a power of 40 kW and a load capacity of 60 tons. Its external dimensions are 18 m (length) x 3.5 m (width) x 5.45 m (height).

The silo also has a conveyor belt that performs repetitive back and forth movements. The waste takes about 4 hours to cover the 18-meter-long silo. The conveyor belt is drilled to drain and collect water from MSW (pre-slurry). A water pump with a flow rate of 511 kg/h transfers the pre-slurry to an effluent treatment plant. Treated water is pumped back (flow rate of 1m³/h) to the collector below the conveyor belt to decrease the odor and viscosity of the pre-slurry.

The primary crusher was designed to receive any type of MSW from the silo, without any pre-selection and choice. It has a power of 150 kW and the MSW granulometry at the outlet of the crusher is 80 mm. Its working capacity is 6 ton/h and it has the following external dimensions: 6 m (length) x 1.6 m (width) x 0.685 m (height).

During crushing, slurry dripping and water evaporation occur due to the friction of the crusher shaft knives with the residue at the rate of 511 kg/ h. To reduce odors and increase the viscosity of the collected pre-slurry, water from the effluent treatment plant is injected into the containment tray at a flow rate of 1 m³/h.

All the crushed residue follows onto a metal conveyor belt which is below the crusher. It should be noted that the process is automatic and exempt from human intervention. The SWPL also has alarms that warn in case of failures and stop the equipment in case of emergency.

According to the Brazilian Law 12,305/10, the implementation of the selective waste collection is a municipal obligation and must be included in any integrated solid waste management plan. Therefore, a waste collection platform was designed (Figure 2). It allows manual separation and collection of recyclable waste such as ferrous, non-ferrous metals, glass, plastics and others.

A rubber conveyor belt with support plates and transfer capacity of up to 8 tons/h, speed of 0.1 m/s and inclination of 45° were installed under a metal platform. Its dimensions are 12 m (length) x 1.2 m (width) x 0.4 m (height). The support plates fixed to the conveyor belt guarantee the transport of the waste without rolling. 8 operators (collectors) are responsible for select the desired waste, which is destined to the recyclable containers by 4 ducts.

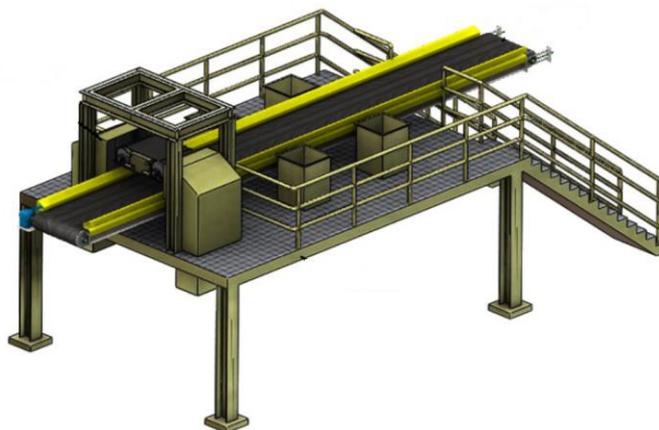


Figure 2. Waste collection platform

A magnetic separator was allocated at the end of the rubber conveyor belt and has the purpose of removing ferrous metals that were not removed by selective collection workers. It was designed to operate in a suspended manner, being positioned transversely to the conveyor belt. The equipment has a power of 1.5 kW and a separation capacity of 0.3 ton/h. Its external dimensions are: 1.067 m (length) x 0.990 (width) x 0.381 (height).

The secondary crusher is an equipment designed to reduce the particle size of the MSW to 60 mm by rotating two axes with interleaved knives. It has a low rotation and high torque. Power of 150 kW, working capacity of 6 ton / h and external dimensions of 5.7 m (length) x 1.6 m (width) x 0.685 m (height).

The MSW with 60 mm is conducted with a metal conveyor belt into an air separator (Fig. 3) to remove high-density materials, such as glass, stones, piles and other non-organic materials.

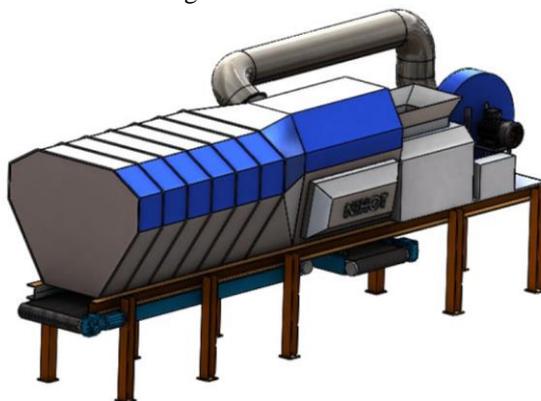


Figure 3. Air separator for high-density waste removal

The continuous flow of air from a centrifugal fan keeps the velocity of the air inflated higher than that required for the pneumatic transport of low-density waste, such as plastics, paper, organic, etc.

In this equipment, there is also moisture removal, at a rate of 127 kg / h, due to the passage of the air stream through the crushed waste.

The air separator has a power of 24 kW and its production capacity is 6 ton/h. The extraction capacity is up to 500 kg/h of high-density wastes that are destined to the extraction container

After the air separator, a metal conveyor belt drives the MSW to the tertiary crusher, which reduces the size of the waste to 40 mm. The equipment has two axes with rotating intercalated knives. Power of 1 x 22 kW + 1 x 18.4 kW, working capacity of 6 ton/h and the following external dimensions: 3.0 m (length) x 1.4 m (width) x 2.3 m (height).

After the tertiary crusher, the MSW with 40 mm is prepared to pass through the non-ferrous metals separator, called Eddy Current (Fig. 4). In its first stage, there is a vibrating track with a magnetic roller that captures the metallic remnants that were not captured in the previous processes. In its second stage, there is an electromagnet that generates a magnetic field that repulses non-ferrous metals, such as copper and aluminum. The Eddy Current equipment has a power of 6,6 kW and its production capacity is 6 tons/h.

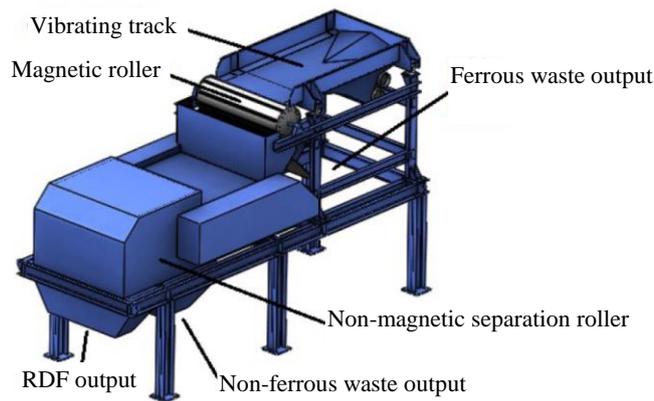


Figure 4. Non-Ferrous metal waste separator: Eddy Current

Then the MSW is transferred by a metal conveyor and, by gravity, it is inserted into the quaternary crusher. At this stage, residues with a particle size of 40 mm and a mass flow rate of 6 ton/h are ground and standardized at a mean particle size of 25 mm.

Figure 5 shows the horizontal tubular rotary dryer. The furnace is the equipment that performs the combustion of the synthesis gas from the thermochemical waste reactor and generates heat for the rotary dryer.

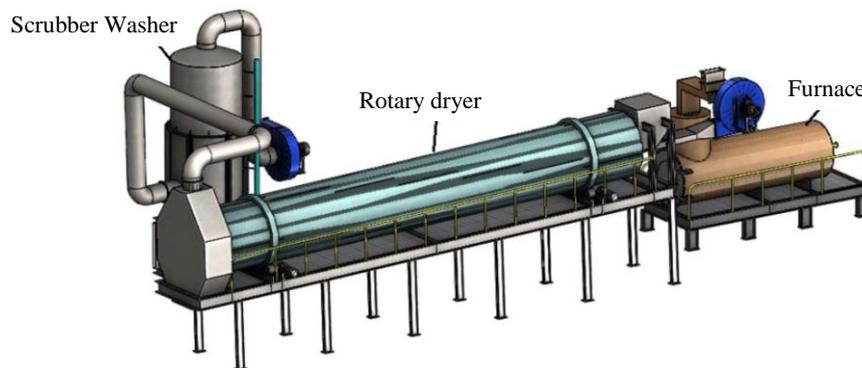


Figure 5. Horizontal tubular rotary dryer.

A metal conveyor belt with 150 mm tall logs leads drives the waste to the horizontal tubular rotary dryer. It provides the drying of the wet MSW, as well as its homogenization. This equipment has the following technical characteristics:

- Power of gear motors: 4 x 3.7 kW;
- Working capacity: 6 ton / h;
- External dimensions: 16 (length) X 2.2 (width) x 5.1 (height) m
- Dryer internal diameter: 1.900 m
- Input Humidity: 30%
- Output Humidity: 15%
- Inlet air temperature: 400 ° C

- Output air temperature: 80 ° C
- Gas flow through the dryer: 1551,28 m³ / h
- Weight: 4600 kg

The Scrubber washer is used to remove particulates, moisture, and odors of the hot air after the dryer.

In the dryer, the MSW with 25% humidity passes through a horizontal tube which is permeated by hot air at 400 °C from the combustion of the synthesis gas in the furnace. This process reduces the moisture content of the waste to 15%, that is, it draws about 400.7 kg/h of water. The dryer also has the function of mixing and homogenizing the RDF in order to produce a uniform fuel. The 15% moisture content RDF is discharged onto a metal conveyor belt below the rotary dryer to be packed and stored.

At the end, the compacted RDF pellets were stored for use in a gasification process and energy generation as presented in Fig. 6.



Figure 6. Compacted RDF pellets

- Mass flow of RDF through the dryer: 12,52 ton/day;
- RDF Granulometry: 25 mm;
- RDF Humidity: 15%;
- RDF Density: 250 kg/m³;
- Pelletized RDF dimensions: 1.50 (length) x 1.10 (width) x 0.72 (height) meters.

The pellets are transported via a forklift to the stock warehouse which has the capacity to store 3200 compacted RDF pellets, with a 60-day autonomy for future use.

According to Miller and Clesceri (2000) the RDF with a moisture content below to 15% can be stored for 3 or 4 months once low moisture content inhibits enzymatic reactions and growth of microorganisms such as bacteria, fungi, and yeasts.

In the absence of RDF in bulk and there is a need to use the stock of fuel stored in the shed, the compacted pellets are unloaded via forklift in a crusher. After crushing and decompressing, the RDF is led by a metal conveyor to the receiving hopper of the thermochemical reactor which converts the RDF into synthesis gas from a gasification process. The thermochemical reactor will be the subject of future work.

3. RESULTS

Some valuable waste components, such as recyclable plastic, paper, electronics, glass, and metal, are often selected and taken by informal collectors from Boa Esperança, hence only the remaining waste components can be converted into synthesis gas and energy. The combined properties of these remaining waste components were calculated to predict the low heating value of MSW (with moisture: 50 wt%) and RDF (with moisture: 15wt%). These properties can be used for an energy analysis and the design of gas power thermal cycles.

Table 2 presents the MSW and RDF composition and the calculated LHV.

Table 2. Mass balance in the waste processing line and calculation/estimation of the average LHV of MSW and RDF.

Composition	Weight (%)	MSW LHV (MJ/kg) Moisture: 50 (wt%)	MSW (kg/h) Moisture: 50 (wt%)	RDF (kg/h) Moisture: 15 (wt%)	RDF LHV (MJ/kg)
Organic waste	35.20	3.3	806.7	474.5	5.6
Fines	3.00	0.3	68.8	40.4	0.5
Paper	6.45	0.5	147.8	86.9	0.8
Packaging	6.00	0.5	137.5	80.9	0.8
Complex	8.75	0.9	200.5	118.0	1.6
Textile	10.00	1.0	229.2	134.8	1.6
Health textile	12.30	1.1	281.9	165.8	1.9
Plastics	8.80	1.5	201.7	118.6	2.5
Glass	1.40	0.0	32.1	0.0	0.0
Metals	5.20	0.0	119.2	0.0	0.0
Not classified	2.90	0.2	66.4	32.4	0.5
Total	100.00	9.3	2291.8	1252.3	15.8

From Tab. 2 it can be seen that the MSW and RDF components were dominated by organic waste, followed by textiles, plastics, papers and others.

According to Pasek et. al. (2013), the heating value is influenced by the moisture content. In this sense, for MSW or RDF to be used in a gasification power plant without any additional fuel, the moisture content should be lower than 50%, the ash content lower than 60%, and the fixed carbon content larger than 25%. Therefore, Table 3 presents the RDF analysis carried out by the Laboratory of the Brazilian Association of Portland Cement - Accredited by ABNT NBR CGCRE ISO/IEC (ABNT, 2017).

Table 3. RDF analyses from the city of Boa Esperança, Minas Gerais, Brazil.

Parameter (Unit)	Mass composition: 100% municipal waste	Mass composition: 100% landfill waste	Mass composition: 50% municipal and 50% landfill waste	Methodology
Potassium (mg/kg)	2711	4211	3253	EPA 3050B
Sodium (mg/kg)	2113	3316	2568	EPA 3050B
Fluoride (mg/kg)	< 0.50	70	80	EPA 5050
Sulfur (% weight)	0.10	0.11	0.11	ASTM-5865
LHV (MJ/kg)	13.2	14.8	15.7	ASTM-5865
HHV (MJ/kg)	14.8	16.3	17.2	ASTM-5865
Nitrogen (%weight)	0.81	0.81	1	ASTM-5865
Hydrogen (%weight)	8	7	7	ASTM-5865
Carbon (%weight)	58	47	57	ASTM-5865
Oxygen (%weight)	33	45	35	ASTM-5865
Chlorine (mg/kg)	4930	15050	6170	EPA 5050
Ash (%weight)	15	27	26	NBR-8289
Moisture (%weight)	25	9.9	15	NBR-8293

From Table 3 it can be seen that the sulfur content is less than 0.11%, which is lower compared to the average sulfur content in coal (0.7%) (The ministry, 2009). The average percentage value of chlorine content obtained of waste fuel was 0,87%; this value is higher compared to the chlorine content in coal (0.3%) (Thomas, 2002) but still within the range of biomass fuels (Duong and Tillman, 2009). The sulfur and chlorine contents are harmless concentrations because they are smaller than 0.3% and 1.0% respectively (Babcock and Wilcox, 1992). Similar results were obtained by Pasek et. al. (2013) during the feasibility study of recovering energy from municipal solid waste to generate electricity.

Wang et. al. (2017) evaluate four different municipal solid wastes (dog manure, horse manure, apple pomace waste and tea waste) and an industrial by-product (NovoGro) used to produce solid fuel pellets. According to the authors the pelletized solid waste exhibited excellent mechanical and thermal properties, including high calorific values (16.98 ± 0.9 MJ/kg), low calorific values (12.75 ± 1.1 MJ/kg), ashes (19 ± 0.8 %), and moisture (12.3 ± 2.3 %).

The calorific value obtained in the present work is in accordance with the values presented in the scientific literature. In addition, this value is close to the values available for commercial biomass fuels, such as sugarcane bagasse, wood pellets, and wood logs. Those results confirm the feasibility of using RDF as a biofuel in GPP.

4. CONCLUSIONS

This work consisted in the design and build a Solid Waste Processing Line (SWPL), with class II waste processing, for co-processing through thermochemical reactions, in accordance with the Brazilian Resolution CONAMA 316/02 (CONAMA, 2002).

The SWPL has the capacity to process 22.9 ton/day of MSW with up to 50 wt% humidity. The waste passes through a series of equipment that provides the removal of moisture, recyclable waste, stones, glass, ferrous and non-ferrous materials.

The final product, after passing through a rotary tubular dryer, is called RDF. The SWPL produces about 12.52 ton/day of pelletized RDF with 15% moisture and low calorific value of 14.8 ± 0.7 MJ/kg. That is, at the end, about 8.88 ton/day of residue moisture is removed, as well as, 0.32 ton/day of glass, 1.09 ton/day of metals, 0.1 ton/day of others.

This is a pioneering project in Brazil. The SWPL as well as a gasification power plant are being built in the city of Boa Esperança, Minas Gerais, under Research & Development operational and economic feasibility verification purposes. In this sense, the system will temporarily not be connected to the grid for energy export. The construction of GPP started in the year 2017 and is expected to be completed in 2019. A second work will be written to present the GPP with the capacity to process up to 30 tons of pelletized RDF per day, resulting in 1.5 MWh of electricity.

Based on the analysis results discussed above, it can be concluded that RDF can be used as biofuel in a GPP without using additional solid or fossil fuel.

In addition to being a proposal to control environmental liabilities, the construction of SPWL has in its scope the creation of a cooperative for the local community to carry out the selective collection of recyclable materials. These characteristics demonstrate the environmental and social character of the present work.

5. ACKNOWLEDGEMENTS

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