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Evaluating the emissions from the gasification processing of municipal solid waste followed by combustion

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A B S T R A C T

In this study, we evaluated the emissions of pollutants generated from the combustion of syngas in the gasification of Municipal Solid Waste (MSW) in Brazil using a mobile grille gasifier fed with domestic waste without any previous separation or grinding. The basic syngas composition (H_2, CH_4 and CO) was analyzed by gas chromatography and the Lower Calorific Value was calculated, which ranged from 1.9 to 10.2 MJ/kg. In the monitoring of combustion gases (CO_2, CO, NO, NO_2, SO_2 and Total Hydrocarbon Content), values were found for these pollutants that were lower than the values established by the Brazilian legislation, except for SO_2. Regarding the determination of the emission of metals, values lower than those permissible in the legislation were found for the most toxic metals grouped as class I (Cd, Hg, Tl). Therefore, it was evident that gasification followed by the combustion of syngas from MSW without prior segregation at source has the advantages of having fewer process steps, allowing the low emission of pollutants into the environment and it avoids that the residues are deposited in landfills, which are generators of leachate and greenhouse gas (methane).

1. Introduction

Different structures for the disposal of Municipal Solid Waste (MSW) are found in Brazil, since each city government is responsible for the environmentally safe management of solid waste from collection to final disposal. The main variances among the different cities are related to economic conditions, displacement distance of the waste, culture of disposal and/or waste reuse, and especially to the lack of suitable technologies to guide economic arrangements for the reuse of solid waste. According to the Brazilian National Solid Waste Policy (BRASIL, 2010); technologies for the energy generation from waste may be used if their technical and environmental feasibility have been proven with the implementation of toxic gas emission monitoring programs approved by environmental agencies.

MSW management is particularly complicated because it is a mixture of a heterogeneous composition that varies in function of the place of production, habits and culture of the urban population generating it. Waste includes recyclable or non-recyclable elements with an average of 50% of organic fraction that can be used for energy generation. It is worth remembering that a significant volume consists of polymeric materials including disposable bags and diapers, which are energetic materials resistant to degradation. Despite the need for the segregation of waste by type, in practice this does not occur in an effective way throughout Brazil (Lino and Ismail, 2012). In general, most of the municipalities have problems related to the correct destination and disposal of MSW. According to the Brazilian Waste Treatment Association, 60% of solid waste are sent to landfills annually, while the rest is sent to rubbish dumps and controlled landfills (ABELPRE, 2015). The difference between the latter is that the controlled landfill receives a cover, but soil is not waterproofed unlike the landfill. But it should to be remembered that over time the landfills present inconveniences and economic costs even services are disabled. Because of the generation of leachate and biogas requires monitoring and/or treatment at least 30 years after its closing (Jovanov et al., in press). Consequently, the land where the landfill has been developed may become uninhabitable by an undefined period.

Utilization of MSW as an energy source require appropriate and properly analyzed technological routes regarding implementation risk. Besides being environmentally correct it is a business opportunity. In relation to economic viability should give not only the balance between revenues and expenses, but also an adequate business model with municipal governments to guarantee the collection of such waste (FEAM-DPED-GEMUC, 2012).

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MSW thermochemical treatment processes are characterized by high temperatures and high conversion rates, allowing an efficient treatment of different types of solid waste. Its main advantage is the high reduction of waste mass and volume, around 75% and 85%, respectively. Also, prolonging the life of landfills, which could then receive only inert, non-recyclable waste, which would not generate leachate or biogas (Arena, 2012). Therefore, this would avoid the emission of greenhouse gas associated to the anaerobic decomposition of organic waste. Furthermore, the MSW thermal treatment processes are compatible with the exploitation of renewable energies, especially when the plant is designed for generation of energy, whether thermal or electric, both used in industrial plants or for the heating of cities. In the utilization of waste to energy, one or more of the three types of thermochemical conversion, incineration, pyrolysis or gasification processes are generally used.

In the gasification process, the solid or liquid carbonaceous material are converted into a syngas through partial oxidation at an elevated temperature of 500–1400 °C and a variable atmospheric pressure of up to 33 bar (Morrin et al., 2012). During this process, most feedstock is thermally decomposed into gas, however small amounts of by-products are also formed, including tar, char and ash (Cohce et al., 2011). Depending on the design and operating conditions of the reactor, it can also generate methane and hydrocarbons (Singh et al., 2011). Thus, the configurations gasification-based technologies depend on the type of application desired by the customer. When the objective is the energetic utilization of MSW synthesis gas, the gasification system can be considered by first performing a gas purification treatment and then burning (Leckner, 2015). This allows the prolongation of the equipment life involved and less emissions of atmospheric pollutants. It is also an appropriate arrangement to produce electrical energy (Arena, 2012). However, it presents higher operational costs of the treatment of gases and the drawback is that the purified hydrogen requires a bigger safety structure. Another possibility is to burn the synthesized gas without any treatment and to take advantage of the thermal energy produced for electricity generation.

The process of gasification of waste combined with plasma is one application that has been much discussed (Zhang et al., 2011; Fabry et al., 2013; Byun et al., 2011; Galeno et al., 2011; Zhang et al., 2012). The treatment of waste with a plasma torch can be used directly to produce syngas or to combust syngas from the conventional gasification process. In general, this process operates at atmospheric pressure and temperatures above 5000 °C (Leal-Quirós, 2004). Plasma gasification plants require a large amount of electricity to operate the plasma torch, usually between 1200 and 2500 MJ per ton of waste (Arena, 2012). Despite that this process has a high level of efficiency and very low emissions as advantages; it does result in a high operational cost.

Gasification combined with combustion as well as other thermal treatments has environmental advantages in relation to incineration, mainly in relation to the emissions of heavy metals, dioxins and furans (Maya et al., 2016; Soni and Naik, 2016). In this process, the type of gasifier, where the crude synthesis gas is produced, is usually coupled to a boiler. This apparatus is the gasification-based installation configuration most commonly used in MSW processing operations (Arena, 2012). It has a combustion/fuel ratio better than conventional waste incineration, which provides a more complete combustion of the gas mixture. However, this system is less efficient in the production of energy due to the gas generally having a low calorific value (LCV) since it would require an energetic reinforcement to improve its combustion. In general, the composition of the syngas is variable due to many factors, such as the reactor model, the form of energy supplied to the process, the injection or not of water vapor together with the oxidizing agent, besides the charge retention time and the type of carbonaceous matter used.

Studies have been carried out to determine the potential of waste as usable energy. For instance, gasification of wood waste (Bhattacharya, 1999; Sun et al., 2009; Sheth and Babu, 2010), agricultural and food waste (Ahmed and Gupta, 2010; Ramzan et al., 2011) and municipal solid waste (He et al., 2009; Luo et al., 2010; Antonopoulos et al., 2011; Chen et al., 2010; Zhang et al., 2008; Lopes et al., 2018; del Alamo et al., 2012; Lusardi, 2014). According to the Brazilian reality and considering that the gasification combined combustion technology is one approach to satisfy to national solid waste policy (PNRS, in the Portuguese abbreviation), this it is relevant a study with practical results from the environmental point of view. In this context, the present study evaluated the effectiveness of the gasification combined combustion process of MSW for the use of the syngas as a source for energy production, and monitoring the emission of metal and residual gases.

2. Methodology

The gasification experiments were carried out in a pilot gasifier installed at the Energia Limpa do Brasil Company (ELBRA), located in Araucária city, Paraná, Brazil. The gasifier is in final stage of development and it has a test license issued by the Environmental Institute of Paraná (IAP) in Brazil. The scheme of the gasifier used in this work was demonstrated in our previous work (Lopes et al., 2015). Fig. 1 shows photo views of the gasifier unit and engine setup. The gasification system developed has a horizontal chamber which presents a differentiated morphology adequate for each function. The combustion system was controlled manually, and the device was fed manually with waste provided by a landfill of Mafra city in the Brazilian state of Santa Catarina and it was transported by Brazilian company Serrana Engenharia Ltd., which has an operating license from environmental agencies.

2.1. Gasification process

During the gasification, several test batches were carried out using MSW, with a mean content of 60% moisture. The waste without segregation was transported in bags of one ton to the processing unit (see Fig. 2). Which were then manually fed onto a rotating conveyor that led to the gasifier without grinding, in the ratio of 100 $kg{\cdot}h^{-1}$.

In the initial step of the gasification process LPG (liquefied petroleum gas) was used until the gasification chamber stabilized at a temperature above 1000 °C. The range temperature of between 600 °C and 800 °C with an average temperature of 740 °C in the chamber was maintained by controlling the addition of the gasifying agent, distributed homogeneously in the processed material. After that, the heat required for operating of gasifier was provide by syngas combustion generated in the process.

2.2. Characterization of the syngas

The syngas from the MSW gasification was characterized by gas chromatographic (GC) aiming the molar quantification of hydrogen (H_2), methane (CH_4), carbon monoxide (CO) and carbon dioxide (CO_2), by the use of external calibration standards. A Thermo Finnigan gas chromatograph was used (Trace GC 3000 model) coupled with a FID/TCD detector (Flame Ionization Detector/Thermal Conductivity Detector), connected in series. The GC separation was carried out in columns packed with Porapak N (2 mm × 3.4 m) and molecular sieve 13× (2 mm × 2 m). The injector temperature was heated to 140 °C. Argon was used as carrier gas with a constant flow rate of 20 cm^3/min using the TCD at 350 °C and FID at