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A new technology for the combined production of charcoal and electricity through cogeneration

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ABSTRACT

This paper presents an historical approach on the development of the existing biomass carbonization technologies in industrial operation in Brazil, the biggest charcoal producing country in the world. The gravimetric yield of charcoal from wood does not usually surpass 25%; the time of each operation cycle is more than seven days; and less than 50% of the energy contained in the feedstock is transformed into charcoal – the rest is discharged into the environment. The electricity generation associated with charcoal production is nowadays inexistent in Brazil. This paper presents the development of an industrial technology of semi-continuous pyrolysis process, characterized by using metallic kilns with forced exhaust system: the Rima Container Kiln (RCK). The results of the test runs are related to 5 m^3 and 40 m^3 kilns, with a thermal power of 200 kW (pilot scale: 5 m^3) and 3000 kW (industrial scale: 40 m^3). The low heating value of the pyrolysis gases is 670 and 1470 kJ/m^3, respectively.

The main results are: a 3 h carbonization time; an average productivity per kiln of 1 ton of charcoal per hour; and a gravimetric yield of 35%. In this paper, four scenarios for the conversion of exhaust gases and tar into electricity were evaluated: the Conventional Rankine Cycle (CRC) and the Organic Rankine Cycle (ORC), each one with and without forest residues utilization. It is shown that the best economic indicators correspond to the scenario where ORC technology is used. The electricity generation cost is around U$30/MWhe for ORC and US$40/MWhe for CRC.

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1. Introduction

1.1. *The relevance of charcoal production in brazil*

Some reports indicate that around the year 500 A.C. the Macedonians used wood to produce charcoal and tar. Even before that, the carbonization of wood was already known and utilized by the Egyptians, the Persians and the Chinese. The process used by these ancient civilizations remains almost unchanged today, especially from the energy loss point of view, which can reach more than 50% of the biomass energy content.

Fig. 1 shows the share of the total energy produced from charcoal and the respective energy loss in the State of Minas Gerais, Brazil from 1978 to 2010 [1]. Energy losses reduction, as observed in recent years, was only possible through process improvement, leading to increase in charcoal yield and more efficient forest handling.

According to the National Energy Balance [2], Brazil has 44% of its energy matrix supplied by renewable sources. From this total, around 10% correspond to wood and charcoal, 15% to hydraulic electric generation, 16% to sugarcane, and 3% corresponds to wind and solar energy based generation. Around 4% of the total installed capacity for electricity generation in Brazil corresponds to thermal power stations, which burn coal, gas, oil and biomass (such as bagasse and wood dust). Nevertheless, there is not a single thermal power installation that uses exhaust energy from carbonization processes.

1.2. *Wood carbonization*

Wood carbonization involves a complex phenomenon that allows the generation of a wide range of chemical compounds, which can be grouped as: charcoal, tar, pyroligneous acid and gases [3].

Table 1, adapted from Refs. [4] and [5], shows the mass fraction content, dry basis, of the main products derived from wood pyrolysis. These results were obtained at laboratory scale without oxygen supply and by using external heating.

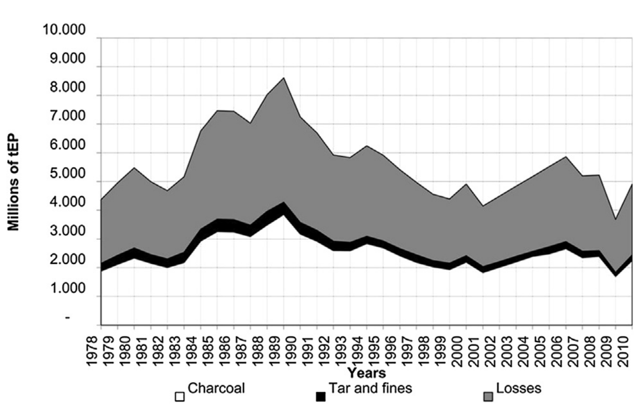

Fig. 1 – Share of the total energy produced from charcoal in the Minas Gerais State, Brazil from 1978 to 2010, as granulated charcoal, other products (dust, tar and losses (smoke).

Table 1 – Products of carbonization.

Products of carbonization	% Dry base
Charcoal (80% fixed carbon)	**33.0**
Pyroligneous acid	**35.5**
(Acetic acid)	(0.5)
(Methanol)	(0.2)
(Soluble tar)	(5.0)
(Water and others)	(23.5)
Insoluble tar	**6.5**
Non condensable gases (NCG)	**25.0**
(Hydrogen – 0.63%)	(0.16)
(CO – 34%)	(8.5)
(CO_2 – 62%)	(15.5)
(Methane – 2.43%)	(0.61)
(Ethane – 0.13%)	(0.03)
(Others – 0.81%)	(0.20)
Total	**100**

The phenomena that occur during carbonization are grouped differently depending on the author. For example, Refs. [3] and [6], divide them in four stages as follows:

- A: Up to 200 °C, there is production of gases, such as water vapor, CO_2, formic and acetic acid.
- B: from 200 to 280 °C, the same gases from zone A are released; but the emission of CO begins and there is a substantial decrease in water vapor emission. The reactions in this zone are endothermic.
- C: from 280 to 500 °C. Carbonization occurs through exothermic reactions. The products obtained in this stage are influenced by secondary reactions, including formation of fuel gases, tar, CO and CH_4.
- D: over 500 °C. All wood has been converted into charcoal. Various secondary reactions take place, catalyzed by the carbonization layer.

According to Ref. [7], sugarcane bagasse and wood pyrolysis can be divided by stages in a similar way based on thermal analysis results. Stage B corresponds to hemicelluloses destruction and stage C to cellulose and lignin conversion into charcoal.

Table 2, shows the main products generated in each stage of carbonization, according to the temperature evolution of the process. The values found in Table 2 correspond to tests performed at laboratory scale as show in Ref. [8].

Fig. 2 presents the photos of wood pieces at different carbonization stages as previously described. From left to right: in the first stage, the wood is dried and the released gases contain only water vapor. In the second stage, the product is a partially carbonized wood, or toasted wood. This toasted wood has the highest energy content per weight and also a great content of volatile matters. In the third stage, hydrocarbons start to be released and carbonization pushes forward to the center of the wood piece, reducing its volume in the radial direction. Finally, in the last stage, when the temperature reaches 500 °C in the center of the wood piece, carbonization may be interrupted. The charcoal at this final temperature has a fixed carbon content of around 75%. Above 500 °C, the charcoal structure and composition continues changing and the fixed carbon content can reach more than 90%.