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**USE OF COCONUT SHELL PRODUCED IN THE BRAZILIAN GREEN
COAST FOR SMALL-SCALE ELECTRICITY GENERATION**

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Abstract: *Being the main by-product derived from the consumption of green coconut, coconut shell offers attractive potential for use in technologies that use gasification systems integrated with an internal combustion engine in regions where there is a great potential for this residue. In this study, it is proposed to analyze the incorporation of a cogeneration system with an internal combustion engine aiming at implementation in the Green Coast region, more specifically in the city of Angra dos Reis. Technical analysis was carried out applying the first Thermodynamics Law to determine the energy utilization of the proposed thermal plant aiming at the later evaluation of the performance of a bubbling fluidized bed gasifier for the production of syngas, as well as economic analyzes in order to check the operational viability of the plant. The study estimated 1786 kg/day of coconut biomass, which provides a potential for generating 107 kWh of electricity. As a result of the technical analysis and overall efficiency of 56% was determined. The cost of electricity produced was estimated at 0.651 R\$/kWh, however, the cost of hot water produced was 0.280 R\$/kWh. Considering the initial investment of the plant and its amortization over the years, a return on investment of approximately 9 years was estimated.*

Keywords: *coconut shell, cogeneration, internal combustion engine, syngas.*

1. INTRODUCTION

In the current Brazilian scenario, the use of advanced biomass energy shows as an imminent potential. However, biomass is still a source of energy dispersed in the Brazilian territory, which implies greater viability in the installation of gasification facilities that use less than 1000 kg/h (CORONADO, SILVEIRA, and ARAUZO, 2006).

According to Martins and Jesus (2011), green coconut shell is a very abundant element in Brazil, such that after every 125 coconuts, after being consumed, they occupy a volume of about 1m³ in landfills, where, according to Carrijo et al. (2002), 85% of the gross weight of the green coconut is attributed to its shell, such that it is destined for landfills.

According to Passos (2005), it is estimated that 1.1 to 3.4% of all urban solid waste in Rio de Janeiro is composed of coconut shells. In the region of Angra dos Reis, according to PERS (2013), the production of green coconut is 0.81 kg / inhab/day, where according to IBGE data (2019), there is a population of 200,407 inhabitants, thus, estimates production of green coconut shell of approximately 1786 kg/day.

Therefore, the present study approaches a technical and economic analysis of a cogeneration power plant characterized by the processing and usage of syngas from the gasification of green coconut shell, through a bubbling fluidized bed gasifier coupled to a cogeneration system of electric energy that uses an internal combustion engine.

2. MATERIALS AND METHODS

2.1. Configuration of the Cogeneration Plant

Figure 1 shows the thermal plant in question, which consists of the admission of the moist green coconut shell (1), passing through a dryer, in which the coconut shell is already dry (2), so it is admitted in the gasifier with air (3), where

the gasification process takes place and the necessary heat is supplied, in a manner that the product of this reaction is a synthesis gas or a poor gas. The latter goes through a cyclone to remove its impurities and then admitted to an internal combustion engine (4), together with air (5) in a poor air/fuel mixture. Around 107 kW of the combustion energy is converted into electricity. Part of the dissipated energy is used with heat exchangers, where a jacket type heat exchanger (countercurrent) is used for cooling, where there is a flow of water at room temperature with entry at (6) and exit at (7) at a higher temperature. For the exhaust gases (8), a hull and tube heat exchanger is used to heat water (9) until saturated steam is obtained and then used in the dryer (10), together with the exhaust gases leaving the heat exchanger (11) and are also directed to the dryer. Finally, the exhaust gases leave the dryer (12), together with the water vapor removed from the biomass moisture (13), escaping through the chimney and the condensed water vapor is removed through another channel (14).

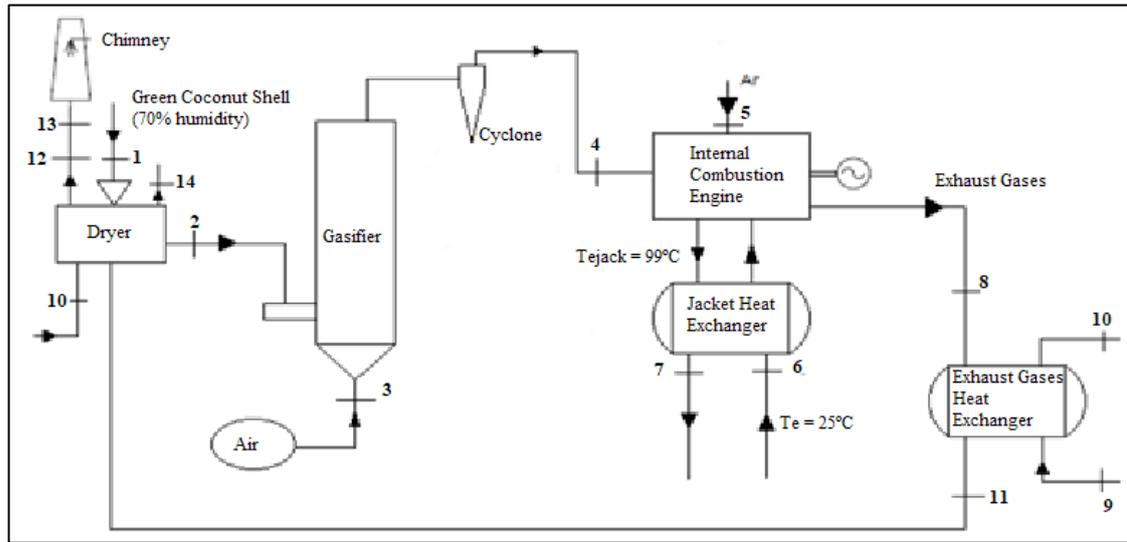


Figure 1. Scheme of the Thermal Plant for Biomass Gasification

2.2. Technical Analysis

First, a thermodynamic analysis was performed on the following control volumes: bubbling fluidized bed gasifier, internal combustion engine of Otto cycle, heat exchangers (countercurrent and hull and tubes), and a rotary dryer, according to the 1st Law of Thermodynamics, see Eq. (1).

$$\dot{Q} - \dot{W} = \sum_{out}(m_{out} \cdot h_{out}) - \sum_{in}(m_{in} \cdot h_{in}) \quad (1)$$

Where:

m: Mass flow at the inlet and outlet (steam, hot water, gases, etc.) [kg/s];

h: Enthalpy of energy flows (steam, hot water, gases, etc.) [kJ/kg];

\dot{Q} : Heat transfer rate through the control volume under analysis [kW];

\dot{W} : Energy power through the control volume under analysis [kW].

Such that the electrical power to be supplied by the motor is given by Eq. (2).

$$\eta_{el} = \frac{E_p}{E_{fuel}} \quad (2)$$

Hence, effectiveness is defined for each type of heat exchanger as described by Bergman et. al (2014). Thus, the thermal efficiency of the heat recovery cycle is determined, according to Eq. (3).

$$\eta_{heat,recov} = \frac{E_{jack} + E_{eg}}{E_{fuel}} \quad (3)$$

2.3. Economic Analysis

This analysis aimed to verify the economic viability of the project following the methodology developed by Silveira, et al. (1994; 2012) and Tuna (1999), being perfected by Xavier (2016), structured as follows. Using Equation (4), the cost of producing the fuel (syngas) is calculated [US\$/kWh].

$$C_{\text{fuel}} = \frac{I_{\text{gasifier}} \cdot f}{H \cdot \dot{E}_{\text{fuel}}} + \frac{C_{\text{shell}} \cdot \dot{m}_{\text{shell}}}{\rho_{\text{shell}} \cdot \dot{E}_{\text{fuel}}} + C_{\text{m.gasifier}} \quad (4)$$

Where:

C_{fuel} : Fuel cost [US\$/kWh];

I_{gasifier} : Investment in the gasifier [US\$];

f : Annuity Factor [1/ano];

H : Hours of equipment operation in the year [3000 horas/ano];

C_{shell} : Coconut shell cost, according to the logistics involved [0.21 US\$/kg];

\dot{m}_{shell} : Mass flow of coconut shell [kg/s];

ρ_{shell} : Coconut shell density [128 kg/m³] (CARDOSO and GONÇALVEZ, 2016);

$C_{\text{m.gasifier}}$: Gasifier maintenance cost [0.02 US\$/kW] (YOSHIOKA, 2008).

The cost of heating water is calculated [US\$/kWh], see Eq. (5).

$$C_{\text{heat.H}_2\text{O}} = \frac{I_{\text{HE}} \cdot f}{H \cdot \dot{E}_{\text{HE}}} + C_{\text{fuel}} \cdot \frac{\dot{E}_{\text{jack}} + \dot{E}_{\text{eg1}} + \left(\frac{\text{Losses}}{4}\right)}{\dot{E}_{\text{HE}}} + C_{\text{m.HE}} \quad (5)$$

Where:

$C_{\text{heat.H}_2\text{O}}$: Cost of heating water in heat exchangers [US\$/kWh];

I_{HE} : Investment in heat exchanger [US\$];

\dot{E}_{HE} : Thermal power used in heat exchangers [US\$/kW];

$C_{\text{m.HE}}$: Maintenance cost of heat exchangers [0.002US\$/kW] (BRIZI, et al., 2014).

Recorded losses are calculated using Eq. (6).

$$\text{Losses} = \dot{E}_{\text{fuel}} - \dot{E}_{\text{p}} - \dot{E}_{\text{jack}} - \dot{E}_{\text{eg}} \quad (6)$$

The cost of reaching dry biomass [US\$/kWh] is calculated, according to Eq. (7).

$$C_{\text{dryer}} = \frac{I_{\text{dryer}} \cdot f}{H \cdot \dot{E}_{\text{dryer}}} + C_{\text{fuel}} \cdot \frac{\dot{E}_{\text{eg2}} + \text{Perdas}/4}{\dot{E}_{\text{dryer}}} + C_{\text{m.dryer}} \quad (7)$$

Where:

C_{dryer} : Cost of dry biomass production in the dryer [US\$/kWh];

I_{dryer} : Investment in the dryer [US\$];

\dot{E}_{dryer} : Thermal power used in the dryer [US\$/kW];

$C_{\text{m.dryer}}$: Dryer maintenance cost [0.0004 US\$/kW] (FREITAS,et al., 2006).

3. RESULTS

3.1. Technical Analysis

In order to dimension the most suitable motor for the thermal plant, the proposed working conditions on it are considered to be 8 hours/day for 330 days, such that the remaining 35 days will be used for failures and necessary maintenance. In this way, there was a total of 223.2 kg / h of available wet biomass, 156.24 kg / h of biomass inserted in the gasifier, and a total of 239 Nm³ / h of syngas introduced in the ICE.

Based on the aforementioned premises, it was decided to use an ICE with a mass fuel flow of 0.074 kg / s. Thus, through a Caterpillar catalog of ICE powered by natural gas, the model shown in Fig. 2 was chosen.



Manufacturer: Caterpillar
 Model: G3516 LE 60 Hz
 Efficiency operating with natural gas: 33.3%
 Operating flow with natural gas: 232 Nm³ / h
 Gas exhaust temperature (T_g): 450 ° C

Figure 2. Caterpillar Engine - Model G3516

The performance of the ICE of the cogeneration plant for the production of electricity and heating, both biomass and water, are shown in Table 2, in view of the methodology for the calculations referred to in the previous topics.

Table 2. Engine performance using green coconut shell gas.

Engine	E_p [kW]	η_{el} [%]	T_{eg} [°C]	\dot{m}_{fuel} [kg/s]	\dot{m}_{eg} [kg/s]
G3516	107.51	30.39	439.4	0.074	0.264

Thus, the graph shown in Fig. 3 was generated, allowing the visualization of the energy distribution of the proposed plant in a percentage evaluation, facilitating its performance evaluation.

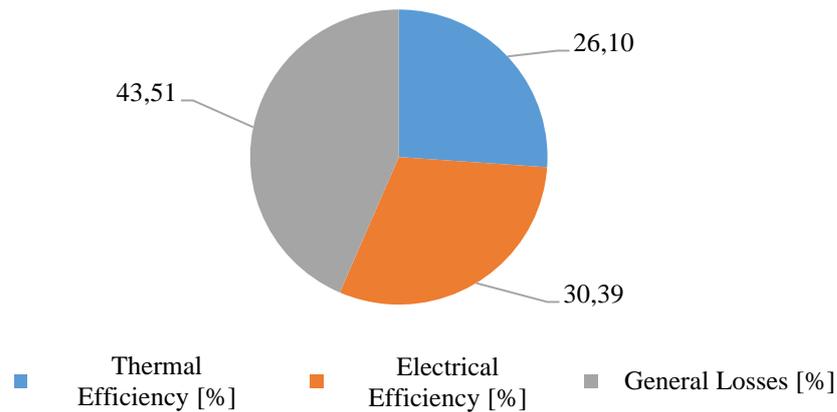


Figure 3. Energy distribution of the proposed plant with G3516 engine

Furthermore, there is the overall efficiency of the thermal plant, shown in Tab. 3.

Table 3. Global Efficiency of the Cogeneration Plant

Engine	E_p [kW]	η_{el} [%]	η_{heat} [%]	η_G [%]
G3516	107.51	30.39	26.10	56.49

3.2. Economic Analysis

Through the mass flow of poor gas, 0.074 kg/s, the electric energy produced in the proposed thermal plant was obtained, which was 107.5 kW, with the same working 3000 hours per year. According to EPE (2018), the average residential energy consumption in the southeastern region was 169 kWh/month in 2017, which allows estimating a total of 153 houses benefited monthly with the implementation of this plant in the Angra dos Reis region.

When analyzing the operation of the studied thermal plant, in an operating period of 3000 hours/year, the graphs presented in Fig. 4 were obtained, in which the costs of fuel production (a), hot water production (b), dry biomass production (c) and electricity production (d), respectively, with the annual interest rate varying between 2%, 4%, and 12%.

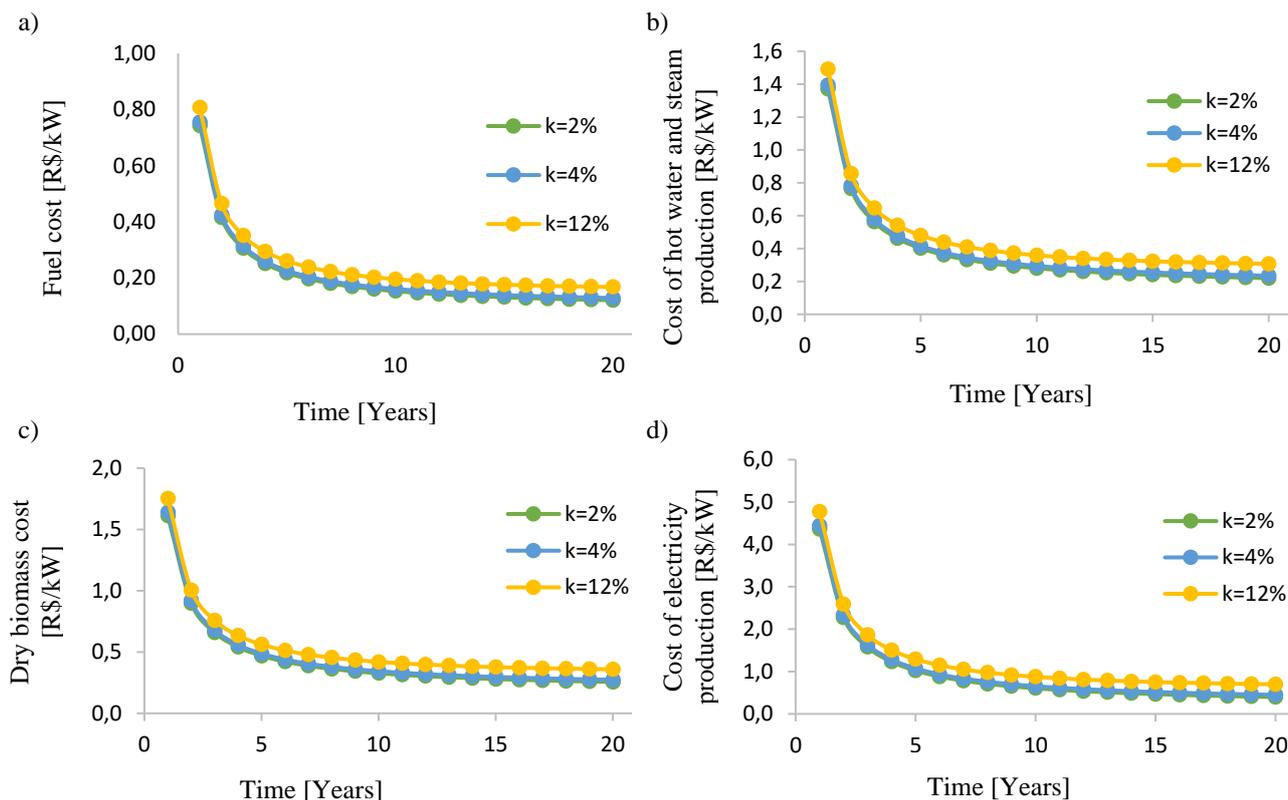


Figure 4. Production costs with interest of 2%, 4% and 12%
a) Fuel - b) Hot Water - c) Dry Biomass - d) Electricity

4. CONCLUSIONS

The use of green coconut shell is presented as one of the most effective ways of obtaining energy due, in addition to its good efficiency, the important socioeconomic bias that the use of this material in gasification plants can bring, which is reinforced by the fact that there is an extremely promising future for the use of biomass in the national and global energy matrix.

Likewise, it is a good alternative because it is an abundant waste, mainly in the coastal regions of the country. Its use for the cogeneration plant, in the Angra dos Reis region, makes it essential that there is an intense collection of the coconut shell, in order to enable the operation of this thermal plant.

The viability of the operation using the G3516 engine with the fuel from the biomass gasification was verified, however with great power loss due to the great difference in energy supplied between natural gas or biogas (47.3 MJ / kg) and syngas (4.7 MJ / kg), only about 10%, but this fact did not imply in the high efficiencies produced by the studied engine, already foreseen in the literature, revolving around 30 - 40%.

Through the implementation of heat exchangers to take advantage of the thermal energy given off by the internal combustion engine, system losses were minimized by 26.1%, making it possible to direct a portion of the energy to the biomass drying process, which in turn time, have proved to be of great energy expenditure.

Therefore, this study allowed an immersion in the thermo-chemical conversion of biomass showing the feasibility of reusing agricultural or industrial waste for the generation or cogeneration of renewable energy, through small technological implementations that already exist.

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