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# COCONUT SHELL GASIFICATION NUMERICAL MODELING IN A DOWNDRAFT REACTOR

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**Abstract.** *This present work aims to evaluate gasification as a method of energy extraction from coconut shell residues in the north of Espírito Santo. Gasification is the conversion of a solid or a liquid fuel into a combustible gas that can be used to feed industry equipment. Given the wide development of the Brazilian agroindustry and the high amount of residues produced by it, the coconut shell stands out in the region for its abundance, low cost and reasonable calorific value. In this way, gasification is highlighted by the production of a clean fuel from residues. Considering these elements, the proximate analysis of the coconut shell was determined experimentally. Secondly, was made a modelling for a downdraft gasifier using the previous results of the proximate analysis. The results show that the proximate analysis is according to the literature and the numerical model developed can predict the gas production very close to the real process.*

**Keywords:** *biomass, energy, gasification, biofuels*

## 1. INTRODUCTION

Increasing use of nonrenewable recourses like fossil-based fuels in addition to the pollution caused by its extraction have led to the rise in demand for renewable energy sources. In that way, the use of biomass is an promising alternative to reduce the impacts caused by the extraction of energy from petrol because of its availability (Zheng *et al.*, 2016).

In this context, combined cycle gasification is one of the most efficient ways of obtaining energy through biomass, even overcoming combustion (Devi, Ptasiński and Janssen, 2003). Gasification is a thermo process to converts solid low cost biomasses into a gas called synthesis gas or syngas. The syngas can be used as a fuel for internal combustion engines and gas turbines, and it consists of a mixture of gases such as hydrogen, carbon oxide, methane, carbon dioxide and vapor (Prando *et al.*, 2016). Although, undesired hydrocarbons might be also produced in the process (Barman, Ghosh and De, 2012)

The efficiency of a gasification system depends on the characteristics of the biomass (moisture/ash/volatile content) and equivalence ratio used in the process. These parameters also control the operating temperatures on the gasifier, which influences the tar formation and maturation (Jeya Singh and Sekhar, 2016). According to Prando *et al.*, the production of tar is the main obstacle to the use of syngas for engines applications since it can cause incrustations in the engine's pipes. Therefore, the type of biomass and the equivalence ratio must be well chosen in order to reduce formation of tar and other impurities that may harm the operation of the other equipments.

The equivalence ratio (ER) is the ratio of the amount of air that was fed to the system to the amount of air that is required for the complete combustion of the biomass (Zheng, *et al.*, 2016). According to (Martínez, *et al.*, 2016), the ER should vary from 0.2 to 0.4 in order to reduce the production of inert gases like N<sub>2</sub>, and consequently, increase the heat value of the syngas. However, Vidian (2016) highlights that the higher the ER value the greater is the temperature in the process and the tar formation; therefore, the author recommends that the ER value should not exceed 0.42 since higher values increase the aromatization of the evolved compounds.

In order to predict the composition of the syngas and the temperature of the process, many theoretical research on gasifying process modelling have been developed based on the thermochemical equations Melgar, *et al.* (2007); Centeno, *et al.* (2012); Jeya Singh and Sekhar (2016). The theoretical results show a good agreement with the

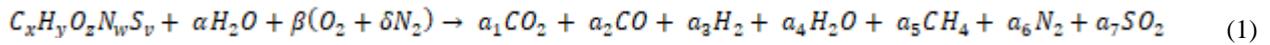
experimental results, which proves the accuracy of the methods as an acceptable way of predicting the gasifier operation temperature and syngas composition.

This study presents the influence of the ER variation in the coconut shell gasification using a fixed bed downdraft gasifier. The composition of the gas and the temperature of the process were predicted theoretically by the stoichiometric equilibrium model developed by Nascimento (2015).

## 2. EXPERIMENTAL AND COMPUTATIONAL PROCEDURES

### 2.1 Gasifier Modelling

The gasifier modelling was made based in a paper developed by Nascimento (2015). According to biomass molecules can be written as  $C_xH_yO_zN_wS_v$  which is given by the ultimate analysis of the coconut shell. The ultimate analysis which gives the biomass content of carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) was obtained previously from the literature. The gasifying agent used in this work is air (79%  $N_2$  and 21%  $O_2$ ) The gasification global reaction can be written as shown in Eq. 1.



where x, y, z, w, v represent the number of atoms of carbon C, H, O, N and S determined by the ultimate analysis of the biomass shown in Figure 8 (Nanda, *et al.*, 2016);  $\alpha$  is the moisture content per mole of biomass,  $\beta$  is the number of moles of air per mole of biomass,  $\delta$  is the number of moles of  $N_2$ , and a1-a7 represent the number of moles of  $CO_2$ , CO,  $H_2$ ,  $H_2O$ ,  $CH_4$ ,  $N_2$  and  $SO_2$ . The Table 1 shows the ultimate analysis of the coconut shell used in this work.

Table 1. Ultimate analysis of biomass.

Atomic Element	% wt.
Carbon (C)	49.5
Hydrogen(H)	6.1
Nitrogen (N)	0.1
Oxygen (O)	40.1
Sulphur (S)	0.01

The stoichmetric balance for each element can be obtained by the following equations:

$$C: x = a_1 + a_2 + a_5 \quad (3)$$

$$H: y + 2\alpha = 2a_3 + 2a_4 + a_5 \quad (4)$$

$$O: z + \alpha + 2\beta = 2a_1 + a_2 + a_4 + 2a_7 \quad (5)$$

$$N: w + 2\beta\delta = 2a_6 \quad (6)$$

$$S: v = a_7 \quad (7)$$

And the sum of the products moles is:

$$a_8 = a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7 \quad (8)$$

Two more equations were obtained by the water-gas shift reaction and the methane reforming reaction (Mendiburu, *et al.*, 2014), which are described in Eq. (9) and (10), respectively.



The equilibrium constant K1 and K2 from Eq. (9) and (10) can be written as a function of Gibbs equation (Mendiburu *et al.*, 2014):

$$K_1 = \frac{a_1 a_3}{a_2 a_4} = e^{-\frac{\theta_{T,CO_2} + \theta_{T,H_2} - \theta_{T,CO} - \theta_{T,H_2O}}{RT}} \quad (11)$$

$$K_2 = \frac{a_5 a_4}{a_2 a_4} = e^{-\frac{\theta_{T,H_2O} + \theta_{T,CH_4} - \theta_{T,CO} - 3\theta_{T,H_2}}{RT}} \quad (12)$$

The temperature (T) used in Eq. (11) and (12) was found by the enthalpy balance for an adiabatic process as described below:

$$\bar{h}_{f,biomass}^0 + \beta(\bar{h}_{f,moisture}^0 + \int_{298}^{T_i} C_{p,moisture} dT_i) = \sum_{products} \alpha_i [\bar{h}_{f,i}^0 + \int_{298}^{T_i} C_{p,i} dT_i] \quad (13)$$

Where:

$\bar{h}_f^0$  is the enthalpy of formation

$T_i$  is the temperature at the gasification zone inlet

i varies from 1 to 8 representing each element of Eq. (8)

$\alpha_i$  is the number of moles of each element of Eq. (8)

$C_p$  is the specific heat at constant pressure

Since  $C_p$  varies with temperature, it could be found by the following equation (Turns, 2000):

$$\int_{298}^{T_i} C_{p,i} dT_i = \left[ a T_i + b \frac{T_i^2}{2} + c \frac{T_i^3}{3} + d \frac{T_i^4}{4} \right]_{298}^{T_i} \quad (14)$$

The equilibrium Eq. (3)-(14) were solved simultaneously with the help of Scilab® software.

The gas production rate was found by Eq. 15.

$$Y_{gas} = \frac{a_7 RT_0}{M_{BIO} P_0} \left( \frac{Nm^3 gas}{kg biomass} \right) \quad (15)$$

The cold gas efficiency (CGE) is defined as the relation between the LHV of the gas by the LHV of the biomass multiplied by the gas production rate, as shown in Eq. 16.

$$CGE = \frac{Y_{gas} LHV_{gas}}{LHV} (\%) \quad (16)$$

The low heating value (LHV) was calculated by the following equation (Rupesh, Muraleedharan, Arun, 2014):

$$LHV_{gas} \left( \frac{MJ}{Nm^3} \right) = (25.7a_3 + 30a_2 + 85.4a_5) \frac{4.2}{1000} \quad (17)$$

## 2.2. Biomass Characterization

The samples of coconut shell used in this work were provided by the company Água de Coco Triunfo Ltda., in São Mateus, Brazil. The coconut shell moisture, ash and volatile matter content were obtained by the standart test method for proximate analysiss tests ASTM D1762-84. The tests were conducted at the Federal Institute of Espírito Santo - São Mateus Campus, São Mateus, Brazil.

A muffle Vulcan® 3-Series 550PD, a desiccator were used and an analytical balance Shimadzu® AUY 220. Four commercial 30ml 41x 37 mm porcelain crucible with a lid were used. The weighing of the sample crucibles was performed on an analytical balance. The equipment and crucibles used in the tests can be seen in Fig. 2 and Fig. 6, respectively.

For the moisture content determination, the crucibles with the lids was placed for 10 minutes in muffle furnace preheated to 750°C. Then, the crucibles were cooled in the desiccator for one hour. Approximately 1 gram of coconut shell was added to each crucible. The samples were placed in the furnace at 105°C for 2 hours. Finally, the samples were placed in the desiccator for 1 hour and weighed. Figure 1 shows a schematics of the moisture content analysis.

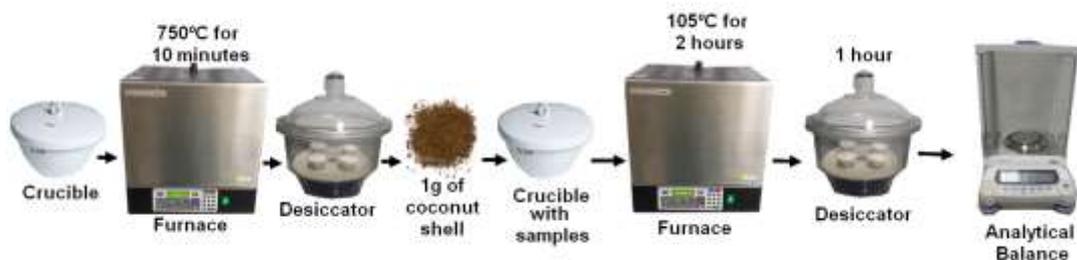


Figure 1. Representation of the moisture content test.

The percentage of moisture content in the sample can be calculated as:

$$\text{Moisture content (\%)} = \left[ \frac{(A-B)}{A} \right] \times 100 \tag{18}$$

Where A corresponds to the weigh of the dry sample in grams, and B is the weight of the sample after the test. As shown in Figure 2, for measuring the volatile matter content, the samples from the previous experiment were placed on the outer ledge of the preheated oven for 2 minutes and then for 3 minutes on the edge of the furnace. The samples were moved to the rear of the furnace for 6 minutes with the oven door closed. Then, the samples were cooled in the desiccator for one hour and weighed.

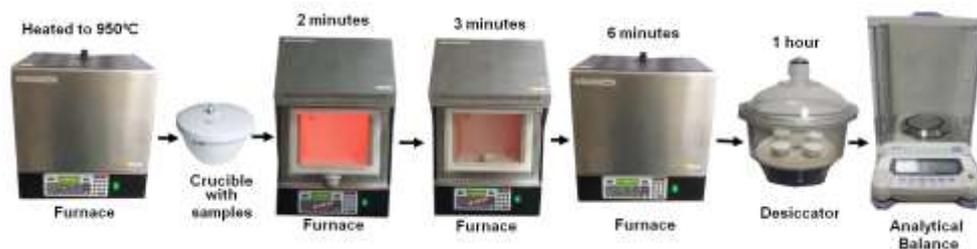


Figure 2. Representation of the volatile matter measurement test

The percentage of volatile matter is:

$$\text{Volatile matter (\%)} = \left[ \frac{(B-C)}{B} \right] \times 100 \tag{19}$$

Where C represents the weight of the sample after drying at 950°C.

Ash was determined by placing the uncovered crucibles and the lids in the oven heated to 750°C for 6 hours. The crucible with the lids were moved to the desiccator for one hour and weighed. This process was repeated until the samples weigh was constant.



Figure 3. Representation of the ash test

The ash content was found by the follow equation:

$$\text{Ash (\%)} = \left( \frac{D}{B} \right) \times 100 \tag{20}$$

Where D is the weigh of the residue in grams.

### 3. RESULTST AND DISCUSSION

The proximate analysis was repeated 8 times and the average results and standart deviation are shown in Tab. 2:

Table 2. Proximate analysis in wet basis

Parameter	Average (%)	Standart Deviation (%)
Moisture	10.276	1.51
Volatile Matter	73.214	0.80
Ash	1.036	1.72
Fixed carbon	15.474	0.12

Even though the biomass characteristics are highly influenced by its origin, the results obtained from the proximate analysis show a good agreement with the literature. The volatile matter, ash and fixed carbon content found in literature are respectively 76,34%, 2,90% e 20,07%, which can verify the results from the tests (Senepati and Behera, 2012), (Kitani, 1999).

The theoretical work was carried out to study the performance variation of the gasifier with the ER's between 0.2-0.45. The variation of the species concentration is shown in Fig. 4. Since the gasification system aims to produce a mixture of gases rich in H<sub>2</sub> and CO (Zheng et al., 2016), this present work aims to maximize the production of these gases. Figure 4 shows a slight decrease in CO and H<sub>2</sub> production as ER increases. This phenomenon happens because H<sub>2</sub> and CH<sub>4</sub> participate in the methanation and water-shift reaction, which contributes to the formation of non-combustible gases such as CO<sub>2</sub> and H<sub>2</sub>O. These results are in good agreement with previous literature, which show that lower values of ER are indicated for a downdraft gasifier (Jeya Singh and Sekhar, 2016), (Martínez, *et al.*, 2016).

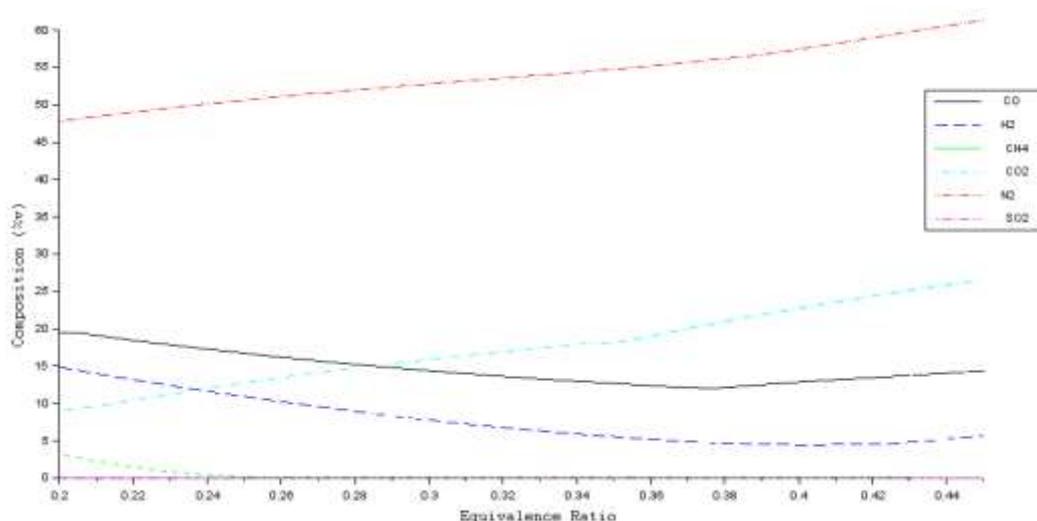


Figure 4. Variation of species concentration

As shown in Fig. 5, the low heating value of the gas decreases drastically as ER increases. This indicates that the ER is affected by the increasing of nitrogen in the gas and consequent dilution of the gas, what was expected according to literature and can be seen in Figure (Zheng, J. et al., 2016).

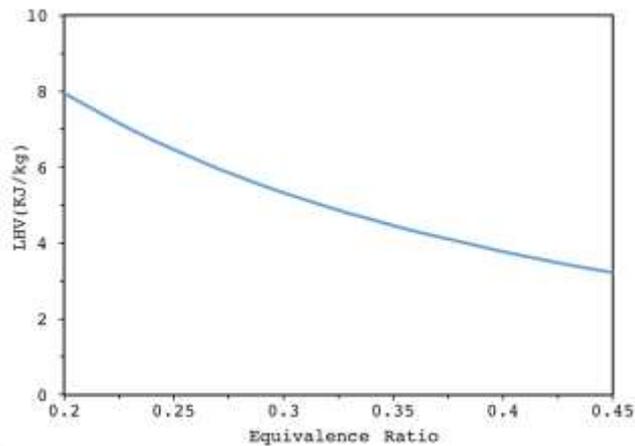


Figure 5. Low Heating Value variation

Figure 6 shows the variation of the cold gas efficiency (CGE) and gas production rate with ER. Although the gas production rate increases with ER, the conversion efficiency slightly decreases, which was expected since the production of CO<sub>2</sub> and N<sub>2</sub> increases and dilutes the gas (Guo, F. et al., 2014), (Centeno, F. et al., 2012)

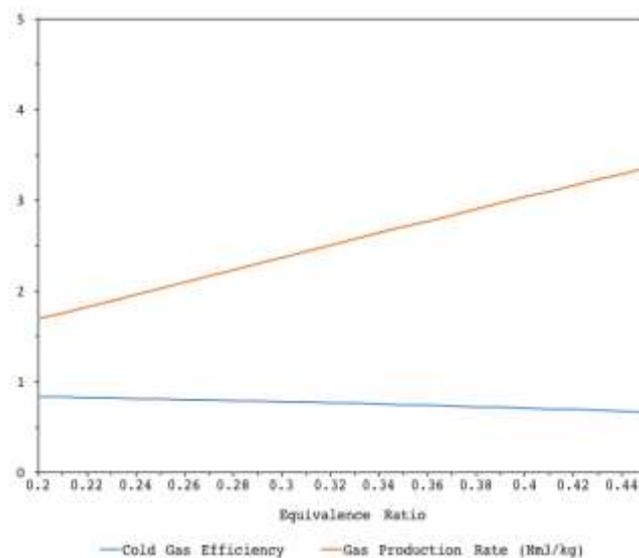


Figure 6. Cold Gas Efficiency and Gas Production Rate variations

#### 4. CONCLUSIONS

The paper shows that the results of the proximate analysis are according to literature and can be used to the characterization of the coconut biomass. The numerical method was able to predict the results of the gasification process, as showed in Figures 4 to 6. According to the graphical results showed in this work, lower equivalence ratio values are more indicated for downdraft reactors since they contribute for a higher LHV gas production and a higher carbon gas efficiency.

#### 5. ACKNOWLEDGMENTS

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