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GASIFICATION OF ALTERNATIVE BIOMASS TO GENERATE POWER WITH SUPPORT OF CFD AND CAD.

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Abstract. *The synthesis gas, also known as syngas, can be produced from gasification of several fuels, being one of them the biomass, which can be originated from various industrial and natural processes. For this study, it is used biomass, with high productive potential in the country, as coconut shell, orange waste and cotton waste, evaluating the applicability to generate power. With a midsize downdraft gasifier reactor in a fixed bed, previously elaborated in SolidWorks software, biomass entrance of 60 kg/h and ER = 0,35, it is made the simulation of the reactor with 0,31 m³, in Ansys FLUENT (CFD) software, and acquire the synthesis gas and his respective molar fractions. The actual work aims to measure and compare the syngas quality and the possibility to generate power from the characterized biomasses, presenting functionality aspects of thermal engines to integrate the gasifier, like internal combustion engine and vapor turbine, in order to produce energy in most efficient way, within the necessary adaptations to utilize this fuel and generate an estimated electrical power of 20kWe.*

Keywords: *Syngas, biomass, gasifier, power.*

1. INTRODUCTION

Due to serious environmental problems today, such as the greenhouse effect and global warming, the incentive for clean and renewable energies has increased on a large scale, but the consumption of fossil fuels remains high, representing around 81.07 % of all energy used in the world (IEA World Energy Balances, 2018). This parameter is about to change in the coming years and biomass gasification is one of the drivers of this framework.

Gasification occurs in reactors, which can have various types and geometries. For this work a downdraft fixed bed reactor with throat is used. In this reactor the first thermochemical zone is the drying, then the pyrolysis, the combustion and finally the gasification. Each process plays an important role for the quality of the final gas, called synthesis gas or syngas. This syngas is a fuel gas having mainly carbon monoxide (CO), hydrogen (H₂) and methane (CH₄) and when air is used as oxidizer, it usually has a LHV between 4 and 7 MJ / Nm³ (Basu, 2012).

The use of syngas is vast and can be used to heat homes, hotels, restaurants, among others. From the Fischer-Tropsch process you can create gasoline, diesel and kerosene. It also has use to produce fuel cells from the H₂ present in the gas, however such use is, for the time being, only theoretical. Another use, which is the focus of this work, is the use for power generation and electric power, using a diesel engine coupled to a generator (Boerrigter; Rauch, 2005).

For this work, computational tools such as SolidWorks® are used to design the gasifier geometry and Ansys FLUENT® for the simulation of the thermochemical process and thus to obtain the synthesis gas quality of different types of biomass. The studied biomasses are orange residues, coconut shells and cotton residues.

2. DEVELOPMENT

For the work performed, a downdraft fixed-bed reactor with throat was chosen, precisely because it is the type of reactor with lower tar rate in the final synthesis gas. This is due to the higher cracking of the tar by the high temperature in the pyrolysis and combustion zones and because there is no direct contact between the produced gas and the previous zones. This simpler syngas makes the reactor have a lower design cost because it requires fewer gas cleaners after firing, making it a good choice for use in remote area for power generation or small-scale production (Nirapure et al., 2015).

Chemically analyzing the gasification process can be separated into four steps: drying, pyrolysis, combustion and reduction, as shown schematically in Fig. 1 (Miranda et al., 2018).

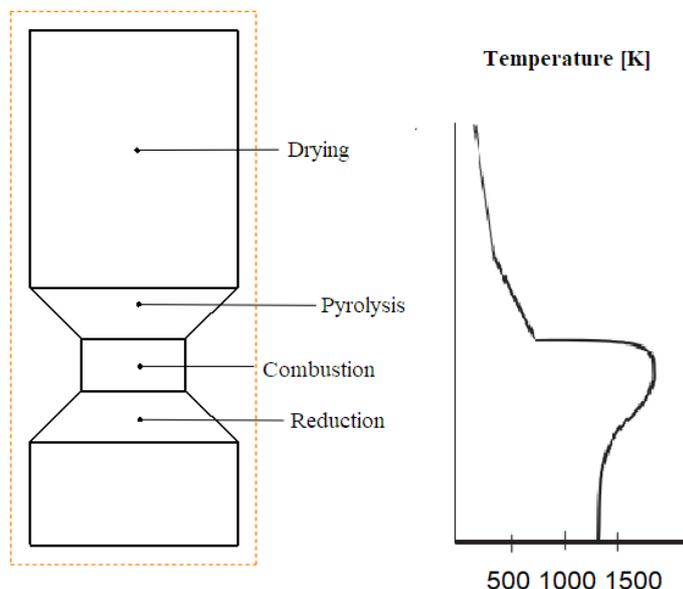


Figure 1. Schematic of the reaction zones in a co-current type gasifier

The gasification reactor of this work uses biomass as fuel due to its near zero. Therefore, three biomasses were chosen according to their production in Brazil and their density of production per hectare to reduce transport costs. Thus, the biomass chosen was orange residue, coconut husk and cotton residues.

Brazil is the largest orange producer in the world with an annual production of around 19 million tons in 2017 in an area corresponding to 630 thousand hectares (IBGE, 2018), with a production density of 30 tons / hectare. As for juice production, it is produced, mainly in the state of São Paulo, around 1.2 million tons of juice. The residues of the orange of interest for gasification, that is, the solids, are the bark, seed and pulp and make up 50 % of the total weight of the fruit (Alexandrino et al., 2007), representing about 600 thousand tons of waste per year in the production of orange juice by the industries.

As syngas production will be simulated in FLUENT®, ultimate analysis and elemental analysis are required. Therefore, the chemical properties of orange residues are in Table 1 (Aguiar et al., 2018).

Table 1. Chemical properties of orange residues

Moisture (%)	Ashes (%)	Volatile matter (%)	Fixed carbon (%)	C (%)	H (%)	O (%)	N (%)	S (%)	HHV (MJ/kg)
7,05	4,23	71,67	17,05	48,61	5,97	43,77	1,59	0,05	19,22

As for the second biomass, the coconut shell was also selected because of its high production, around 1.7 million tons in 2017 in an area of 242 thousand hectares, with a production yield of 7.1 ton/hect (IGBE, 2018). The main and most important residue for the gasification is the coconut shell representing about 85 % of the total weight of the fruit (Senhoras,2004).

The chemical properties of coconut shell are shown below in Table 2 (Vigouroux, 2001).

Table 2. Chemical properties of coconut shell

Moisture (%)	Ashes (%)	Volatile matter (%)	Fixed carbon (%)	C (%)	H (%)	O (%)	N (%)	S (%)	HHV (MJ/kg)
5,60	0,47	71,84	22,09	52,60	6,60	39,70	0,30	0,80	21,91

The third biomass chosen was the cotton residue, with an annual production of around 3 million tons in 2017, using 1.2 million hectares for cultivation and thus corresponding to a production density of 2,5 ton/ha (De Oliveira et al, 2017). The interesting residue for gasification is the cotton seed, which represents 61 % of the total weight of the plant (IBGE, 2018), an expressive percentage of great value for an energetic use of cogeneration in the textile and oil industries themselves.

The properties of cotton waste are shown in Table 3 (Magasiner, 1987).

Table 3. Chemical properties of cotton residues

Moisture (%)	Ashes (%)	Volatile matter (%)	Fixed carbon (%)	C (%)	H (%)	O (%)	N (%)	S (%)	HHV (MJ/kg)
9,70	2,57	68,70	19,03	49,90	6,30	42,70	1,00	0,10	19,38

2.1 Computational simulation

The use of computational tools to simulate real problems is of great value today due to the reduction of design costs, giving the possibility to evaluate, in case of gasifiers, different geometries and fuels without necessarily building a reactor and having the fuels. But for that, the computational model must be valid, so it must be compared with real experimental data and if it gives final values of PCI very close when compared, it can be considered that the mathematical model used is usable, facilitating and speeding up future projects. Therefore, for this study Ansys FLUENT® was used with the boundary conditions already established by (Yepes Maya et al., 2017).

The geometry is 1.5 [m] high and 0.6 [m] inlet diameter and was designed in SolidWorks and tetrahedrally Ansys MESH® and then Ansys FLUENT® transformed into a polyhedral mesh, as shown in Figs. 2 and 3.

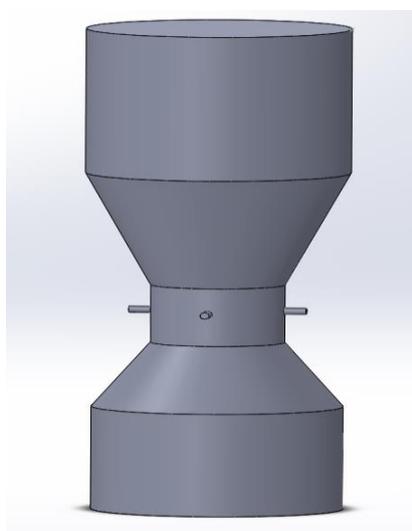


Figure 2. Reactor geometry

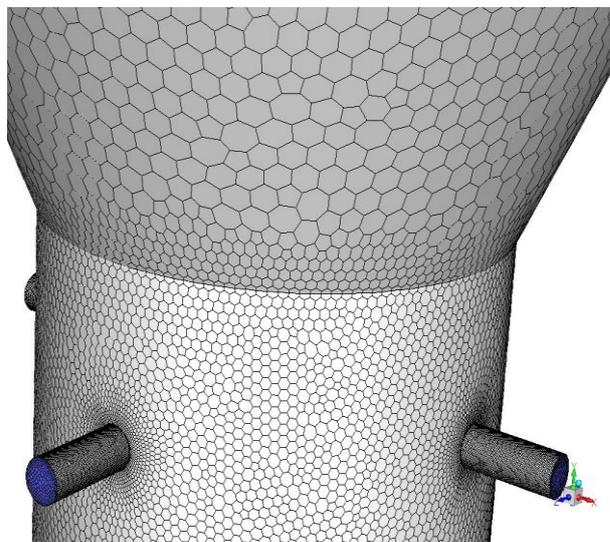


Figura 3. Reactor mesh

From the ready-made model and the meshed geometry, the gasification reactor was simulated in Ansys FLUENT®, for three different biomasses with a mass flow rate of 60 kg/h and in each of the four air inlets had a mass flow of 36 [kg/h]. This ratio of mass flows represents an equivalence ratio equal to 0.35, being between the variation proposed by (Jayathilake; Rudra, 2017) of 0.25 to 0.43.

Experimentally established temperatures by (Yepes Maya et al., 2017) were used for the boundary conditions and the reactor permanent regime, non-premixed combustion and a probability density function (PDF) of the species was generated from the chemical composition of the chosen biomass. The PDF calculates the possibilities of formation and transformation of each species in each element of the mesh, indicating at the end of the simulation the molecules reduced throughout the gasification process. Fig. 4 indicates the PDF chart (Ansys FLUENT®, 2018).

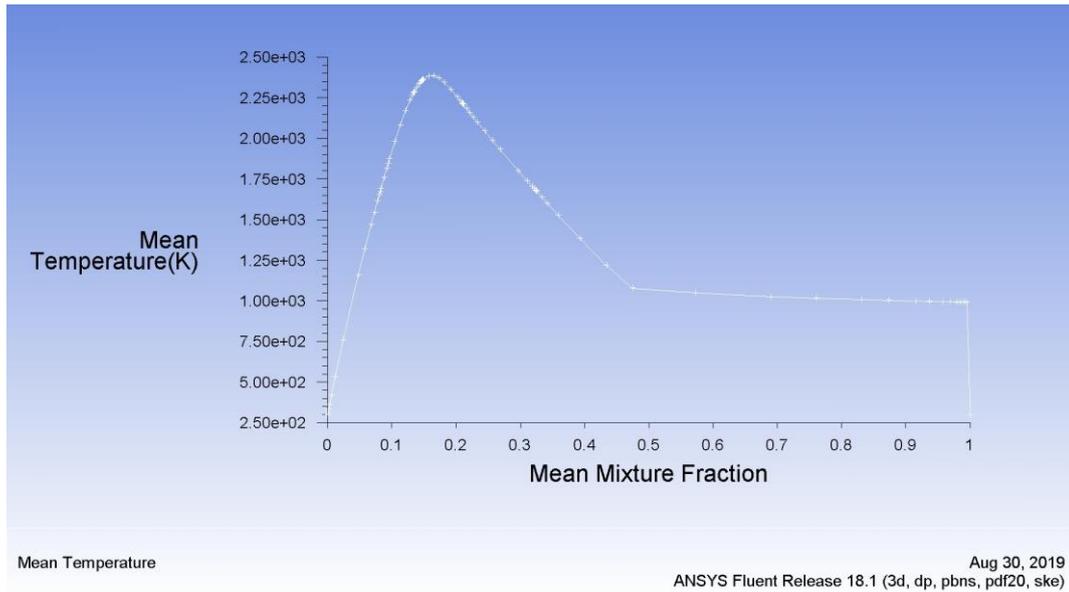


Figure 4. PDF of mean temperature by mean fraction of mixture

The equations governing the system are mass conservation, moment conservation and the energy equation shown in Eq. (1), (2) and (3).

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m \quad (1)$$

$$\frac{\partial (\rho \vec{v})}{\partial t} + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla \cdot p + \nabla \cdot (\vec{\tau}) + \rho \vec{g} + \vec{F} \quad (2)$$

$$\frac{\partial (\rho H)}{\partial t} + \nabla \cdot (\rho \vec{v} H) = \nabla \cdot \left(\frac{k_t}{c_p} \nabla H \right) + S_h \quad (3)$$

From these conditions the temperature profiles in K and the H₂, CO and CH₄, molar fractions of the orange residues are shown in Figs. 5, 6, 7 and 8.

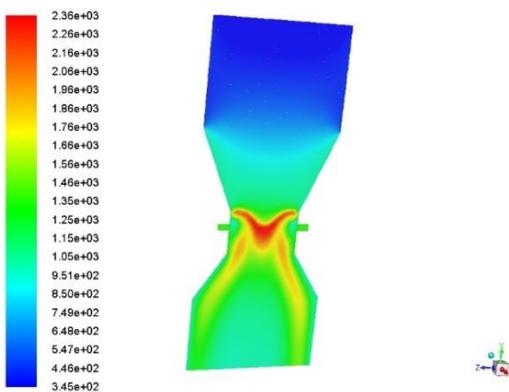


Figure 5. Temperature profile

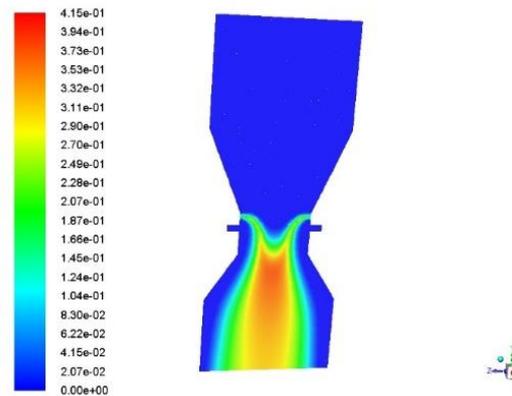


Figure 6. H₂ molar fraction profile

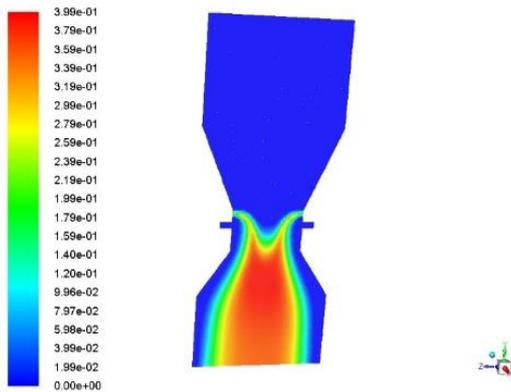


Figure 7. CO molar fraction profile

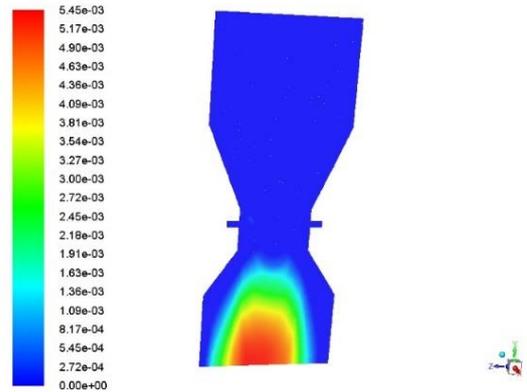


Figure 8. CH₄ molar fraction profile

Figure 5. shows the temperature profile according to what is expected, where the lower temperatures stay in the drying zone and the highest in combustion and reduction zone. That profile demonstrates that the model used for simulation is correct, burning the biomass where the oxidant enters and reacting to transform into the right gaseous species. Figure 6. indicates the production of H₂ from the consumption of CO and H₂O, both incomplete combustion products, out the water-gas shift reaction. Since the equivalent ratio of oxidizing and oxidizer are lower than the necessary to a complete combustion, the CO is created, as shown in Fig 7., exactly where the lower temperatures profiles are. Once CH₄ need water, CO and more resident time to be formed, those fractions are far small then the others.

An important parameter when dealing with fuel gases is their lower calorific value (LHV). The LHV of the gas is calculated from the volumetric mole fraction of the gas fuels: CO, H₂ and CH₄. According to the methodology adopted by the (De Sales et al., 2017), the lower calorific value of CO, H₂ and CH₄ is 12.696 MJ/Nm³, 10.768 MJ/Nm³ and 35.866 MJ/Nm³.

The LHV of dry gas is determined from Eq. 4 (Yepes Maya et al., 2017).

$$LHV_{syngas} = 12696 (CO) + 10768 (H_2) + 35866 (CH_4) \quad [MJ/Nm^3] \quad (4)$$

At where:

- CO - Molar fraction of carbon monoxide;
- H₂ - Molar fraction;
- CH₄ - Molar fraction of methane.

Thus, generating the respective PCIs of each biomass from the volumetric molar fractions, as shown in Table 4.

Tabel 4. Volumetric concentration e syngas PCI

Biomass	H ₂ (%)	CO (%)	CH ₄ (%)	LHV (kJ/Nm ³)
Orange residues	20,75	19,95	0,22	4844,68
Coconut shell	20,30	17,70	0,29	4536,53
Cotton residues	21,15	19,10	0,26	4794,62

Tabel 5. Syngas density

Biomass	Density (kg/m ³)
Orange residues	0,987
Coconut shell	0,966
Cotton residues	0,974

2.2 Choice of power generation method

Due to problems involving the lack of information on the geometry of the engine components such as spark plugs, inlet valves, piston, compression ratio, among others, we do not use commonly used formulas to calculate the final power (Amorim, 2005).

With the difficulties encountered for the adaptation of an engine to use syngas as fuel, a generator set was chosen, consisting of a diesel engine adapted for gas combustion (biogas, syngas and LPG) and an electric generator, Green Energy, model GEBR30, 25 kVA and 20 kWe, MWM brand, D229 engine and 1800 rpm (Green Energy, 2018). From the fuel supply requirements for this generator set, the three biomasses studied in this article could be used to generate 20 kWe at the end of the biomass processing cycle.

With the choice of the gas generator set and the data from catalogs (Green Energy, 2018), syngas demand analysis is performed from the consumption of 13 Nm³ / h of natural gas (NG) required to generate 20 kWe.

Thus, using the LHV of the NG and its density, can be made a comparison with the syngas produced applying the same parameters to analyse if the reactor produces enough syngas to generate 20 kWe.

So, using GN LHV of 35.98 MJ / m³ and density 0.76 kg / m³ (ERSE, 2017), and LHV and biomass density presented in Tables 4 and 5, we obtain a consumption equivalent to the chosen biomass, as shown in Table 6. Also the amount of fuel species produced during gasification in Nm³ / h.

Biomass	Necessary amount of syngas (Nm ³ /h)	Generated amount of syngas (Nm ³ /h)
Orange residues	74,34	84,98
Coconut shell	79,39	81,25
Cotton residues	75,12	85,26

2.3 Chemical reactions

In the process to produce synthesis gas some chemical reactions must occur, so bellow has a brief explanation of what happens inside the reactor (Kostúr & Anová, 2009).

Combustion of carbon	$C + O_2 \rightarrow CO_2$
Partial oxidation	$C + 1/2 O_2 \rightarrow CO$
Oxidation CO	$CO + 1/2 O_2 \rightarrow CO_2$
Water gas shift	$CO + H_2 O \rightarrow CO_2 + H_2$
Methanation	$CO + 3H_2 \rightarrow CH_4 + H_2 O$
Hydrogenization	$C + 2H_2 \rightarrow CH_4$
Boudouard's reaction	$C + CO_2 \rightarrow 2CO$
Reaction steam-carbon	$C + H_2 O \rightarrow CO + H_2$
Loosening of hydrogen	$2H \text{ (in coal)} \rightarrow H_2 \text{ (gas)}$.

3. CONCLUSIONS

It is possible to conclude that unconventional biomass can generate a reasonable power of 20 kWe using commercial generator set and it is important to note that different biomass generate larger or smaller LHVs, depending on their moisture, carbon, oxygen and hydrogen fractions, requiring more attention when exchanging the biomass used, since the difference in LHV can make the project unfeasible. Because of these variations, orange and cotton residues generate an abundance of syngas, respectively, about 12.52 % and 11.89 % of what is needed to generate 20 kWe, which may be stored for generation when there is lack of biomass or for cogeneration, burning the excess to produce heat for some industry process or residential heating.

Therefore, the better biomass in terms of better syngas produced and abundance of residues is the orange, that can produce a syngas with 4844,68 kJ/Nm³ low heating value and gas composition of 20,75 % H₂, 19,95 % CO and 0,22 % CH₄.

Thus, it is important to notice that each reactor design has the most suitable biomass to produce syngas and in this case was orange residues, but if analyze others biomass with different reactor design and with different oxidizer, the LHV of the synthesis gas will be higher or lower than the presented in this paper.

4. ACKNOWLEDGMENT

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