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## CONSTRUCTION OF A BENCH CO-CURRENT BED MODEL GASIFIER SUITABLE FOR THE LOCAL BIOMASSES

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**Abstract.** *Alternative energy sources are indispensable for a sustainable social and technological progress. Brazil is a major producer in the agricultural area where some by-products classified as biomass. These can be in turn used in a gasification process, which makes use of a thermal technology for the treatment of solid and organic waste, producing a combustible gas. However, studies are still needed to determine if it is viable to gasify certain biomasses and to distinguish their efficiencies. Due to the need of faster tests with small amounts of biomass, an equipment with reduced proportions was idealized. Gasifier such as the counter-current model and fluidized bed produce synthesis gas with high concentration of impurities and require complex and expensive equipment for the filtration and washing of the gases produced. Considering these needs and limitations for tests, it was decided to construct a bench gasifier with fixed and co-current bed because its conception and operation is less complex besides producing a gas freer of tar and particulates (impurities). The gasifier bed was narrowed using alumina sphere of several diameters. The use of alumina is an attempt to improve the overall efficiency by improving the thermal efficiency of the gasifier, as it harnesses the thermal energy of the radiation that would be lost and redirects it to the combustion. The thermal insulation to be used is an outer sheath coating with ceramic fiber blanket, improving the overall thermal efficiency of the system.*

**Keywords:** Biomass gasification, biomass, syngas

### 1. INTRODUCTION

Brazil as a developing nation increases its primary production of energy considerably every year since 2005. The final report of the BEN (Balanço de Energia Nacional) 2016 shows that in general the production of energy through renewable sources in Brazil is significant when analyzed the total energy consumption, representing up to 41,9% of the total energy production in 2015. Sugar cane products and firewood are the only two biomass with significant percentage in this scenario with 17,6% and 8,6% respectively in 2015. (Chart 1) (EMPRESA DE PESQUISA ENERGÉTICA, 2016)

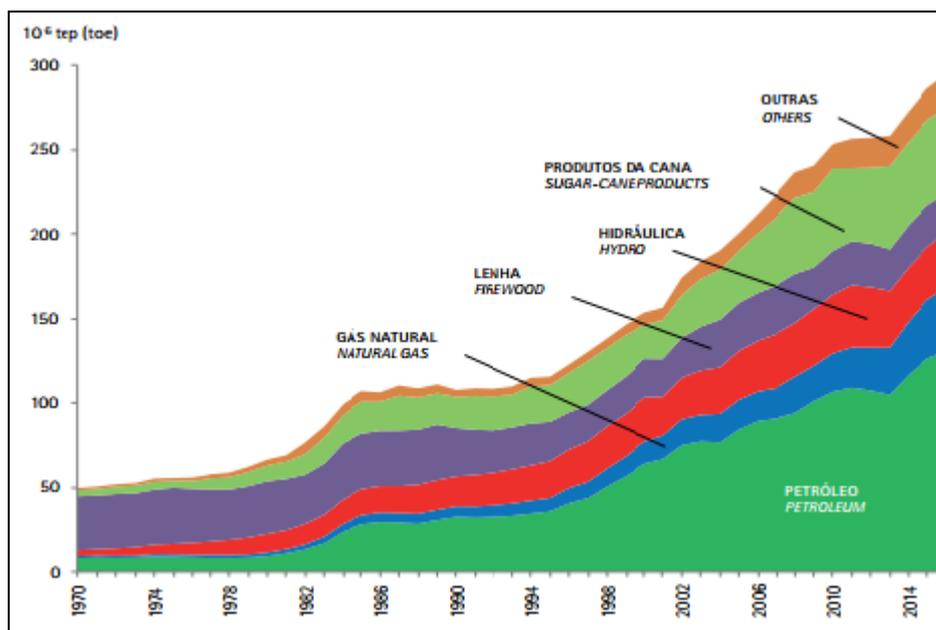


Chart 1 – Primary energy production by EMPRESA DE PESQUISA ENERGÉTICA, 2016

Still according to BEN 2016, even though Brazil has inverted its situation in the external petroleum supply dependency scenario, going from consumer to provider in 2006 and once again in 2015. The external coal supply dependency remains quite elevated for some years closing with a 22568000 tons dependency in 2015 (Chart 2) (EMPRESA DE PESQUISA ENERGÉTICA, 2016). Ideally this high coal consumption used for energy generation could be lower with a greater development of different energy generations methods and preferable sustainable such as the burn and gasification of biomass.

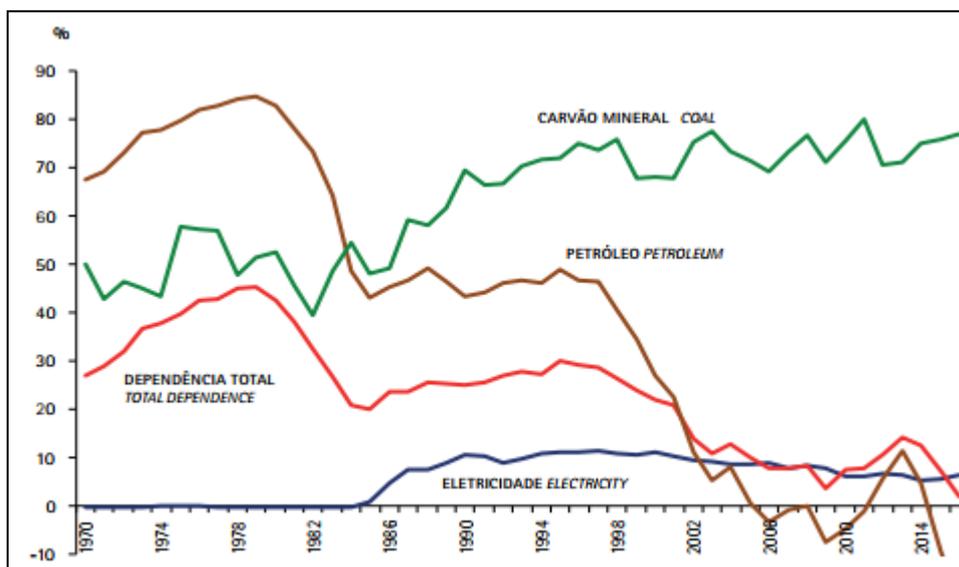


Chart 2 – External dependence on energy by EMPRESA DE PESQUISA ENERGÉTICA, 2016

According to Andrade (2007, p. 6), biomass is considered to be all material of organic origin such as wood, animal debris and organic waste. However, other authors affirm that biomass, besides its organic nature, is characterized by being used in the generation of energy, usually through its burning (MURANO, 2006, p.14) (ARBEX et al, 2004, p.2) . Currently, the use of energetic forests and agricultural residues such as rice husks, sawdust and sugarcane bagasse as biomass are of great interest. (LORA, 2003).

Brazil is a country rich in biodiversity and ranks high in the ranking of producers of various agricultural products such as sugarcane, soybean, corn, cassava, oranges, coffee among others (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2016). Many of these products have normally wasteful parts such as husks and bagasse. There are, therefore, several organic materials with potential to be used as biomass for the

production of electric energy or synthesis gas, making possible the reduction of Brazilian dependence on mineral coal for energy production. According to Júnior (2013), the biomass of babaçu, in the state of Maranhão, biomass of the coco-da-baía, in the Ceará, Bahia, Sergipe and in the irrigated perimeters in the São Francisco Valley and the palm biomass in the Southeast of Bahia are worth mentioning. In order to know the feasibility of some of these materials as biomass for gas production, further experiments and studies of these biomasses are required.

As an option in the production of electric energy and reduction of biodegradable solid waste emitted by industries, gasification technology can be used as a part of the solution (SILVA et al, 2004).

According to Martinez et al., several types of reactors can be used for the development of gasification, with different factors for their classification: according to the calorific value from the produced gas, the type of oxidizing agent, working pressure and relative movement of the fuel and the gassing agent among others. Fluid bed (bubbling or circulating) and fixed bed reactors (concurrent, countercurrent or cross flow) are the most known and developed to date. Each one presents advantages and disadvantages with respect to its final application, capacity of processing and operation among others.

The feasibility of biogas production from local biomasses was studied together with the construction of a concurrent fixed bed benchtop gasifier

## 2. GASIFICATION

The gasification process consists basically in the production of fuel gas also known as synthesis gas or syngas made from a series of reactions involving high temperatures where part of the biomass used is partially oxidized with controlled amounts of oxidizer. Atmospheric air, oxygen and water vapor are the most commonly used oxidizers in this process. The water or moisture of the oxidants and biomass itself when it reacts with other organic molecules in high temperature environments resulting in hydrogen, carbon monoxide and methane, which in the correct proportions indicates a syngas of good quality. The calorific value of the produced gas also varies with the type of oxidizer used among other parameters (ANDRADE, 2007). According to McKendry (2002), when used atmospheric the calorific value of the gas and smaller, varying between 4 and 6 MJ / Nm<sup>3</sup>. With oxygen and water vapor this value can be up to 18 MJ / Nm<sup>3</sup>.

During the gasification process, the biomass passes through some well-defined stages inside the bed, except for fluidized beds where there is no clear distinction between the stages, each crucial to a successful gasification. The first zone is the drying zone and occurs from approximately 100 ° C. This zone is characterized by the removal of part of the water from the organic matter reducing the humidity of the biomass and providing H<sub>2</sub>O molecules for reactions that will occur in the following zones.

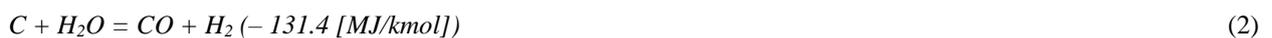
Between 400°C and 600°C according to Sánchez, 2010, or between 300°C and 500°C (for coal) according to Moura, 2012, there is the pyrolysis zone, which is a process of thermochemical degradation that occurs when heat is applied to a substance or material, with scarce amounts of oxygen. In this sense, pyrolysis is an endothermic process that requires an external source of energy (heat) to occur. This process allows the transformation of the biomass into solid, gaseous and liquid fraction. The solid fraction consists of ashes and particulates, the gaseous in carbon monoxide, hydrogen and nitrogen and the liquid in concentrated vapors of tar and acids as well as condensable gases of the gas fraction. In short, this zone is characterized by the formation of these fractions as well as the breakdown of hydrocarbons and the reactions that occur in it are considered endothermic. (LORA et al).

The reduction zone is in the range of 600°C to 950°C according to Sánchez, 2010, and in the range of 800°C to 1000°C according to R. Andrade, 2007. It is where several reactions take place. Andrade, 2007 highlights as the main reactions the following.

Boudouard reaction (Eq. 1)



Gas-water displacement reaction (Eq. 2)



Homogeneous reactions (gas phase) (Eq. 3 and Eq. 4)



Methane formation reaction (Eq. 5)



Therefore, the reduction phase is characterized mainly by the formation of  $H_2$  and  $CO$  found in the produced gas and as an endothermic zone.

The combustion zone or oxidation zone, as the name suggests, is where biomass oxidation occurs. Because it is an extremely exothermic zone, it is characterized by being the provider of most of the energy necessary for the reactions and endothermic processes that occur during the other zones. The temperature in this zone can reach  $1300^\circ C$  depending on the model and the operating regime of the gasifier (Sánchez, 2010).

The location and area occupied by each stage depends on the type of gasifier as well as the bed size. For example, a cross flow gasifier has a zone of combustion and reduction concentrated at the center of the bed and occupies a reduced volume. This also means that this gasifier does not require ceramic coating in the combustion zone, which further decreases its weight and size when compared to other gasifiers (SÁNCHEZ, 2010).

### 3. CONCURRENT GASIFIER

In a concurrent gasifier, as shown in Figure 1, the arrangement of zones from the top to the bottom is: Drying zone; Pyrolysis zone; Combustion zone; Reduction zone. This arrangement of zones causes the tar and volatiles formed in the pyrolysis to pass through the zones of combustion and reduction that allows breaking of some of these substances considered pollutants of the gas. In contrast, the removal of the syngas carried out at the bottom of the bed, after the reduction zone, implies a gas with a high level of solid or particulate impurities as well as the biomass ashes themselves. However, the removal of these impurities is simpler and requires less complex and specific components, and cleaning can be done simply by cyclone, for example (SÁNCHEZ, 2010). Due to the high complexity of removing chemical impurities (tar) and the low amount of these impurities in the gas produced from the concurrent gasifier, constructing a prototype of this model was agreed as the best option.

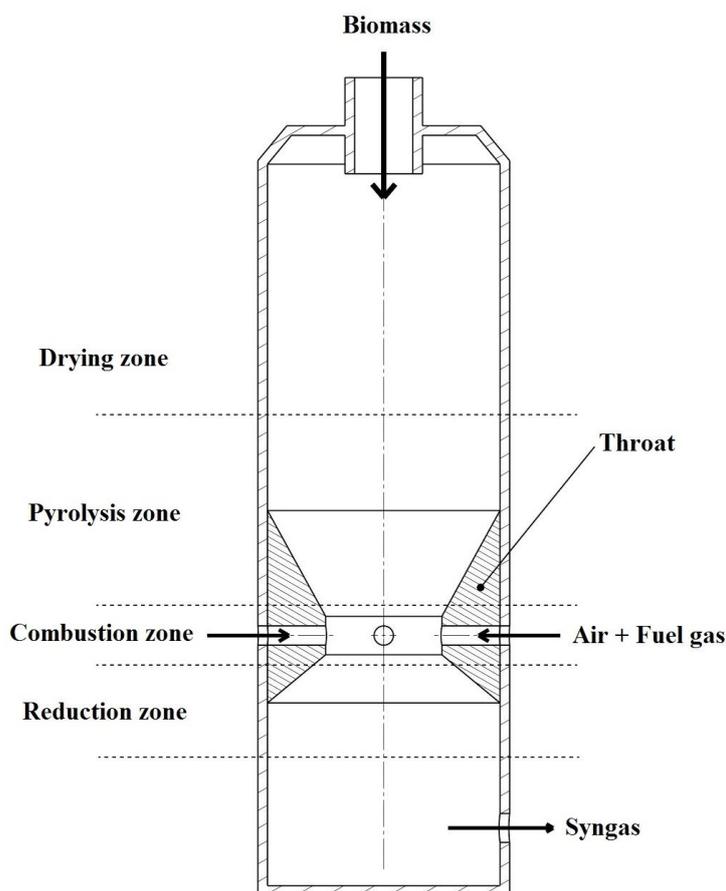


Figure 1 – One-stage Concurrent Gasifier by Author, 2017

The concurrent gasifier can be further classified into one or two stages. The one-stage gasifier has only one point of injection in the throat area, where is injected the mixture of fuel and oxidizer. In contrast, this dual stage equipment has two injection points, the first being the same as the one-stage gasifier and the second above this point, close to the drying zone, where the oxidizer is injected. This leads to an increase in temperature in the area above the combustion zone, which results in a larger quantity of broken tar molecules. This leads to a synthesis gas relatively freer from this type of impurity (ANDRADE, 2007).

The so-called throat area is a narrowing of the bed's inner diameter. Injection of the air-fuel mixture takes place internally in the throat. This happens in order to achieve a higher temperature in the combustion zone as the temperature decreases with the distance from the nozzle outlet. The throat is usually made of a refractory material so that the heat can be reflected and losses by conduction are reduced.

#### 4. CONCLUSION

It was built a bench gasifier due to its reduced dimensions, which is more consistent with the size of the laboratory where the gasifier will be used. Its reduced design has as advantages the best movement of the equipment by the laboratory and to nearby localities, the possibility of small-scale tests and its maintenance and modification facilitated.

It was also decided to construct a segmented bed gasifier. The total length of the bed is proximally 600 mm (Figure 2). The intention of this segmentation was to achieve a better maintenance and easy access to the interior of the equipment, so this bed is separated into five parts that will be assembled and sealed by means of a fitting and a small layer of silicone.



Figure 2 – Constructed Gasifier without thermal insulation by the Author, 2017

The narrowing of the bed (throat) will be done with  $\frac{1}{2}$  "diameter alumina spheres (Al302) held in position by a steel mesh. The narrowing will provide a reduction of the internal diameter from 120 mm to 50 mm. To improve thermal efficiency, 45 mm of ceramic wool is placed in contact with the external wall of the gasifier.

The supply of atmospheric air and combustible gas for combustion within the bed will be performed by injector tubes. Two nozzles were positioned at an angle of  $180^\circ$  from each other around the bed and a distance of 67 mm from the base of the gasifier. Compressed air and LPG gas with a pressure of approximately 3 bars are mixed before entering the injector. In order to achieve more even heating of the alumina spheres throughout the throat area, this component has 3 gas outlets, two on the sides and one directed to the top of the gasifier

#### 5. REFERENCES

- EMPRESA DE PESQUISA ENERGÉTICA.,2016. Balanço Energético Nacional 2016: Base year 2015. Rio de Janeiro.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS., 2016. "Crop statistics." Statistics Division (ESS). Set. 2017 <<http://www.fao.org/faostat/en/#data/QC/visualize>>
- Júnior, C. de. L., 2013. "Potencial do aproveitamento energético de fontes de biomassa na região Nordeste do Brasil". 2013. 74 f. Tese (Doutorado) - UFPE, Centro de Tecnologia e Geociências, Programa de Pós-graduação em Tecnologias Energéticas e Nucleares, Recife. Set. 2017 <<http://repositorio.ufpe.br/handle/123456789/10160?show=full>>
- Sánchez, C. S., 2010. "Tecnologia da gaseificação de biomassa". Campinas, SP: Átomo. p.430
- Arbex, M. A.; CANÇADO, J. E. D.; PEREIRA, L. A. A.; BRAGA, A. L. F.; SALDIVA, P. H. N., 2004. "Queima de biomassa e efeitos sobre a saúde". *Jornal Brasileiro de Pneumologia*. São Paulo, v.30, n. 2, p. 158-175. Set. 2017 <<http://www.scielo.br/pdf/jbpneu/v30n2/v30n2a15>>

- Murano, W., 2006. “Avaliação do funcionamento de motor ice com gás de baixo poder calorífico proveniente da gaseificação de casca de arroz”. 2006. 86 f. Dissertação (Mestrado em Engenharia Mecânica) - Departamento de engenharia térmica e de fluidos, Universidade Estadual de Campinas, Campinas. Set. 2017 <<http://repositorio.unicamp.br/bitstream/REPOSIP/264119/1/Muraro%2c%20Wilson.pdf>>
- Andrade, R. V., 2007. “Gaseificação de Biomassa: Uma Análise Teórica e Experimental”. 2007. 205 f. Tese (Doutorado em Engenharia Mecânica) - Instituto de Engenharia Mecânica, Universidade Federal de Itajubá, Itajubá. 2007. Set. 2017 <<http://saturno.unifei.edu.br/bim/0032784.pdf>>
- Moura, V. P.; Santos, C. S.; Macedo, H. R., 2012. “Aproveitamento Energético de Biomassas e Resíduos”. Palmas, TO. Set. 2017 <<http://www.ebah.com.br/content/ABAAAfUcKkJ/biomassa-energia>>
- Mckendry, P., 2002. “Energy production from biomass (part 3): gasification technologies”. *Bioresource Technology*, Colchester, v. 83, n. 1, p. 55–63. Set. 2017 <<http://www.sciencedirect.com/science/article/pii/S0960852401001201>>
- Silva, J. N.; Sobrinho, J. C.; Emílio, T. S., 2004. “Utilização de biomassa na secagem de produtos agrícolas via gaseificação de biomassa com combustão adjacente dos gases produzidos”. *Engenharia Agrícola*, Jaboticabal, v.24, n.2, p.405-411. Set. 2017 <<http://www.scielo.br/pdf/%0D/eagri/v24n2/v24n2a20.pdf>>
- Lora, E. E. S.; Andrade, R. V.; Ángel, J. D. M.; Leite, M. A. H.; Rocha, M. H.; Sales, C. A. V. B.; Mendoza, M. A. G.; Coral, D. del S. O. “Gaseificação e pirólise para a conversão da biomassa em eletricidade e biocombustíveis”. In: Lora, E. E. S., Venturine, O. J. (Coords). *Biocombustíveis*. São Paulo: Interciência. p. 412-498. Set. 2017 <<http://www.nest.unifei.edu.br/portugues/pags/downloads/files/BiocombustiveisCap06.pdf>>

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