DESIGN OF A COMPACT UPDRAFT GASIFIER FOR LABORATORY ACTIVITIES

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Abstract. Currently exists in Brazil more than eight biomass gasifier development projects. It shows the Brazilian academic and industrial communities interest in such technology. All the ongoing projects focus on pre-commercial equipments and none of them are flexible enough to be applied either on educational or basic research. This work shows the design of a small scale gasifier to be used in academic laboratories for training, development of tar measurement technique and acquire gasification data, all very simple and at low cost. The gasifier detailed here is fueled with açai seeds (18 kg/h), has its reactor of stainless steel tube with ID 150 mm and height of 1500 mm (70 kWt). It does not have insulation on its wall, having instead an air jacket that removes heat before comes into the reactor. Its operation and maintenance is easy and cheap, has air flow control, ports to obtain the reactor temperature profiles and ports for gas extraction aiming its composition quantification. This gasifier will be initially used on gasification courses and an elaboration of a protocol to measure tar concentration within the exit gases.

Keywords*: updraft gasifier, design, biomass gasification.*

1. INTRODUCTION

It exists now more than eleven projects of biomass gasifiers in development in Brazil. Among them, they stand out the projects of UNIFOR, UNICAMP, UFPA (I,II,III), UFAM, UnB, UFSM, UNIFACS, UFPE and UNIFEI, as well as projects in development in several countries, as for example in Recent work (Luis *et al*,1997), besides experimental works (Belonio, 2006) and (Tom Reed, 2005). That shows the actual national and international interest in such technology, all seeking to obtain technologies commercially efficient. All of the Brazilian projects are on pre-commercial stage, and among them, none was specially designed to be used as a tool for human resources qualification or to be applied in laboratory activity on the development of auxiliary techniques such as tar measurements or experimental data generation for numeric models validation.

The gasifiers can be classified in accordance with (Ciferno, 2002): in function of the pressure (atmospheric or pressurized) or in function of the bed type (fixed or fluidized). Fixed bed gasifiers are classified as downdraft (fuel and air flow on same direction), updraft (fuel flows down and air moves up) and crossed flow (air cross-flow with fuel). Fluidized beds become separated in bubbling and circulating. Fixed bed gasify has a simple operation, an acceptable efficient, working with fuels with a broad range of size (10 - 100 mm) and density, suitable for wood and coal gasification. The disadvantage of this type of gasifier is the fact that they loss a great deal of efficient when it is scale up.

The present work presents the design and construction of a small updraft gasifier. Numeric calculations were used help its design, calculating the heat transfer, material thermal dilations, final gases composition and internal air flow. The calculation to determine the exit gases composition and its temperature was performed Pelegrine software (Pelegrine, 2006). This soft was applied successfully biomass gasification.

2. CONCEPT AND ARRANGEMENT

The type of gasifier chosen was an updraft because it produces gases with high heat value (Netto, 2006) as shown in the table 1, and its gas has high tar content (Knoef, 2005). Foreseen major application for such gasifier in a laboratory would be heat generation and to test proposal set up to measure tar and particulate contents in the exit gases. Therefore updraft gasifier is the one that fits better to the requirements. As a fuel, authors choose açaí seeds (euterpes oleracea), due not only the great abundance in the area as well as for its size and shape (spherical). To perform a thermo chemistry calculation, açai elementary analysis is required, but this information is not available in the literature. Instead, eucalyptus was used (Luis *et al*,1997) as shown in the Table 2.

Table 1. Immediate Analysis of the açaí seed, mass basis, obtained in EBMA lab.

Fixed carbon (%)	**Volatile (%)**	**Ash (%)**	**PCS (kJ/kg)**	**Bulk Density (kg/m^3)**
19,45	79,44	1, 1057	19127,68	240

Table 2. . Elementary Analysis of the eucalyptus, mass basis.

C (%)	**H (%)**	**O (%)**	**N (%)**	**S (%)**	**A (%)**	**W (%)**
34,30	4,11	30,78	0,21	0,007	0,504	30

where “A” stands for ash and “W” for water.

As a design principle, the authors decided for do not use refractory material on the reactor wall in order to simplifier the construction and make it cheaper as possible, but easy to operate, maintenance and safe (avoid operator contact with gasifier gases). It should be easy to obtain operational parameters as temperature and pressure in the different areas of the reactor. The gasifier must have ports for gas extraction and controllers for air flow.

The final gasifier conception is formed by two concentric tubes with the internal tube of stainless steel and the external of commercial steel. In the space among the tubes air will flow and remove the excess of heat from the internal tube and preserving its integrity. The biomass and air feeding are continuous and will be done through a simple manual functional system.

3. TOOLS FOR DESIGN

The design parameters adopted on the gasifier designer were the internal diameter (150 mm) and equivalence ratio (Higman, 2003) equal to 0,3,(oxidizer shortage). The superficial velocity (Reed,1999) a range of 0,46 to 0,98 m/s was considered. Once defined the superficial velocity, the internal diameter and height of the reactor could be calculated. The air and biomass flow rates, biomass residence time were obtained through Equations (1, 2 and 3) respectively.

$$\dot{m}_{ar} = \phi \cdot \left.\frac{\dot{m}_{bio}}{\dot{m}_{ar}}\right|_{st} \cdot \dot{m}_{bio} \tag{1}$$

$$\dot{m}_{bio} = A_{st} \cdot \rho_{bio} \cdot V_s \left(\phi \cdot \left.\frac{\dot{m}_{bio}}{\dot{m}_{ar}}\right|_{st} + 1 \right)^{-1} \tag{2}$$

$$t_r = \frac{V \cdot \rho_{bio}}{\dot{m}_{bio}} \tag{3}$$

Where:

$\dot{m}_{bio}$ = Açaí mass flow rate;

$\dot{m}_{ar}$ = Air mass flow rate;

ρ_{bio} = Biomass density;

Vs = Superficial Velocity;

A = Reactor cross area;

ϕ = Equivalence ratio.

Quantification of the heat flux was performed with conventional heat transfer techniques. The final gases composition was performed using the Pelegrine software (Pelegrine *et al*, 2006) that simulates the gasification process, in that way, one inputs biomass volatile, fixed carbon and moisture mass fractions as it is shown in the table 2, besides the equivalence ratio. The software also uses the energy equation and calculates the exit gases final temperature, all under equilibrium conditions.

A heat transfer calculation was used to quantify the temperature distribution at the reactor wall (internal tube) and on the grate. The calculation was performed assuming that the internal and external reactor wall has the same temperature. Following (Reed, 2005) recommendation, authors choose that the combustion zone is at 1000°C and 100 mm height. The gasification zone is at 800°C and 200 mm height. The pyrolysis is at 550°C and 500 mm height. The drying is at 100°C and 700 mm height. The equations adopted are (Diez, 2000):

$$T_m = T_f + \frac{T_p}{2} \tag{4}$$

$$\mathrm{Re} = \nu \frac{D * \rho}{\eta} \tag{5}$$

$$S_t = \frac{Nu}{\mathrm{Re} * \mathrm{Pr}} \tag{6}$$

$$S_t = e^{\left[-3{,}796 - 0{,}205 * \ln(\mathrm{Re}) - 0{,}0505 * \ln(\mathrm{Pr}) - 0{,}0225 * \ln(\mathrm{Pr})^2\right]} \quad \text{Polley correlation} \tag{7}$$

$$h_c = \frac{Nu * K}{d} \tag{8}$$

$$Q = hc * (\pi * d * L)(T_p - T_f) = mcp(T_2 - T_1) \tag{9}$$

$$\mathrm{v} = \frac{L}{t} \tag{10}$$

Where:

T_f = fluid temperature
T_p = wall temperature
Re = Reynolds number
v = medium velocity
D = pipe diameter
ρ = fluid density
η = dynamic viscosity
St = Stanton number
Nu = Nusselt number
K = thermal transfer coefficient
L = Zone height
T1= temp. in the beginning of each area
T2 = temp. in the end of each area
t = time for the fluid to cross each area
hc = convectivon coefficient

4. RESULTS E CONCLUSIONS

The final result for the gasifier consuming açai seed can be seen at Figure 1. The final dimensions for the internal tube is 150 mm ID, the external tube has 250 mm ID, and its height is 1500 mm. The fuel consumption will be of 18 kg/h of açaí seed it will produce gases with 70 kWt. The reactor load will be of 5 kg of açai seeds.

The feeding system is composed of a conical reservoir of stainless steel (Figure 2) with 5L volume. It is approximately for little more than 1 kg of açaí seed with bulk density of 240 kg/m3 and diameter of 1 cm. The reservoir has an opening system for the interior of the concentric tube in conical format that guarantees a better biomass feeding distribution.

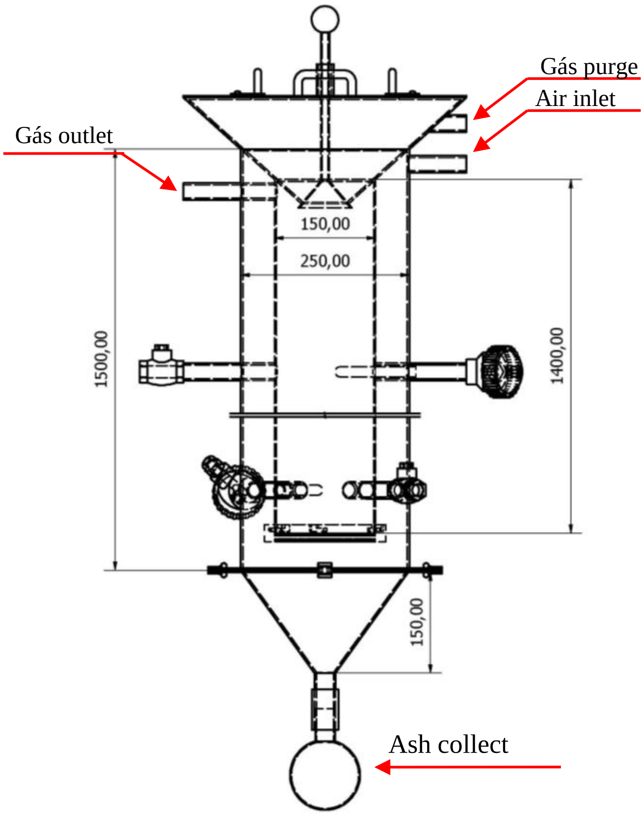


Figure 1. Cylindrical Reactor Dimensions

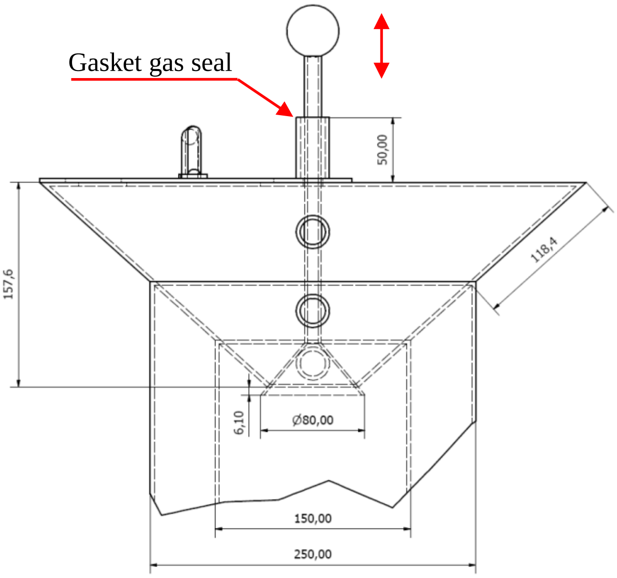


Figure 2. Feeding system Dimensions

A gasket gas seal was used to block gases from the reactor leakage to the lab room. The feeding system has a purge port to remove the gases from the reactor before the feeding gate is open. This system removes all residual gas that enters during the opening of the internal gate. The cover of the cone reservoir has rubber seals under tits border so that there is not possible gases leakage.

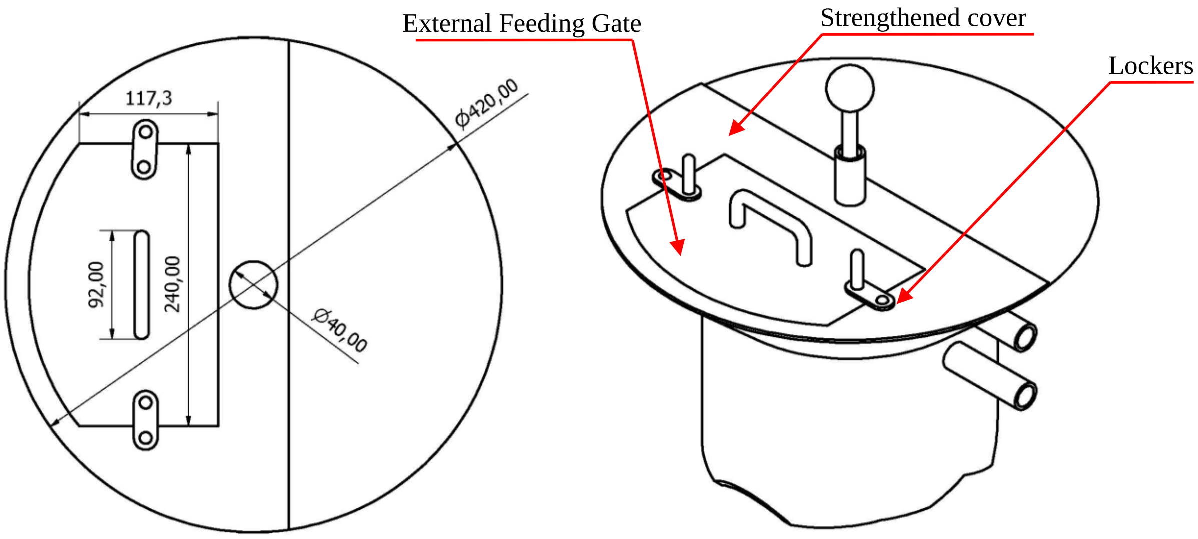


Figure 3. feeding System Dimensions

The feeding air is made from the top and flows down way cooling the internal tube and enters into the internal tube (reactor) through a grate that also works as biomass contention. The grate possesses a system of fitting type "clamps fast", made of melted iron. For better observation of the produced ashes, it was put in the inferior part a glass balloon (Barrio, 2000) coupled to a cone, attached to the gasifier body through a quick lock. The illustration below shows in details the gasifier details besides showing the helical position of the thermocouples and gas sampling ports.

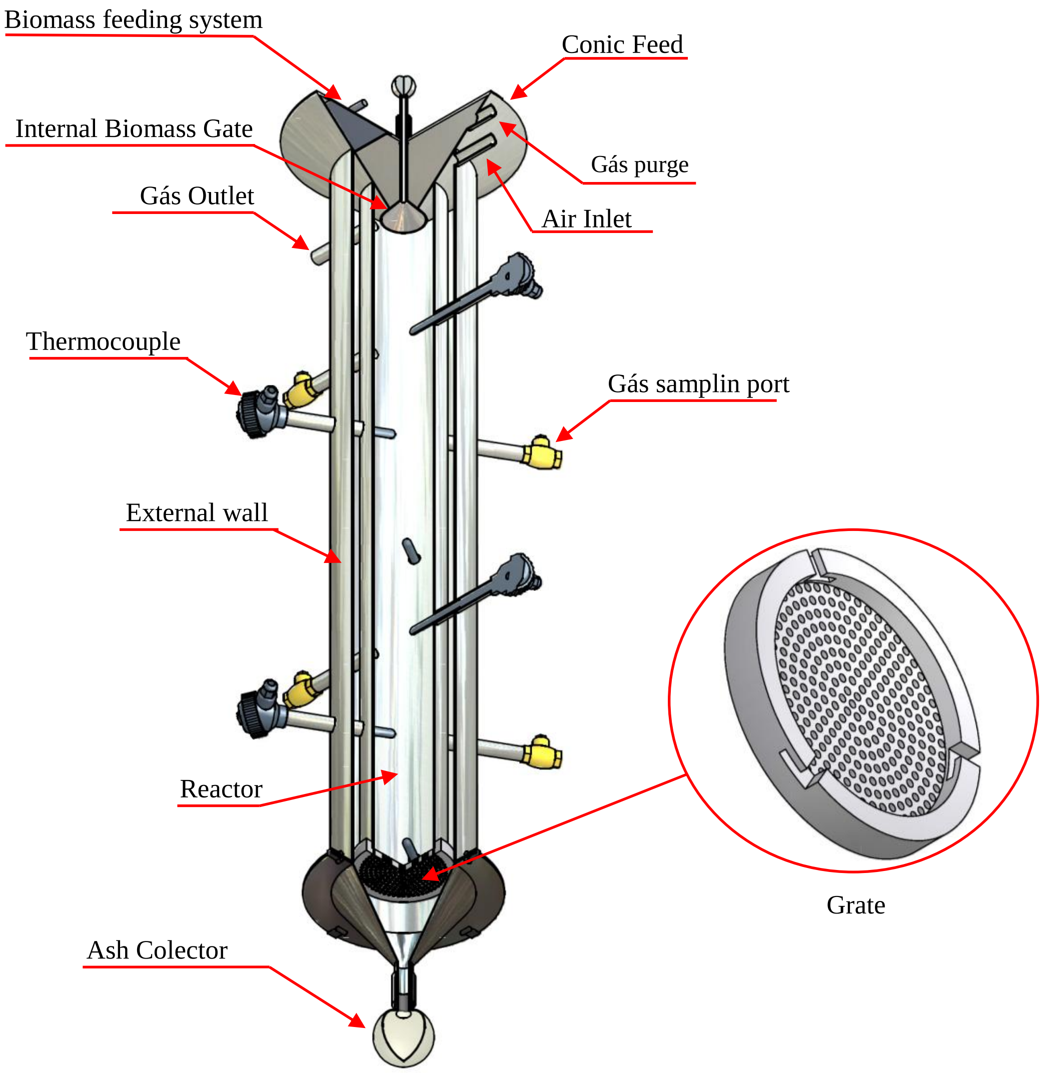


Figure 4. Gasifier 3D

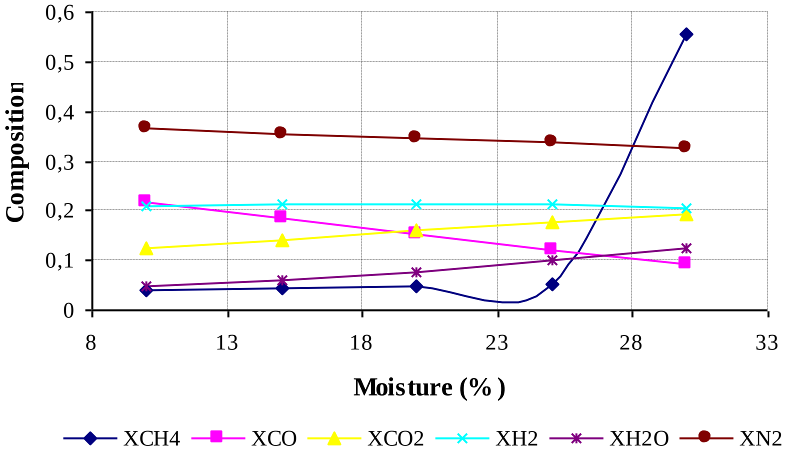
The gasifier was designed so that there were not significant heat losses. Air that passes between walls absorbs heat from the reactor and brings it into the reactor when it crosses the grate. The critical design parameter was the grate temperature. It must stay at low temperature, otherwise it can be melt. Therefore the air temperature at the lowest gasifier position was calculated. The heat transfer calculation was performed with equations 4 to 10. Solving these equations one finds that the air velocity at grate entrance is 0,6702 m/s. This calculation was performed with the air temperature at gasifier entrance at 25° C and the cross area where the air flows is 0,01374 m^2. Made all of the calculations results are presented at Table 3. There can be seen how the air temperature raises from the air inlet port up to the grate and the time taken. Table 3 also shows the used constants (Diéz, 2000). Finally, the air arrives at the grate grating with a temperature of 120°C, what means that there will be no possibility of grate melting of the grating, and the air cooling effect is pretty efficient.

Table 3. Estimate of the temperature and of the time that the air that goes by the grating

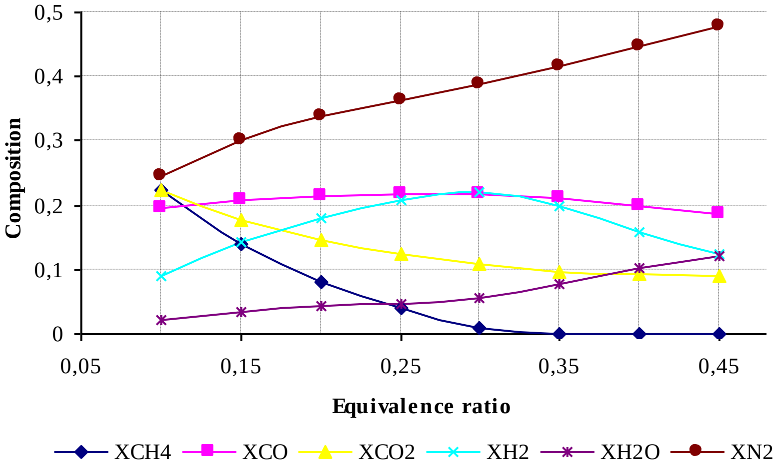
Zona	**T_m (K)**	**η_{ar} (kg/m^3)**	**K_{ar} (W/m°C)**	**ρ_{ar} (kg/m^3)**	**cp (kJ/kg°C)**	**Pr**	**T_2 (°C)**	**t (s)**
Secagem	335,50	$2,0140.10^{-5}$	0,02900	1,0310	1,00813	0,7000	30,60	1,0440
Pirólise	563,00	$2,8922.10^{-5}$	0,04438	0,6281	1,04316	0,6800	87,06	0,4000
Gasificação	716,53	$3,3813.10^{-5}$	0,05320	0,4923	1,07800	0,6846	106,50	0,1230
Combustão	826,50	$3,7000.10^{-5}$	0,06000	0,4270	1,10380	0,6906	**120,00**	0,0531

Graph 1 show the exit gas composition performed with Pelegrine software. This graph shows that moisture content affect in opposite way CO and CH_4 concentration. Low moisture increases CO content and high moisture content increases CH_4 fraction.

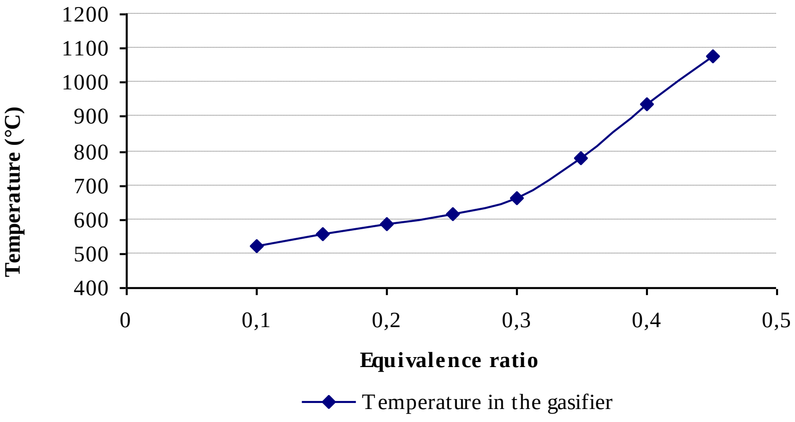
Graph 1. Species concentration varying with moisture content. Pressure=1 atm



Graph 2. Exit gas concentration as function of the equivalence ratio



Graph 3. Evolution of the temperature in function of the equivalence reason



Graphs 2 and 3 show the gas composition and temperature respectively, varying the equivalence ratio. CO fraction is larger when the equivalence ratio is 0,25 and whose temperature would be the little more than 600°C. These Graph show the commitment that exists between equivalence ratio and gas HHV. Increasing the equivalent ratio, the reactor temperature increases, accelerating the gas production. On the other hand, increasing the equivalence ratio, more nitrogen in add to the exit gases, reducing its HHV.

This gasifier seems very promising but it is yet in experimental phase. It is very simple in its architecture, and will have as complement a gas cleaning system, flare and gases measurement system. In this gasifier they will also be used other biomass types as sawdust and wood shavings.

5. ACKNOWLEDGEMENTS

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