EXPERIMENTAL MEASUREMENTS OF TEMPERATURE AND CO CONCENTRATIONS PROFILES NEAR THE CUCLONIC COMBUSTOR INTERNAL WALL FUELED BU SAWDUST AND AIR.

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Abstract: *Aiming the study of biomass combustion on a fluidized bed, a cyclonic combustor (4m height, 1.64m ED, 0.82 ID) was built and instrumented at EBMA laboratory in UFPA. The air/sawdust mixture with equivalent ratio of* Φ_1*=0.78 and* Φ_2*=0.83, was injected tangentially at the bottom of combustion chamber's internal wall. Temperature and CO concentration from botton to up was obtained throug 8 thermocouples and 9 gas sampling ports on the longitudinal section of combustor and smokestack. The profiles obtained showed 3 distinct regions: volatile combustion on the bottom, above this one a region where accurs a residual carbon gasification and, at top, the oxidation of CO produced in previous region. Gas measurements on smokestack have showed that it still has a large amount of CO, hence it means that it is necessary to increase the resident time of particles in the combustor or accelerate the gasification reaction to reduce particulated matter emission.*

Keywords*: cyclonic combustor, biomass combustion, experimental measures.*

1. INTRODUCTION.

The efficiency of a typical sawmill located at Para state, Brazil, is 35% (Veríssimo, 2001). This industry, in 1990, had a yield de 1.2 million m³, therefore their amount of residue is burning it at open sky or in large furnaces. A typical furnace is fixed beat with 12 m of diameter and 15 m high, low combustion efficiency producing pollutants with high concentration of CO, hydrocarbons and particulates. A cyclonic furnace has been proof to be a technical and economic alternative for the traditional furnace with advantage of allowing the combustion control what leads to a higher combustion efficiency, less pollutant emission and accept a large type of residues (Ushima, 1998).

A cyclone furnace is a cylindrical chamber where the solid fuel is burned in air suspension, following a cyclone pathway (rotation with vertical movement) caused by a tangential injection of air and fuel at the base of the cylindrical chamber (can be at the top do). The tangential injection causes high velocity gradient between gas and particle producing high coefficient o heat and mass transfer leading to high rates of release in combustion as 4-8 MW/m³ (Ushima, 2000). Temperatures inside of the combustion chamber is in the range of 1650°C, high enough to melt the ash and turning it on slag (Borman and Ragland, 1998). The flow inside the cyclone chamber impasses a centrifugal force on the particle driving it to the furnace wall and promoting the combustion at the boundary layer (Tillman, 1991). (Fredriksson, 1999) reports that the rotational flow turns the flame more stable, difficulty quenching, and raises the residence time promoting a more homogeneous fuel-air mixing.

Kops, 2004 and Cunha, 2005 reported computational simulation of sawdust combustion in air in cyclone furnaces using the commercial code \fluent and they showed the isothermal follow is not axis-symmetric, instead, it is 3D transient but they had of enough experimental data to validate the numerical results. This work will present are longitudinal temperatures and concentration, obtained on the wall for equivalence ratio of Φ_1=0.78 and Φ_2=0.83 (fuel poor mixture).

2. EXPERIMENTAL APPARATUS.

The combustor, as seen in figure 1, can be divided in three parts: air-sawdust feeding system, combustion chamber and exhaustion gases clean system. The feeding system has two inlets, one for sawdust (in red) and another for air (in gray). They are mixed in the fan and tangentially injected at the bottom of the cylindrical chamber (in blue).

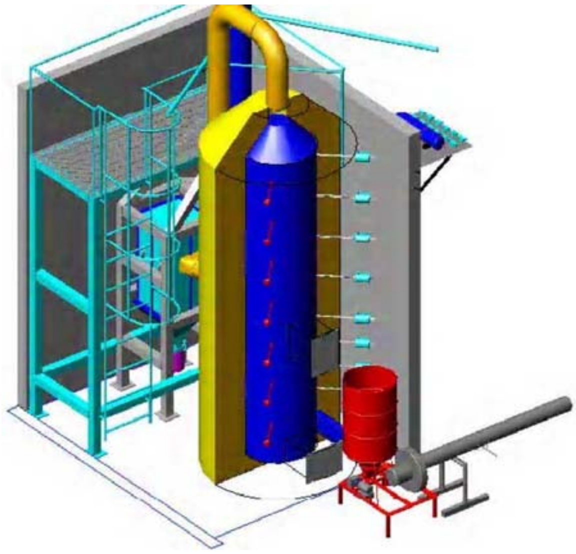

Figure 1: The cyclone furnace built at EBMA/UFPA facility

The biomass feeding system is a barrel, with open top and a gate on the bottom. Inside the barrel, there have four rotational pads to move the sawdust and avoid its clogging. The pads drive the sawdust to the gate and it falls in the driving screw that moves the biomass to the fan suction meet the inlet air. Both, the screw drive and the fan have variable rotation what controls the sawdust and air mass flow rate figure 2.

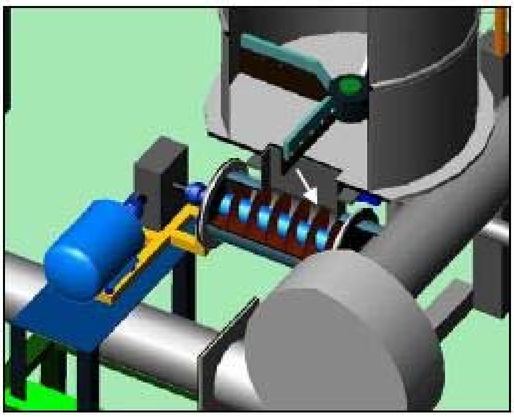

Figure 2: Air-sawdust geeding system

The cylindrical combustion chamber was made of solid clay brick, linked with refractory cement, adobe and clay. Its internal diameters is 840 mm, the external is 1660 mm and height of 4.0 m. It has an inspection door used for fire up the burner and follow up its internal erosion. One side wall has 7 thermocouples types (90% platinum – 10 rhodium) distributed vertically and spaced 50 cm from each other a numbered top to bottom 1 to 7. The number 1 is 3.5 cm form the bottom and the number 7 only 0.5 m from the bottom, as can be seen at figure 3(a) (left side in red). All the TC are connected to a PICO TG 08 board and to a computer, allowing temperature register online.

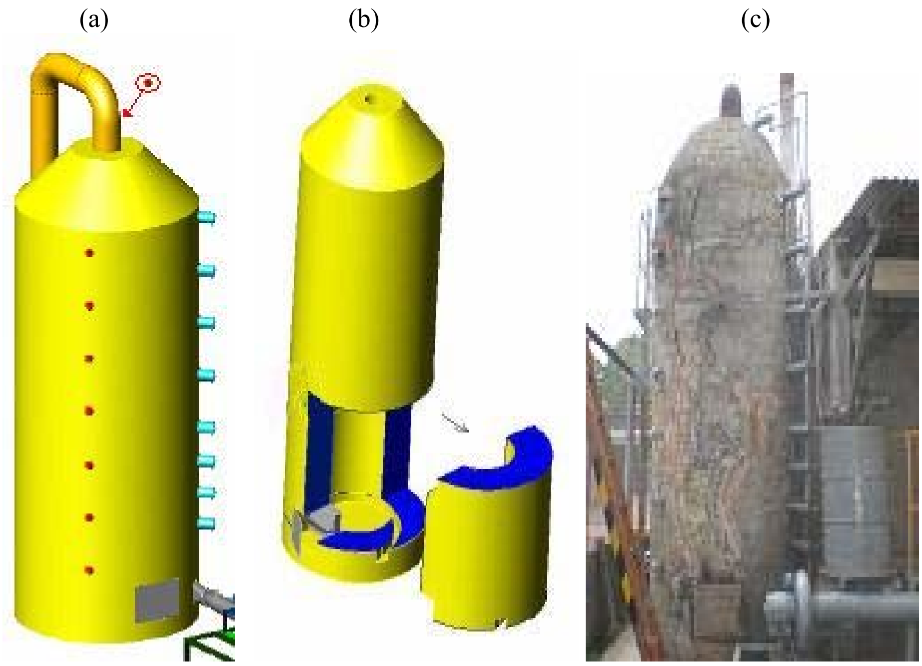

Figure 3 : (a) cyclone combustor external view ; (b) exploded view ; (c) picture of constructed combustor

Ninety degree, counter clock wise, from the thermocouples, there is a vertical line of ports to collect gas samples to have its composition quantified (figure 3(a) blue parts). The furnace has 8 stainless steel ports distributed vertically and spaced the first five from top to down are spaced 50cm from each other, the remaining four are spaced 30cm and numbered from top to bottom 8- 1. The highest is 3.5 m from the bottom and the 8 is only 0.6 m form the bottom. Those ports have a water cooling to quenching sample from reaction. The gas sample was analyzed with tempest 100 an electrochemical analyzer that measure CO, O_2, SO_2, NO_x concentration as requested.

The top of the combustor has conical shape and meet a 150 mm ID casting iron pipe that collect all gases and drive it gas cleaning system. None the start of the casting iron pipe has two ports one for temperature measurement and another for gas sampling, (figure 3 (a)), both located 4 m above the bottom (numbered zero) and similar the ones described above except that the TC is positioned at the center of the pipe. The gas cleaning is a cluster of 4 cyclones designed to retain particles bigger than 5 microns in a chamber under the cyclones. The cleaned gases are then sent to the atmosphere.

3 . EXPERIMETAL PROCEDURE

The furnace was designed to operate with equivalence ratio of 1 and air flow rate of 0.26 kg/s and sawdust flow rate of 0.04 kg/s. It caused the highest temperature in the chamber it be above 2,000 ºC, above the instrumentation limit and jeopardizing the furnace structure. Therefore decision was taken to operate at lower equivalence ratio, (around 0.8). It means operate with excess of air, with 0.26 kg/s and 0.03 kg/s of air and sawdust respectively. The air flow rate was controlled trough the fan rotation. Previously was elaborated a calibration rpm x kg/h curve. The sawdust flow rate was controlled trough the screw drive rotation, but we were not able to obtain a calibration curve because the fuel were not uniform enough. Instead, the sawdust flow rate was obtained dividing a known mass of sawdust in stored between marks in the feeding barrel for the time of its consumption.

The furnace operated slightly above the ambient pressure and the air inflow varied between 28 and 32 ºC a long of the experiment that usually took around 8 hours. The air moisture contain varied from 82 to 93 %.

4. SAWDUST CARACTERIZATION

The sawdust was obtained from sawmills located at Belém, PA, area, that work with dry logs. Care was taken to do measurements always using the same wood species, and as much as possible, obtaining the residue from the same sawmill. The sawdust diameter distribution was measured at UFPA / Chemistry Laboratory using Rossin – Rammler technique and the following results were obtained: dmin = 20 μm; dmax = 400 μm; dav = 184 μm; n = 2.64.

Sawdust characterization for energy conversion purpose was performed at the EBMA/UFPA Laboratory and can be see on the table 1 (RENDEIRO, 1999).

Table 1 – Measured sawdust characterization on mass basis.

Elementary Analysis (%)		Physical properties (%)	
C	52.70	Volatiles	31.5
H	6.01	Fixed carbon	44
O	41.23	Ashes	1.99
N	-	Moisture content	23.5
Cl	-	HHV(MJ/kg)	19.77

Table 2 shows biomass physical properties adopt in this work and the reference source where it was obtained.

Table 2 Adopted wood physical properties

Physical Properties		References
Densidade (kg/m^3)	500	Ragland (1991)
Calor Especifico (J/kg-K)	1.760	Van Wvlen (1993)
Condutividade térmica(W/m-K)	0.173	Ragland (1998)
Temperatura de Pirolise (K)	473	Ushima (1998)

5. BIOMASS COMBUSTION CHARACHERIZATION

Vegetable solid biomass is a porous structure made mainly of carbon, hydrogen, oxygen and ash, with elementary composition of $C_{3.3\text{-}4.9}H_{5.1\text{-}7.2}O_{2.0\text{-}3.1}$ combined in such way that three different structures co-exist: cellulose, hemicelluloses and lignin (TILLMAN, 1991). The oxidation requires three phases. The first is the heating and drying. This phase occurs up to 110°C where the biomass receives heat a water is removed as steam the second phase is the pyrolysis that happens around 450-500°C, where the biomass releases its volatiles and becomes mostly carbon: charcoal. The volatiles mix with the surrounded air, reacts forming a flame and releasing heat. If the combustor is start, the remaining charcoal, together with the ash compose the particulate and exist as emission pollutant.

On the other hand, if the charcoal is able to receive heat to come up to 800-1200°C, has long enough residence time in the combustor and steam is present the charcoal is able to come a gasification process turning to be CO, CH_4 and H_2. Those gases are also fuel that are able to react with the remaining O_2. This gasification process reduces the total of particulate emission, making the emissions more environmental friendly. The reactions that rule this third phase are:

Heterogeneous reaction

$C+1/2O_2 \rightarrow CO$ carbon oxidation (slow)

$C+O_2 \rightarrow CO_2$ carbon oxidation (slow)

$C+CO_2 \rightarrow 2CO$ boudouard reaction (fast)

$C+H_2O \rightarrow CO+H_2$ water-gas reaction (faster)

$C+H_2 \rightarrow CH_4$ metane formation (fast)

Homogeneuos reaction

$$CO+H_2O \rightarrow CO_2+H_2$$
$$CH_4+H_2O \rightarrow CO+3H_2$$

Notice a competition that existe for oxigen on the volatile and synthesis gas combustion. If there does not have enough oxigen, most of it will be consumed on the volatile combustio and the furmace outflow gases wilol be rich on CO and other sythesis gases.

6. EXPERIMENTAL RESULTS AND DISCOSSION

Important is to say that temperature measurements were acquired on-line, but species concentration were obtained after command. After temperature reading indicates that the furnace combustion was steady (it should not vary more than 10% during 1h). Sample were extracted and analyzed, one each a time, starting with the port "0" and moving to port "8". 11 minutes were taken to obtain the full species profiles from the top to the bottom at the chamber wall.

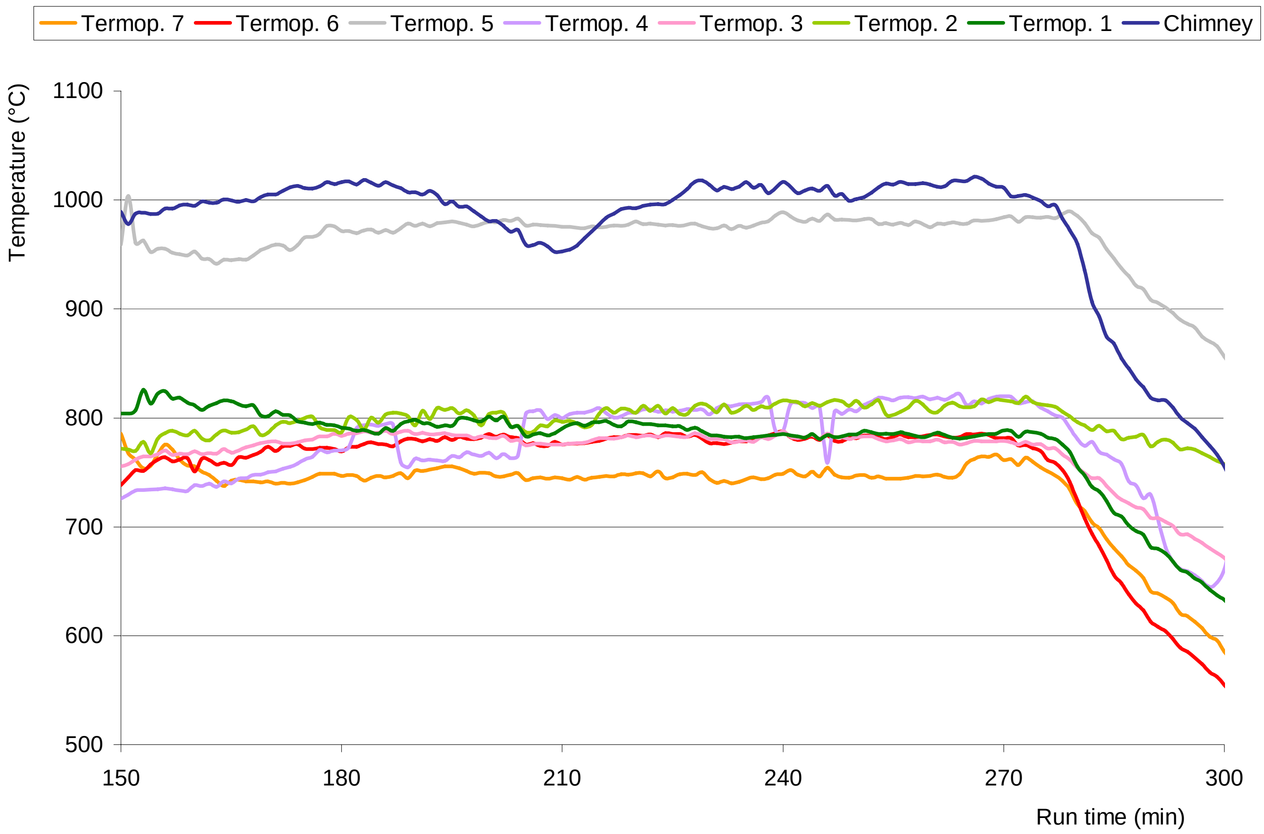

Figure 4: Gases temperature behavior, with time, for the gases at the furnace wall at all eight ports

During the period, five species profiles were obtained. The species concentration was obtained and an average was calculated. The figure 5 shows the temperature and CO profiles with height. Subscript (1) means equivalence ratio 0.78 and (2), equivalence ratio of 0.83.

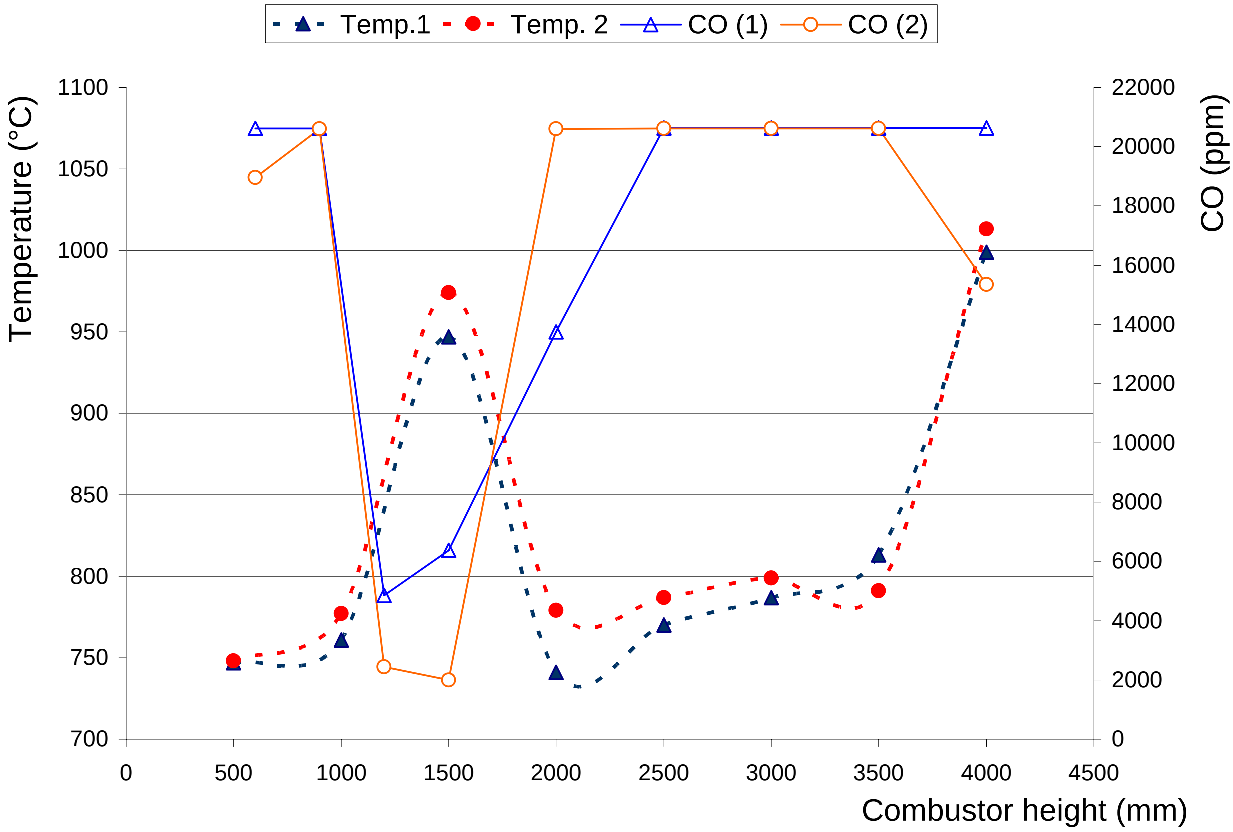

Figure 5: Temperature and CO profile, at furnace wall and furnace exit. (1) is for equivalence ratio of 0.78 and (2) for equivalence ratio of 0.83.

Four different regions can be identified in figure 5. The first is at the chamber inlet with low temperature (~750°C). Second, with a temperature peak (~950°C). Third has a decrease on temperature, back to 750°C. Finally the fourth is characterized for the highest temperature peak (~1000°C). The CO concentration also has four different regions. The first chamber meter, high concentration of CO, indicating the star of the volatiles combustion. Second, a fast decreasing on CO concentration indicating the end of volatiles combustion. Third, a gradual increasing CO concentration, indicating the residual charcoal gasification processes. Fourth region, the CO concentration, decreases indicating the combustion of CO, turning to be CO_2 and releasing heat.

The fat line for CO concentration between 2.0 and 3.5 m is due to the fact that the gas concentration achieved the upper limit of the Tempest 100, what is 20,600 ppm of CO. This fact does not compromise the phenomenon described above because surely the value is above the ones expressed in the figure 5.

7. CONCLUSIONS

The above description shows that the cyclone furnace has three major regions as following:

- The first, from the bottom to 1.5 m, the biomass is dried, volatiles are produced and burned. The temperature grows slowly up to 1.0 m, because drying and pyrolysis process are endothermic. The last 0.5 m is where the volatiles combustion occurs;

- The second region, from 1.5 to 3.5 m is where the charcoal gasification occurs. Initially the concentration increases with height up to achieve the combustion limit causing the combustion process to occur from 3.5 to 4.0 m. The room for the second region is very large (2.0 m) was induces to believe that steam inject in this area would accelerate the gasification reaction and reduce such volume. This is a possibility to be verified;

- The third region, from 1.5 to 3.5 m, is where the gases from charcoal gasification reacts and release heat. Surely the fact of the flow is concentrated at the exit due the injector shape at the burner exit, helps the co combustion to occur.

8. ACKNOWLEDGMENTS

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10. RESPONSIBILITY NOTICE

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