DRYING AND BURNING CHARACTERISTICS OF IPÊ BRANCO WOOD CYLINDERS

A. Castro,
and F. S. Costa,

INPE - Instituto Nacional de Pesquisas Espaciais
LCP - Laboratório Associado de Combustão e Propulsão
Rodovia Presidente Dutra, km 40
CEP: 12 630-000, Cachoeira Paulista, São Paulo, Brasil
andre@lcp.inpe.br
fernando@lcp.inpe.br

ABSTRACT

This work presents the drying and burning characteristics of Ipê Branco (Tabebuia rosco-alba) wood cylinders. The drying, self-ignition, flaming and smoldering phases under a constant heat flux are analysed. The effects of moisture content on characteristic times, mass evolution and consumption rates are described. The Ipê Branco cylinders presented flaming only for moisture contents equal or below 40% on dry basis. It is verified that the moisture content influences significantly the drying and flaming phases of the burning process of the Ipê Branco cylinders, however there is no significant effect on smoldering rates.

Keywords: combustion, wood, flame, smoldering, biomass.

INTRODUCTION

Combustion of biomass in fires releases a large amount of pollutants in the atmosphere, increasing global warming, acid rain formation, smoke production and particulates. It causes direct problems to the health of populations, worsen visibility conditions, produces ecological unbalance with reduction in biodiversity, damage the biogeochemical cycles and other adverse effects (Crutzen e Andreae, 1990).

Intense clearing fires occur annualy in the Brazilian Amazonia deforestation arc, between May and September, aiming the preparation of land for use in agriculture and cattle pasture. The felled vegetation is sun dried maintaining different levels of moisture, thus influencing the burning process and the composition and amount of the gases released, which also depend on physical and chemical characteristics of wood. Long droughts increase the risks of forest fires, like those occurred in the Roraima State in 1996 and 2003, which have devastated large areas.

The research group on forest fires of the Combustion and Propulsion Associated Laboratory from INPE has been investigating in the last years several aspects of fires in the Brazilian Amazonia, by means of prescribed burns (Costa et al., 2000; Carvalho et al., 2000). These studies have not focused yet on the characterization of different species under fire conditions, determining their individual behavior during all phases of burning. Moisture content, porosity and other chemical and physical characteristics can affect the mass loss rate, the release of volatiles and the formation of products during combustion.

In the other hand the utilization of wood in structures, buildings, houses, thermal protection and furnitures increases the risks of fires. Therefore it is of great interest to investigate the burning of wood and cellulosic materials, in general, in order to prevent fires in residences, industries and buildings.

Combustion of biomass presents several phases: pre-heating, drying, ignition, pyrolysis, flaming and smoldering. Flaming occurs after ignition during pyrolysis. Smoldering is a flameless burning process that can last several days after fires, specially in the case of large logs or ground vegetation.

Several theoretical, numerical and experimental works were made about the phases of burning of wood. Among others, Tinney (1965), Trabaud (1976), Kanury (1994), Yokelson et al. (1996), Sastamonien and Richard (1996), and Spearpoint (1999) have made contributions concerning the pyrolysis and burning of woods from cold and temperate weather regions. Tinney (1965) compared simplified numerical results, using a thermic model, with experimental results obtained from burning cylindric wood samples under heated air. Trabaud (1976) determined times of ignition and burning of bush samples from the Mediterranean region of France. Kanury (1994) developed a simplified theoretical model concerning the several phases of biomass burning. Yokelson et al. (1996) measured the emissions during flaming and smoldering of various kinds of biomass. Saastamonien and Richard (1996) presented detailed numerical simulations of simultaneous drying and pyrolysis of biomass. Spearpoint (1999) determined combustion characteristics of cellulosic materials using a conic calorimeter and validated an integral model of ignition and pyrolysis. Castro et al. (2001) presented experimental results concerning the burning of Pine (*Pinus elliot*) under a constant heat flux. Costa et al. (2003) presented a theoretical model describing all phases of burning and experimental results of Embaúba Preta (*Cecropia pachystachya*) cylinders under a constant heat flux. Pine is a softwood that occurs mostly in cold regions of Brazil and Embaúba Preta is a softwood that occurs mostly in warmer regions of Brazil.

The objective of this work is to present new results of the burning characteristics for Ipê Branco (*Tabebuia rosco-alba*) cylinders under a constant heat flux. Ipê Branco is a hard-wood present in most regions of Brazil.

Results of this work can be employed in the validation of numerical codes and related studies of fire prevention and the simulation of forest fires.

EXPERIMENTAL SETUP

It was built a cylindrical heater system, 10 cm diameter, with two electrical resistances, 1 kW each one, as shown in Fig. (1). The system was surrounded by a steel tube, 20 cm diameter, covered with aluminum foil, in order to reduce radiation losses.

A support was positioned inside the heater system and placed on a digital scale, with a 0.005 g precision and stabilization time less than 2 s. The support had on its top a aluminum disc to control the air flux entering the heater system, and also a steel cylinder where the wood cylinder was placed, to avoid gas recirculation on the wood sample, as shown in Fig. 1. The scale serial output was linked to a notebook computer which registered the weighing data.

The heater was turned on by a temperature controller connected to a thermocouple positioned inside the heater, outside the flame zone.

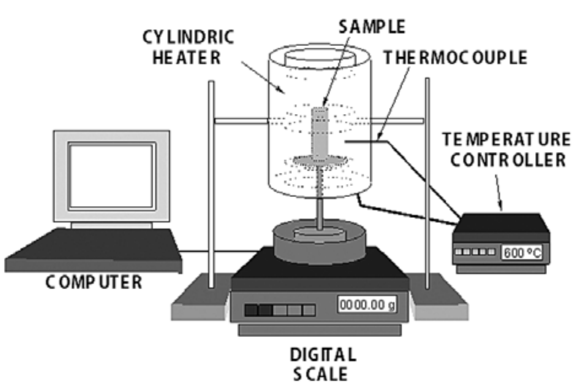

Figure 1. Experimental setup.

SAMPLE PREPARATION

Wood samples were obtained from Ipê Branco (Tabebuia rosco-alba) trees, recently cut. The logs were cut in 60 cm dowells, which were packed and frozen until machining. Freezing reduced moisture losses and wood deterioration, and yielded better machining conditions. The samples were machined as 3 cm diameter cylinders with 10 cm length, in the direction of the wood fibers. Just after machining the cylinders were packed and frozen again.

Due to any inclusions and density variations in the samples, a set of 24 samples with mass within approximately ± 3 % of the average mass of a set of 47 samples was selected. 6 groups of 4 samples with total mass approximately equal were selected. Before ovendrying, the samples were left 24 hr at ambient conditions to attain thermal equilibrium with air (25 oC). The oven temperature was set at 103 oC, since tests were made at 600 m altitude. At the sea level the standard temperature is usually 105 oC. It is believed that only moisture is released from wood at this temperature. Table 1 shows the masses of wood cylinders before and after oven drying.

Table 1. Masses of cylinders before and after oven drying. M=moisture content (%), dry basis.

M	0%		20%	
mass*(*g*)	m_i	m_o	m_i	m_o
samples	67,34	34,40	73,39	44,03
	71,20	35,20	72,19	43,31
	71,45	36,30	70,60	42,36
	70,40	35,00	67,75	40,65
average	70,1	35,23	70,98	42,59
M	40%		60%	
mass*(*g*)	m_i	m_o	m_i	m_o
samples	72,78	50,95	72,76	58,21
	72,18	50,53	71,81	57,45
	70,57	49,40	70,21	56,17
	67,77	47,44	68,05	54,44
average	70,83	49,58	70,71	56,57
M	80%		100%	
mass*(*g*)	m_i	m_o	m_i	m_o

samples	72,40	65,16	72,36	72,36
	71,81	64,63	71,24	71,24
	70,08	63,07	70,12	70,12
	69,62	62,66	70,00	70,00
average	70,98	63,88	70,93	70,93

*m_i = initial mass; m_o = mass after oven drying.

The average ovendry density was 504 kg/m³ measured from one of the groups of Ipê Branco cylinders. Then, the test samples were prepared by ovendrying them until the required moisture contents, yielding 6 groups of 4 samples with moisture contents M = 0, 20, 40, 60, 80 and 100 % on dry basis, respectively. The wood samples with known moisture contents were packed and frozen.

TEST PROCEDURE

Initially the heater system and the sample support were aligned vertically on the scale and the computer was connected to the scale serial output and turned on.

The heater system was closed at its top by a metal disk to allow a faster heating. The heater was turned on until reaching a temperature of 500 oC, measured by the thermocouple inside the heater, as showed in Fig. (1). The heater was left at 500 oC for 5 minutes and then the metal cover was removed. The heater system reduced its temperature to 430 oC, by natural convection, and then remained at this temperature up to flaming.

The samples were unfrozen 24 hr before the test. A sample with a known moisture content was unpacked, verified its mass and rapidly positioned on the sample support inside the heater. Thus, the scale registered the instantaneous mass of the sample at intervals of 1s during about 30 min, under a constant heat flux, simulating fire conditions.

Natural convection caused by electrical heating, flaming or smoldering brought cold air from the ambient into the heater thus keeping the burning process.

RESULTS

The curves of mass evolution of selected Ipê Branco samples with M = 0, 20, 40, 60, 80 and 100 %, dry basis, are showed in Fig. (2). The data were selected at 10 s intervals, reducing scale stabilization effects. Figure (3) shows the normalized mass curves of all 24 samples, m/m_o, versus time, where m_o is the initial mass of each sample.

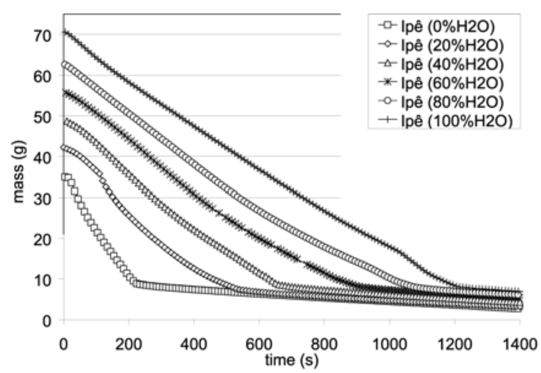

Figure 2. Mass evolution of Ipê Branco dowells.

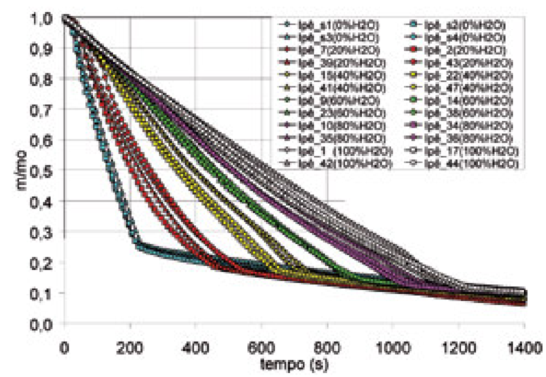

Figure 3. Normalized mass evolution of Ipê Branco dowells.

It is seen in Figs. (2) and (3) that moisture levels influence the mass evolution of the samples and the times where can occur a change of curvature in the plots. These times can indicate the self-ignition and the end of flaming. In the case of Ipê Branco samples with moisture contents above 40 % there is no clear self-ignition, probably due to a small mass flux of volatiles or the simultaneous release of water and volatiles at significant levels. According to Kanury (1977), it is required a minimum flux of volatiles to attain the lower limit of flammability of the gaseous mixture and to cause self-ignition in the boundary layer adjacent to the wood cylinder.

It should be noted that the samples have a constant heat flux from the electrical heaters, however, during the flaming period, there is also radiation from the flame, and there are heat losses by convection and radiation from the sample surface.

The normalized mass of the Ipê Branco samples varied from 8 to 14 % at 1200 s and from 6 to 12 % at 1400 s. All curves after 1200 s, during the smoldering phase, keep about the same inclination.

Figure (4) shows the mass consumption rates of the samples, $CR = -dm/dt$, versus time. During flaming the mass derivatives have an approximate parabolic shape, and after its end, during smoldering, the mass consumption rate is approximately constant and very low, decreasing very sligthly. The samples with moisture levels above 40 % did not ignite, as mentioned before, probably due to the low release of volatiles and the water cooling during the pyrolysis phase.

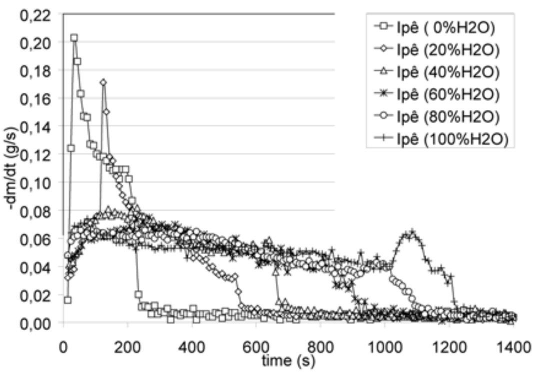

Figure 4. Mass consumption rates of Ipê Branco dowells.

Since the mass of the sample changes with time it was also defined a normalized consumption rate:

$$NCR = -\frac{100}{m}\frac{dm}{dt} \qquad (1)$$

Figure (5) shows the normalized consumption rates versus time of the Ipê Branco samples. It is seen that the pyrolysis region where flaming occurs keeps an approximate parabolic shape, as in the mass derivative plots, for moisture contents 0 and 20 %, while the normalized consumption rates increase steadily most of the time for higher moisture contents. The self-ignition points can be easily identified in the 0 and 20 % cases. The end of flaming points can be easily identified in all samples. Normalized smoldering rates increase very slightly with time.

It was observed that samples kept an approximate cylindrical shape during the entire burning process, despite formation of cracks on their surfaces.

Samples with lower levels of moisture have very small self-ignition times. Nevertheless, there is always some water inside the cells and cellwalls, with release of water in all cases.

Figure (6) shows the fraction of mass consumed at each phase for all samples. In Fig. (6) the mass consumed by smoldering is assumed as the difference between the initial mass and the mass loss after drying and pyrolysis. Thus, the ash mass was neglected.

The maximum consumed mass fraction in the drying and pyrolysis period is above 85 % for samples with M ≥ 60 %. The consumed mass fraction during the flaming periods is about 70 % for samples with M = 0 and 20 %, 10 % for M = 40 % and 0 % for higher values of M.

Figure (7) shows the ignition and the end of pyrolysis times with or without flaming for all samples. A correlation fit for the end of pyrolysis time is showed on Fig. (7), based on the average values of each moisture content group. The difference between the end of pyrolysis time and the drying time is the pyrolysis time. Figure (8) shows pictures of the cylinders of Ipê Branco inside the calorimeter. The flaming, flame extinction and smoldering periods are depicted in Fig. (8).

All samples up to M = 40 % presented ignition and, consequently, a flame period, while only one sample with M = 60 % and only one sample with M = 100 % presented ignition, showing a very short flaming period. The flaming time is maximum for moisture contents about 20 %. End of pyrolysis times increase about 6 times from M = 0 to 100 %, from 220 s to 1200 s.

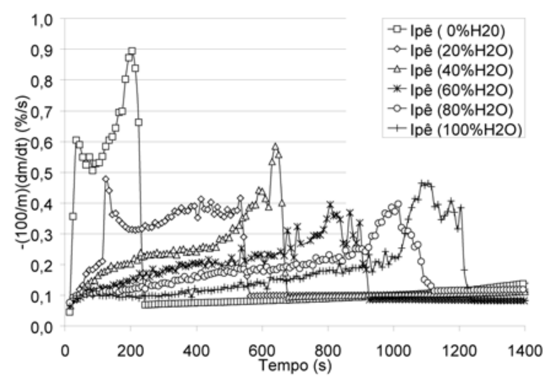

Figure 5. Normalized consumption rates of Ipê Branco dowells.

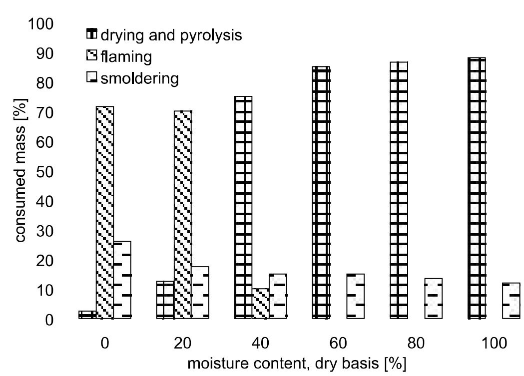

Figure 6. Consumed mass in the different phases of drying and burning of Ipê Branco dowells.

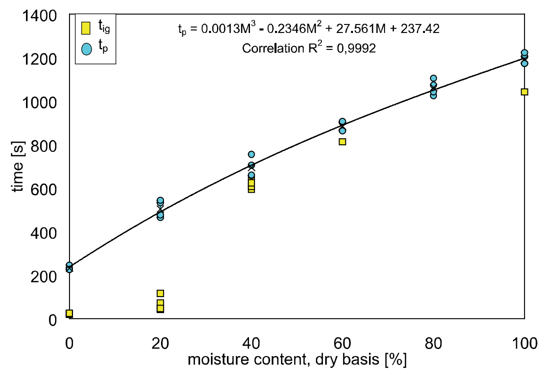

Figure 7. Times of self-ignition, t_{ig}, and times of end of pyrolysis, t_p, of Ipê Branco dowells, with or without flaming.

a) Flaming.

b) Flame extinction.

c) Smoldering.

Figure 8. Pictures of Ipê Branco wood dowells inside the cylindrical calorimeter.

CONCLUSIONS

An experimental investigation of drying, self-ignition, pyrolysis, flaming and smoldering of wood cylinders was made. Ipê Branco samples (3 cm diameter and 10 cm length) presented a significant flaming period for samples with moisture contents up to 40 %, on dry basis. There was no ignition for higher moisture contents possibly because the relatively slow release of volatiles or the simultaneous release of water and volatiles in significant levels at these conditions. Moisture content affected significantly the drying and pyrolysis phases, the fraction of consumed mass of each phase, the characteristic times, however had no significant effect on smoldering rates.

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