Environmental and Energy Performance Evaluation of an Alternative Biomass Fuel Obtained from Wood Residues Generated in a Metropolitan Area

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Abstract:

This paper presents the results of experiments related to the development and use of wood residues discharged as garbage within the city of Belo Horizonte, Brazil, as raw material for the production of an alternative biomass fuel for use in small scale industrial plants. Samples of the wood wastes discharged in the municipal solid waste landfill were collected, and submitted to mechanical and thermal processing, in order to produce uniform product with proper characteristics for use as fuel. In laboratory scale, the heat content after different thermal treatments were measured, with the aim to determine the optimal processing conditions for improving the calorific value of the fuel. Using the results of the laboratory tests, the full scale industrial experiments were performed. The energy release in fueling an industrial oven of a bakery was assessed, together with the isokinetic sampling and determination of particulate and gaseous releases to the atmosphere. The same determinations were done for comparison among the (a) thermal and mechanical processed wood residues at two different temperatures and (b) coarse timber. The results showed that the lower heating value of the wood residues (16.3 MJ/kg) were higher than for fresh timber (13.2 MJ/kg), and increased after complete drying to 17.4 MJ/kg. With the thermal processing, the optimal condition at industrial testes was obtained at the temperature range from 220 to 240ºC, where the heating value reached 18.7 MJ/kg. In industrial oven, the use of the alternative fuel showed the best results for the energy release and atmospheric emissions of particulates. For the fuel treated at 220 to 240°C, the measured particulate concentration in the exhaust gases was 137 mg/Nm^3 and the specific emission rate was 1.7 g of particulates for each kg of fuel burnt, whereas for the coarse wood they were 203 mg/Nm^3 and 4.6 g/kg respectively. An estimate of the potential for reducing emissions of greenhouse gases is also presented, and it was found that 1 t of the biofuel is able to reduce the equivalent CO_2 emissions of: a) 1.3 t by avoiding methane formation in the landfill; b) 0.4 t by switching the use of fossil fuel; and/or c) 0.18 t by improving the energy efficiency in conventional timber ovens.

Keywords: biomass fuels – energy – greenhouse gas emissions – particulates emissions

1. Introduction

The use of wood as source of energy is one of the most ancient human practices. Indeed, the capacity of dominating fire is considered a crucial point in the transition of the primitive human society into civilization. Timber and charcoal remained as the main source of energy for the most of the time in the human history, only with the advent of industrial revolution coal and other fossil fuels became dominant in developed countries. But firewood remains as main energy source in developing countries.

In Brazil for example, wood was responsible for more than 50% of the thermal sources of energy in the fifties, and only in the last four decades it decreased to the present situation, where it is estimated that biomass corresponds to about 27% of the energy consumed (Rezende, 1982). In the Brazilian state of Minas Gerais, the energy balance revealed (CEMIG, 2003) that firewood and derivatives were responsible in 2002 for 8.5 millions toe (tons of oil equivalent), what corresponds to 30.9% of the total energy demand of the state. Wood and derivates supplied 35.6% of the total energy for industrial activities, and 35.6% of the residential, showing that wood is still an important and strategic source of energy. Nevertheless, the final output of the energy obtained by different primary energy sources reveals that the biomass has a smaller participation, mainly because the low efficiency of the conversion systems for biomass uses (ovens, charcoal conversion, etc.).

The climate changes related to the burning of fossil carbon reserves, and the increasing prices of crude oil, are imposing a trend to raise again the use of wood and biomass as a source of energy. This inducement must be followed by some restrictions and regulations, like the planning and proper management of land use, in order to protect natural ecosystems, and the control of atmospheric emissions in combustion systems. Since the amount of energy demanded by human activities is huge, the optimization of biomass use as a fuel must also be a goal. This could include the use of residues from agriculture, forestry, and management of urban wastes as possible source of energy.

2. Experimental

This paper describes the results of an experiment on the development and use of wood residues discharged as garbage within the city of Belo Horizonte, Brazil, as raw material for the production of an alternative biomass fuel for use in small scale industrial plants, like bakeries and meat and food processing industry. Wood residues discharged in the municipal solid waste landfill were separated, and submitted to mechanical and thermal processing, in order to produce uniform product with proper characteristics for use as fuel.

The experiments were carried out in two phases (Figure 1). First, in laboratory scale, the samples were grinded and the optimal conditions for thermal processing were evaluated. The aim was to process the samples in an electric oven, achieving a soft and controlled thermal conversion of the wood at temperatures bellow the carbonization process, increasing its heating values. A first experiment used a sample of 14 kg of the wood pieces generated by size reduction of 74 kg of the wood residues obtained in the landfill. The sample was grinded to pass the 60 mesh sieve (0.25 mm), and dried at 105 °C to constant weight. Small portions of the sample were submitted to thermal processing inside an open recipient, which was heated in an electric oven for 15 minutes at different temperatures, being the recipient immediately closed after the treatment with a ceramic cover, for preventing spontaneous combustion. The following temperatures were used for the thermal processing: 140, 180, 220, 260, 300°C. For each temperature, and for a sample with no thermal processing, the heating values were determined in a calorimeter bomb, as well as the weight losses during the process. For the calorimetric measurement about 4 g of the sample was used, and triplicate measurements were performed.

After the evaluation of the results obtained, a second laboratory test was performed in the same way as above, six months later, using another 12 kg sample from the stored 74 kg of wood pieces. The sample was grinded to 0.25 mm, dried, and submitted to thermal treatments in closed ceramic recipients for 15 minutes at the following temperatures: 200, 210, 220, and 230°C. After cooling to ambient temperatures, the thermal processed samples were maintained in open recipients in the laboratory and weighted again after 24, 48 and 72 hours, in order to assess the capability of water absorption, i.e., to asses its stability by storage.

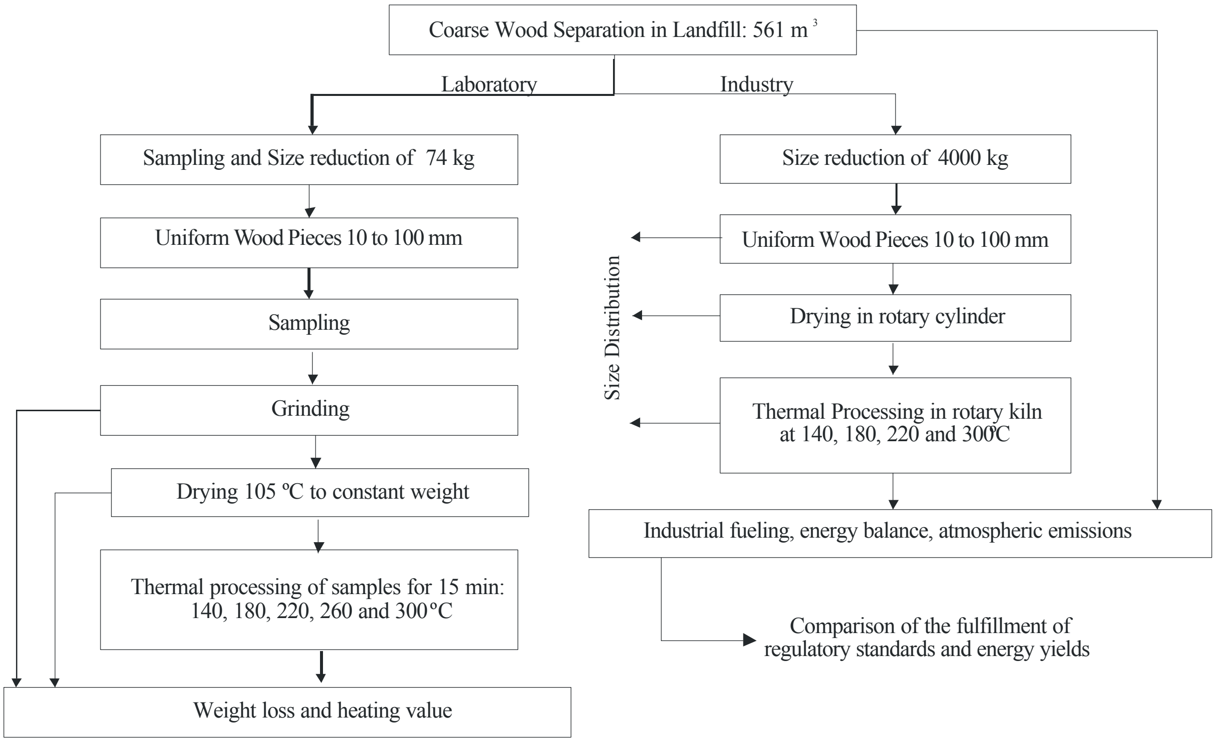

Figure 1 - Scheme of the experiments undertaken, including the laboratory tests (on the left) and the industrial scale tests (on the right). The laboratory tests were performed for determining the optimal condition of thermal processing of the wood pieces for improvement of the heat values, and the industrial experiments in a bakery situated in the urban area of Belo Horizonte, for measuring the environmental performance related to the atmospheric emissions of particulates, and assessment of the energy efficiency of the alternative fuel, compared to the conventional timber.

Using the results of the laboratory tests, the full scale industrial experiments were performed. About 4000 kg of the wood residues were separated in the landfill, mainly the wood from urban vegetation (tree suppression or treatment) was selected. In the commercial facilities it is also desirable to use wood wastes discharged to the landfill by residential, commercial and industrial activities. These wastes normally contain many iron and metallic pieces that have to be separated before the mechanical processing. The residue was processed mechanically (size reduction to between 10 and 100 mm), and submitted to thermal processing in a rotary kiln (1.2 m diameter and 1.86 m length), heated internally and externally (double wall) by circulation of hot gases generated in the combustion of the fine fractions of wood within a separated oven. The heat supply was regulated by valves that controlled the flow of hot gases to the kiln. The wood pieces were processed in batch operations in the rotary kiln, in which they remained for 15 minutes at the final range of temperature selected, namely: a) 160 to 180°C; b) 200 to 220°C; c) 220 to 240°C and d) 240 to 260°C. After the thermal processing, the content of the kiln was discharged into ventilated screens for cooling to room temperature.

The obtained alternative fuel was tested in an industrial oven of a bakery in the city of Belo Horizonte. During daily routine production periods (from 2:00 a.m. to 16:00 h), in which the baker oven is maintained at 180 to 200°C, the use of the alternative fuels was tested, with the measurement of the atmospheric emissions of particulate matter in the stack gases using the isokinetic sampling procedure (US-EPA Method 5). The following fuels were tested in the industrial oven:

a) Mechanical processed wood pieces thermally treated at 160 to 180°C;
b) Mechanical processed wood pieces thermally treated at 220 to 240°C;
c) Conventional wood pieces without mechanical and thermal processing (timber).

For each fuel the sampling procedure was undertaken in three runs, with 60 minutes sampling in each run, during which the following parameters were measured in 12 points inside the stack, for 2.5 minutes in each point: temperature, humidity, gas velocity, gas composition, gas flow and corrected gas flow for normal conditions of pressure and temperature, particulate matter mass concentration, and emission rate of particulate matter.

Once the environmental viability of the alternative fuel was confirmed, an estimate of the potential reduction of emissions of greenhouse gases – GHG was accomplished, under the assumption that the alternative fuel use can be able to avoid the following GHG emissions:

a) By avoiding the anaerobic biodegradation of the wastes directed to the landfill, avoiding the methane formation.
b) By substitution of the fossil fuels in industrial processes, reducing the CO_2 emissions accordingly;
c) By increasing the thermal efficiency of existing wood fired ovens that use conventional timber, avoiding the CO_2 emissions proportionally.

3. Results and Discussion

Table 1 shows the mean results of the heating values of the samples processed in the laboratory experiments. It can be seen that the lower heating value of the wood residues (16.3 MJ/kg for the second experiment) was higher than the values cited in literature for fresh timber (13.2 MJ/kg for fresh timber with 30% water content, according to Diniz, 1981). This is because the used residues were naturally dried by keeping then in ambient conditions for at least 120 days. After drying to constant weight at 105°C, the calorific value increased to 17.4 MJ/kg. The chosen condition for thermal treatment was 200ºC, where the heating content reached 19.1 MJ/kg, i.e. a gain of 17% compared to the raw material, or of 45% when compared to conventional timber. Rising the temperature above this level was considered to be unnecessary, since the gains in heating values were too small. In the first experiment, with the open recipient, the high weight losses in the thermal processing indicated that the wood pyrolisis was too strong and the access of air oxygen resulted in the uncontrolled carbonization. The high heating values obtained were offset by the weight losses.

In the industrial use for energy release in an bakery oven, the prepared alternative fuels showed best results both for the energy release and atmospheric emissions, compared to conventional timber. Figure 2 shows pictures of the bakery oven burning conventional timber and the thermal processed fuel (220 to 240°C). It can be seen that the release of energy in the alternative fuel is much more intensive. The stability of the operational conditions of the oven was also much more pronounced, since the supply and release of energy in the mechanically and thermally treated wood was smoothly, compared to the supply of large pieces of humid timber that occurred in the conventional operation procedure.

Table 2 shows the results of the heating values measured for the thermal processing of the wood pieces in the industrial furnace. The best conditions for the thermal processing was considered to be at the temperature range of 220 to 240°C, where the lower heating value is close to the best results obtained in the laboratory tests.

Table 1 - Mean heating values (higher and lower) and weight losses related to the untreated sample in the laboratory experiments. The thermal treatment was undertaken keeping the wood samples, grinded to size smaller than 0.25 mm, at the programmed temperature for 15 minutes. The first experiment was carried in open ceramic recipients, which were closed by covering just after the finishing the treatment, and the second inside a closed ceramic recipient. Differences in the two experiments were attributable partly to a difference in the composition of the two samples, since the dry samples with no thermal processing showed intrinsically different heating values. But the large weight losses in the first experiment indicated that the wood pyrolisis reached the uncontrolled carbonization.

Thermal Treatment	First experiment (open recipient)			Second experiment (closed recipient)		
	Heating values (MJ/kg)		Weight-loss (%)	Heating values (MJ/kg)		Weight-loss (%)
	Lower	Higher		Lower	Higher	
No treatment	--	--	0.00	16.31	17.68	0.00
105°C (dry)	16.18	17.55	13.00	17.40	18.71	5.73
140°C	18.73	20.08	13.38	--	--	--
180°C	19.05	20.39	14.88	--	--	--
200°C	--	--	--	19.12	20.42	7.14
210°C	--	--	--	19.13	20.46	7.16
220°C	21.57	22.05	48.92	19.14	20.49	7.28
230°C	--	--	--	19.15	20.50	7.29
260°C	22.43	22.43	51.12	--	--	--
300°C	23.81	23.81	74.78	--	--	--

Table 2 - Mean heating values (higher and lower) of the obtained fuels in the industrial thermal treatment experiments. The thermal treatment was undertaken keeping the raw material, consisting of wood pieces with size 10 to 100 mm, in a rotary kiln at the programmed temperature range for 15 minutes, and discharging it afterwards to a ventilated screen, where it cooled down to ambient temperature. The processing at the temperature range of 220 to 240°C was considered the best condition for a full scale processing, with large increase of the heating value and acceptable weight losses.

Thermal Treatment	Heating values (MJ/kg)		Weight Loss (%)
	Lower	Higher	
160 to 180°C	18.13	19.48	10.5
200 to 220°C	18.78	20.08	17.5
220 to 240°C	18.73	20.03	18.9
240 to 260°C	19.10	19.98	21.5

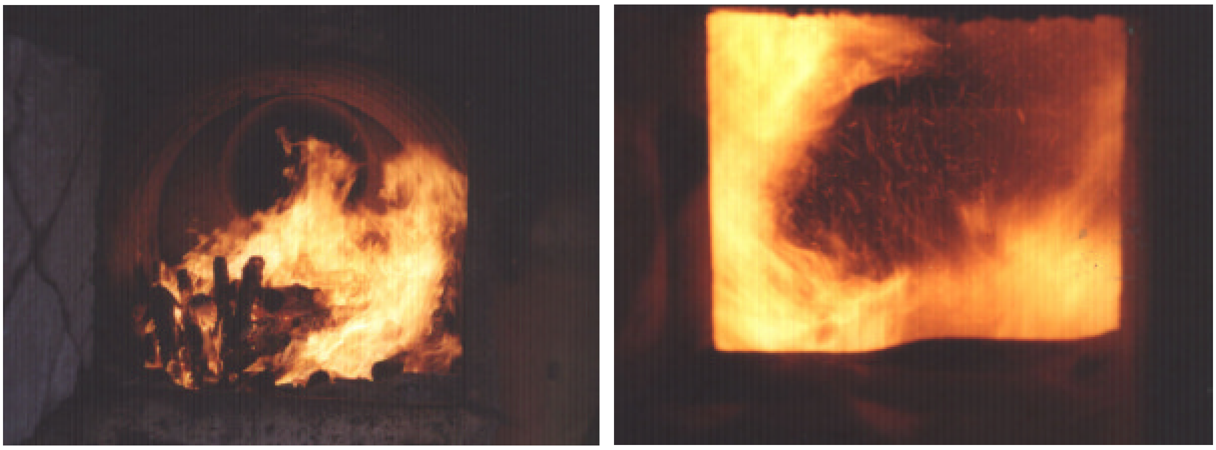

Figure 2 – Photographs of the bakery furnace burning conventional timber (left) and alternative fuels obtained by mechanical and thermal processing (220-240°C) of wood residues (right), showing the difference in energy release intensity in both situations.

Table 3 shows the measured emissions of particulate matter when using the three tested fuels. It is clearly seen that the emissions with the alternative fuels are much lower, and capable of accomplishing the imposed emission standard in Minas Gerais, of 150 mg/m^3, without the need of equipments for exhaust gas treatment. This is an important economical benefit of the use of the alternative fuel, since it can substitute the conventional timber without the need of gas cleaning devices. The rate of particulate emissions related to the burned fuel showed the largest difference between the experiments: the thermal processed fuel yielded 1.7 g of particulates for each kg fuel burnt, where for the coarse wood it was 4.6 g/kg.

Table 3 – Atmospheric emissions of particulate matter by an industrial bakery oven burning conventional timber and the alternative biofuels obtained by thermal treatment of wood residues at sizes 10 to 100 mm. The treated residues were able to fulfill the environmental standard of 150 mg/Nm^3 valid in Minas Gerais. The particulate emission rates and the specific emissions per kg of burnt fuel are much more favorable to the alternative fuels, as compared to the conventional.

Parameters	Fuels		
	Conventional Timber	Biofuel treated at 160 to 180°C	Biofuel treated at 220 to 240°C
Stack gases temperature (°C)	242	213	259
Stack gases flow (Nm^3/h)	371	381	363
Particulate Matter (mg/Nm^3)	203	111	137
Emission rate (g/h)	74.7	42.4	49.5
Specific emission rate (g/kg)	4.57	2.77	1.73

Due to the fact that the bakery oven was fed manually when burning conventional timber, and using an automatic device for supplying the small pieces of wood by a rotating helices at constant speed, when burning the alternative fuels, it was not possible to optimize its operation for achieving the lowest fuel consumption in each case. Also, the energy balance for measuring the useful heat obtained could not be accomplished in this experiment. Further experiments will be undertaken to measure the gains in heat release and transfer to the final use, and to measure the potential reduction of fuel consumption when substituting the conventional timber for the alternative fuel.

In the case of substitution of an oil furnace for the alternative fuel, it can be estimated that the equipment has to be adapted, with a substantial increase in volume of the reaction zone, and adaptation of the air supply. The reasons for that needs are related to both the volumetric energy content of the fuels (kJ/m^3) and the release intensity (reaction kinetics), that are lower for wood pieces than for fuel oil. Nevertheless, the alternative fuel will avoid the need for gas treatment and has lower prices, what makes its use highly promising for the near future.

Another point to be considered is that greenhouse gases emissions can be substantially lowered by using the alternative biomass fuel. Table 4 presents the potential reduction of CO_2 emissions for three types of mechanisms incurred, when using 1 ton of the biofuel: a) by avoiding methane formation in the landfill (1.3 t of CO_2 equivalent), by switching fuel oil (0.4 t CO_2), or by improving energy efficiency of existing timber ovens (0.177 t of CO_2). It is important to notice that the first mechanism is additive to the second or to the third, when the biofuel is used for achieving Certified Emission Reductions according to the Clean Development Mechanism of the Kyoto Protocol (UNFCC, 2002).

Table 4 – Potential CO_2 emission reduction when using 1 ton of the alternative biofuel for three types of mechanisms.

Mechanism[(a)]	Reduction Potential (t of CO_2 equivalent)
Avoidance of Methane Formation in Landfill[(b)]	1.294
Switching fuel oil[(c)]	0.395
Energy efficiency improvement in timber ovens[(d)]	0.177

[(a)]The energy consumption for the thermal treatment of the biofuel was not considered, since this heating can be supplied in an industrial biofuel production by the unused wood pieces smaller than 10 mm. [(b)] Default values from IPCC (1996) for methane formation from wood residues, and the Global Warming Potential of methane were used. [(b)]Heating values and CO_2 emission factors for fuel oil from IPCC (1996) were used, compared to the heating value of the biofuel presented in this paper. [(d)] The measured 45% difference in the heating value of the biofuel compared to fresh timber, and the CO_2 emission factor for solid biomass from IPCC (1996), were used.

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