Elsevier Editorial System(tm) for Biomass and Bioenergy
Manuscript Draft

Manuscript Number: JBB-D-08-00609

Title: Improving the quality of wood for energy generation by controlling the storage conditions

Article Type: Research Paper

Section/Category:

Keywords: Storage time, Harvest season, Storage season, Particles size of wood fuel, Biomass species

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Manuscript Region of Origin:

Abstract: This paper aims to determine the properties affected by storage that increase the quality of wood fuel in Santa Catarina, Brazil. Logs with bark of Pinus taeda and Eucalyptus dunnii and edges of Pinus spp were used in this work. Materials were collected freshly, after two, four and six months of storage. Four lots were analyzed according to the season of the year. The analysis of moisture content, gross and net calorific value, chemical composition and ash content revealed that these properties are influenced by the storage time, the species, particle size and distribution of the wood fuel. Spring and summer were the best harvest and storage seasons. The best storage time

is from two to four months. Additionally, the particle size and distribution of wood fuel has more influence on the variation of physical and chemical properties than the species of the wood fuel.

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Please find enclosed our manuscript entiteled “**Improving the quality of wood for energy generation by controlling the storage conditions**“ by Martha Andreia Brand, Graciela Inês Bolzon de Muñiz, Waldir Ferreira Quirino and José Otávio Brito, which we wish to submit for publication in the journal of Biomass and Bioenergy.

Our work emerged from the need to improve the efficiency of the largest biomass-based energy generator of Latin America located in south Brazil.
Our results demonstrated that the control of storage conditions can improve the quality of wood fuel. Actually, our results were already applied in our plant and increased 30% the energy generation.
These result are original and have not been published elsewhere. We hope you find this manuscript suitable for publication.

Yours sincerely

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Improving the quality of wood for energy generation by controlling the storage conditions

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Abstract

This paper aims to determine the properties affected by storage that increase the quality of wood fuel in Santa Catarina, Brazil. Logs with bark of *Pinus taeda* and *Eucalyptus dunnii* and edges of *Pinus spp* were used in this work. Materials were collected freshly, after two, four and six months of storage. Four lots were analyzed according to the season of the year. The analysis of moisture content, gross and net calorific value, chemical composition and ash content revealed that these properties are influenced by the storage time, the species, particle size and distribution of the wood fuel. Spring and summer were the best harvest and storage seasons. The best storage time is from two to four months. Additionally, the particle size and distribution of wood fuel has more influence on the variation of physical and chemical properties than the species of the wood fuel.

Keywords

Storage time, Harvest season, Storage season, Particles size of wood fuel, Biomass species

1. INTRODUCTION

Logging residues that are comminuted, and burned directly after logging, suffer no changes in energy content [1]. However, its use in this condition is not ideal due to high moisture content that implicates in low energetic quality.

Studies of the storage of wood originated from forest operations have demonstrated that the transformation of wood in chips or particles, followed by storage in piles, causes significant energetic losses [2]. Storage in uncomminuted form maintains the quality of the fuel. However, certain volumes of wood fuel have to be stored in the form of chips [3].

While analyzing studies that evaluated the effect of storage on the wood fuel energetic variations [1,4,5], it became noticeable that the factors that influence the energetic alterations include: size of the particles and the way the wood fuel is stored; location and time of storage; moisture content in the moment of the piles are made and during the storage period; storage season; species of the trees and also the different methods of pile preparation.

Studies that evaluated the characteristics of the wood destined for energy generation [3-11] and that consider storage as a factor related to the energetic gain of wood fuel [1-7,9,12,13] list the following variables to be analyzed in storage experiments: chemical composition (elementary and immediate); moisture content; basic density – considering in this variable the loss of mass by physical, chemical and biodegradation effects; size of the particle (granulometry); calorific value; ash content; and wood species.

Regarding the chemical properties, [11] affirm that the elementary chemical composition is a very important characteristic of the biomass used as fuel. This is due to the fact that it constitutes the base for the analysis of the combustion processes such as the calculation of the air volume necessary for combustion, quantity of gases generated and enthalpy. By knowing this property, the calorific value of the fuel can also be determined and an evaluation of the environmental impact by burning of biomass can be made.

The influence of the storage method in the chemical composition of particles of forest residues was evaluated by JIRJIS [13]. In this study, the most prominent changes of the wood fuel were related to microbial activity and heating.

The decomposition by microorganisms and chemical oxidation processes causes a buildup of heat, carbon dioxide and water to occur [4]. Piles of chipped wood accumulate heat and, under certain conditions, self-ignition can occur and if the water produced by the decomposition does not evaporate, the moisture content of the material increases, resulting in a raise of the costs of drying.

Moisture is a very important variable when considering the energetic potential of the wood because it has the greatest influence on the energetic variation of the material [3,7-9]. This occurs because moisture decreases the useful energy for generation systems by reducing the net calorific value.

The moisture content of wood fuel, being very irregular, can make the combustion process difficult, causing a need of constant adjustments in the air admission system of the equipments [14]. The variation of the moisture content of the material that enters the combustion system is also one of the main factors accountable for the appearance of comminuted material, usually carbon, together with gases produced during the burning. Such particles, resulting from the partially burned material, can cause environmental pollution problems. Therefore, the advantage of eliminating and standardizing the quantity of water in wood fuel is quite evident.

Thörnqvist [4] concluded that, regarding moisture content, dryer materials have a smaller variation and energetic loss during storage. On the other hand, a raise of the moisture content, the energetic loss increases of to a certain point and then begins decreasing [1].

During the storage of forest fuels, moisture content affects primarily the heat value of fuel, matter loss and amount of microfungal spores. The effective heat value and matter loss directly influence the fuel's energy content [1]. For this reason, it is important to avoid that the moisture content of the chips is increased during storing in order to reduce the moisture content of the chips as much as is economically feasible and develop furnaces having a flat efficiency curve and tolerating a high critical moisture content.

Along with the dissimilarity of the moisture content, the common problems of wood storage include dry matter loss [2,4]. However, THÖRNQVIST [1] affirms that the energy content and energy quality of forest residues are strongly dependent on these two variables during the storage period.

The goal of this work is to analyze the influence of the harvest season and storage season, storage time and type of wood fuel (species, particle size and shape of the material) on the physical and chemical properties of the wood with bark destined to energy generation in order to obtain a view of the effect of storage on the quality of the wood fuel destined to energy generation.

2. METHODOLOGY

In this work, logs with bark of the species *Pinus taeda* L. and *Eucalyptus dunnii* Maid. with various diameters between 8 to 40 cm and average length of 2.4m were used. Besides the logs, edges of the species *Pinus spp.*, either containing bark or not, with average length of 2m were also used. The study was carried out in the city of Lages, in the state of Santa

Catarina, Brazil, between October 2003 and February 2005. The meteorological data of the period of the study are presented in Table 1.

INSERT TABLE 1

In order to evaluate the harvest season, samplings were carried out in October 2003 (lot 1), January (lot 2), May (lot 3) and August 2004 (lot 4). Regarding the storage season, each lot remained stored for the period of six months. The samples of freshly harvested wood fuel with two, four and six months of storage were collected for analysis (Table 2).

INSERT TABLE 2

The logs of *Pinus* and *Eucalyptus* and the edges of *Pinus* were stored in different piles with average dimensions of 6m of length, 2.5m of width, 2.5m of height, and approximate volume of biomass of $10m^3$. A space of 3.5m was left between one pile and another, in order to facilitate sampling and propitiate aeration.

The piles were built so that the length of the logs remained in the East-West direction, so that there would be maximum solar radiation on the surface of logs, according to HILLEBRAND [16].

In each sampling, logs with bark and edges that were in the base, middle and top of the piles were collected. Without removing the bark, the logs and edges were transformed into chips. The determination of the physical and chemical properties of the wood fuel was carried out on these chips.

The moisture content in the wet base was verified in the chips after cutting of the logs, being determined by the weight difference between the wet material received for analysis and after drying in a stove at 103 ± 2°C until reaching constant weight.

For the chemical analysis, the chips were dried and transformed in sawdust according to the TAPPI 257 Norm (Sampling and preparing wood for analysis) and TAPPI 264 Norm (Preparation of wood for chemical analysis including procedures of removal of extractive and determination of moisture content). After this preparation, the cold and hot water solubility of wood, sodium hydroxide of wood and ash content were determined (TAPPI T-207 - Water solubility of wood and pulp; TAPPI 212 - One percent sodium hydroxide solubility of wood and pulp; TAPPI 211 - Ash in wood, pulp, paper and paperboard: combustion at 525ºC). The chemical composition was included in this work because the quantity of extractives obtained in different seasons and periods of storage can indicate chemical alterations occurred in the wood fuel due to storage [17-21].

The gross and net calorific values in the wet base (net calorific value) were determined using an IKA Model 2000 bomb calorimeter and the DIN 51900 Norm (Determining the gross calorific value of solid and liquid fuels using the bomb calorimeter, and calculation of net calorific value) [22]. The net calorific value was obtained in the bomb calorimeter by analyzing the moisture content in the wet base, ash content and percentage of hydrogen of the sample, which was standardized in 6%.

The statistical analysis of the data was carried out through the ANOVA/MANOVA, being that the F test was used to verify the significant variation to the level of 95%. The confirmation of the variation was carried out using the Tukey Test.

3. RESULTS AND DISCUSSIONS

3.1 Harvest and storage season

The properties of the wood fuel, according to the harvest season, can be visualized in Table 3.

INSERT TABLE 3

Harvest season had a significant influence on the variation of the following properties: moisture content, net calorific value and sodium hydroxide solubility of wood.

The properties affected by the harvest season are directly related to the metabolic intensity of the trees in relation to the growth season. Thus, during spring and summer, in spite of the fact that the moisture content is lower, the quantity of metabolites is higher, which is indicated by superior values of extractive solubility. This tendency was also observed in the properties that did not have a significant statistical variation (cold water solubility and ash content). The gross calorific value, in spite of having presented a significant variation, also had a tendency to increase during spring and summer.

Therefore, the harvest season had a positive influence on the wood fuel in the summer and spring and a negative influence in the autumn and winter, considering the energetic use immediately after the harvest. However, considering that the moisture contents were high independently of the harvest season, the use of wood fuel immediately after the harvest is not recommended because the useful energy for the generation system will be low.

Table 4 demonstrates that the results obtained regarding the influence of the storage season on the properties of wood fuel are important for energy generation.

INSERT TABLE 4

The storage season had significant influence on the following properties: moisture content, net calorific value, cold and hot water solubility of wood and sodium hydroxide solubility of wood.

As occurred with the harvest season, the storage season also influenced the stored wood fuel positively in the summer and spring and negatively in the autumn and winter.

Therefore, the best periods for storage were between the months of October and May and between August and February. In these storage conditions, certain conditions in the wood fuel properties were obtained that improved its performance regarding energetic use, mainly related to moisture content and net calorific value. For this reason, if the wood fuel is collected in the end of the winter or spring and remains stored during the summer, it will have a better performance of energy generation.

However, the harvest and storage season can't always be used as tools for storage control. This occurs because many times market issues such as the demand and offer of wood fuel will determine the harvest season and whether the material be stored or not, independently of the time of the year.

3.2 Storage time

The results obtained in this work, as illustrated on Table 5, demonstrate that the storage time had influence on the moisture content, net calorific value, cold and hot water solubility of wood and sodium hydroxide solubility of wood. The ideal storage time was four months, time in which the lowest values of moisture content and highest values of gross calorific value were observed.

INSERT TABLE 5

However, BRAND [23] correlated the storage time with season and concluded that the ideal time can vary from two to four months, depending on the period in which the wood fuel is stored.

Moreover, the storage time had a significant influence on moisture content, net calorific value, cold and hot water solubility of wood and sodium hydroxide solubility of wood, not affecting the alterations occurred on the gross calorific value and ash content.

Another important aspect is that in periods of over four months, the moisture content increases again and the biodegradation processes begin, which is indicated by a small increase of the sodium hydroxide solubility. This behavioral tendency was similar to the one observed by THÖRNQVIST [1,4]. However, in this study, the moisture contents at the end of six months did not equal the initial values.

3.3 Species, particle size and shape of the wood fuel

In order to analyze the effect of the species, particle size and shape of the stored wood fuel, the results presented are correlated with storage time (Table 6).

The species, particle size and shape of the wood fuel (logs or edges) had an influence on moisture content, gross and net calorific value, hot water solubility of wood, sodium hydroxide solubility of wood and ash content.

Regarding the species, this variable only had influence on the gross calorific value and ash content, while the particle size and shape of the wood fuel had an influence on the moisture content and net calorific value.

When comparing the wood fuel in shape of logs and edges of the species *Pinus spp.* in different storage times, it could be concluded that storage had a more positive effect on the edges. This occurred because the more aeration in the pile, along with the larger superficial area of wood with the environment caused a greater and faster loss of moisture in the edges. However, this same reason accelerated the chemical reactions of transformation and loss of extractives, thus changing the chemical composition, which, at the end of six months of storage, started the biodegradation process. This aspect was confirmed by the higher values of moisture content, hot water solubility and sodium hydroxide solubility observed at the end of the storage period, as demonstrated in Table 6.

The edge of *Pinus* was the material that lost more moisture during storage, followed by *Eucalyptus*; with more alteration on the chemical composition, chemical reactions and biodegradation and had a greater gain of useful energy available for the combustion systems (net calorific value).

The interaction effect between the species, type of wood fuel and storage time also demonstrated that the ideal storage time varied in relation to the species and type of wood fuel. Two months of storage were necessary for the edge to reach the minimum moisture content necessary for a satisfactory combustion performance, while for the logs of *Pinus* and *Eucalyptus*, at least four months were necessary.

The highest values of gross calorific value and ash content on the logs of *Pinus,* in comparison with the edges of *Pinus*, can be attributed to a higher quantity of bark on the logs in comparison with the edges.

INSERT TABLE 6

4. CONCLUSIONS

Harvest and storage seasons

The harvest and storage seasons influenced the moisture content, net calorific value and chemical composition.

The best seasons for collecting the wood fuel were spring and summer and the best seasons for storage were between October and May and between August and February (spring and summer in the region studied).

The use of recently harvested wood fuel is not recommended for energy generation due to high moisture content, which contributes directly for the decrease of useful energy for generation systems.

Storage time

Storage time had influence on the moisture content, chemical composition and net calorific value of the wood fuel.

The storage time might vary from two to four months depending on the period of the year in which the storage is carried out and the size and shape of the wood fuel.

Species, particle size and shape of the wood fuel

The species, size and shape of the wood fuel had an influence on the properties of wood fuel submitted to storage.

The shape of the material had a greater influence on the variations of the wood fuel properties during storage than the species.

The wood fuel with the best behavior during storage was the edge of *Pinus*.

Acknowledgements

Authors thank the financial support from CAPES, CNPq, EPAGRI, Klabin and Tractebel Energia.

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Table

Tables

Table 1. Climatic conditions of the Lages region – October 2003 to February 2005

DATA	YEAR																
	2003			2004												2005	
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Rainfall (mm)	119	94	225	81	114	144	82	103	28	233	52	278	162	104	136	147	47
Temperature (ºC)	18	19	20	21	21	20	19	13	13	12	14	17	17	19	20	22	22
Relative Moisture (%)	76	72	79	78	76	77	83	85	82	84	77	82	75	76	76	76	75

SOURCE: Empresa de Pesquisa Agropercuária e Extensão Rural de Santa Catarina - EPAGRI [15]

NOTE: The total rainfall of 2004 was 1517mm and the averages of temperature and relative moisture were 17°C and 79%, respectively.

The data presented reflect the climatic conditions of typical years of the region.

Table 2. Experimental design of the storage of wood fuel in relation to harvest and storage seasons

Lots	1	2	3	4
Harvest season	October/2003 to May/2004	January/2004 to August/2004	May/2004 to November/2004	August/2004 to February/2005
Sampling months	October	January	May	August
	November	April	June	October
	March	June	September	November
	May	August	November	February

Table 3. Physical and chemical properties of the wood with bark in relation to the harvest season

VARIABLE	HARVEST SEASON			
	October/2003	January/2004	May/2004	August/2004
Moisture content (%)	52a	53ab	59c	57bc
Gross calorific value (kcal/kg)	4699a	4719a	4674a	4664a
Net calorific value (kcal/kg)	1790a	1774a	1422b	1513b
Cold water solubility of wood (%)	2.85a	2.71a	2.63a	2.04a
Hot water solubility of wood (%)	3.75a	3.87a	2.05a	3.05a
Sodium hydroxide solubility of wood (%)	16.98a	16.27a	12.94b	12.64b
Ash content (%)	0.59a	0.57a	0.51a	0.49a

NOTES: The values represent the average of the results obtained before storage of wood fuel (logs of *Pinus taeds* and *Eucalyptus dunnii* and edges of *Pinus spp.*) without distinguishing species or particle size.

Averages followed by the same letter do not differ statistically (Tukey Test, P>0.05).

Table 4. Physical and chemical properties of the wood with bark in relation to the storage season

VARIABLE	STORAGE SEASON			
	October/2003 to May/2004	January/2004 to August/2004	May/2004 to November/2004	August/2004 to February/2005
Moisture content (%)	39ac	48ab	48b	38c
Gross calorific value (kcal/kg)	4709a	4688a	4736a	4735a
Net calorific value (kcal/kg)	2483a	1974b	2023b	2508a
Cold water solubility of wood (%)	2.60ab	2.70ab	2.75a	1.98b
Hot water solubility of wood (%)	4.09a	3.36ab	3.13b	2.94b
Sodium hydroxide solubility of wood (%)	15.39a	12.54b	11.56b	12.35b
Ash content (%)	0.53a	0.50a	0.49a	0.65a

NOTES: The values represent the average of the results obtained for the stored wood fuel (logs of *Pinus taeda* and *Eucalyptus dunnii* and edges of *Pinus spp.*) without distinguishing species or granulometry.

Averages followed by the same letter do not differ statistically (Tukey Test, P>0.05).

Table 5. Physical and chemical properties of wood with bark in relation to storage time

VARIABLE	STORAGE TIME			
	Recently harvested	2 months	4 months	6 months
Moisture content (%)	56a	44b	33c	38bc
Gross calorific value (kcal/kg)	4686a	4729a	4724a	4739a
Net calorific value (kcal/kg)	1611a	2197b	2756c	2524bc
Cold water solubility of wood (%)	2.55a	3.68b	2.00ac	1.74c
Hot water solubility of wood (%)	3.24a	4.22b	3.11a	2.96a
Sodium hydroxide solubility of wood (%)	14.56a	12.46b	12.34b	12.64b
Ash content (%)	0.54a	0.60a	0.45a	0.60a

NOTES: The values represent the average results obtained for the stored wood fuel (logs of *Pinus taeda* and *Eucalyptus dunnii* and edges of *Pinus spp.*) without distinguishing species or granulometry.

Averages followed by the same letter do not differ statistically (Tukey Test, P>0,05).

Table 6. Physical and chemical properties of the wood with bark in relation to the type of wood fuel and time of storage

Variable/Wood Fuel	Recently harvested	Two months	Four months	Six months
Moisture content on the wet base (%)				
Logs of *Pinus*	59a	58a	46a	51a
Edges of *Pinus*	54a	28c	15c	28b
Logs of *Eucalyptus*	54a	43b	34b	32b
Cold water solubility of wood (%)				
Logs of *Pinus*	2.09a	3.46a	1.86a	1.62a
Edges of *Pinus*	2.14a	3.91a	1.87a	1.85a
Logs of Eucalyptus	3.31a	3.72a	2.23a	1.78a
Hot water solubility of wood (%)				
Logs of *Pinus*	3.03ab	4.03a	2.72a	2.15a
Edges of *Pinus*	2.08b	4.42a	3.26a	4.09b
Logs of *Eucalyptus*	4.32a	4.25a	3.39a	2.93ab
Sodium hydroxide solubility of wood (%)				
Logs of *Pinus*	14.24ab	11.72a	11.86a	11.73a
Edges of *Pinus*	12.43b	11.72a	11.97a	13.81a
Logs of *Eucalyptus*	16.49a	13.76a	13.08a	12.67a
Gross calorific value (kcal/kg)				
Logs of *Pinus*	4788a	4806a	4839a	4792a
Edges of *Pinus*	4743a	4779a	4715b	4845a

Logs of *Eucalyptus*	4542b	4615b	4616c	4606b
Net calorific value (kcal/kg)				
Logs of *Pinus*	1479a	1545c	2198b	1875b
Edges of *Pinus*	1741a	3056a	3674a	3093a
Logs of *Eucalyptus*	1646a	2204b	2624b	2746a
Ash content (%)				
Logs of *Pinus*	0.45ab	0.41b	0.39b	0.43b
Edges of *Pinus*	0.34b	0.31b	0.31b	0.35b
Logs of *Eucalyptus*	0.78a	1.02a	0.61a	0.97a

Note: Averages followed by the same letter do not differ statistically (Tukey Test, P>0,05). The data must be observed using the COLUMN of the Table (Variation between the types of wood fuels evaluated).