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STORAGE AS A TOOL TO INCREASE THE QUALITY OF WOOD FUEL

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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 moisture content, gross and net calorific value, chemical changes and ash content were the properties analyzed. The results showed that the factors that affect the storage are: the harvest season and the storage season, the storage time, the species, particle size and distribution of the wood fuel. The properties affected are: moisture content, net calorific value and chemical composition of wood fuel. Storage is an excellent tool for improving the quality of wood fuel. Spring and summer are the best harvest times and storage seasons. It's best storage time is from two to four months. 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

The use of wood fuel immediately after the harvest implicates in low energetic efficiency, mainly due to the material's high moisture content. This variable, together with low values of specific mass and calorific value contribute for the devaluation of this resource when compared to other energy sources.

However, these disadvantages can be minimized through treatments that affect these properties positively and make the wood fuel more competitive in the processes of energy generation. One of these treatments is the storage operation, which brings significant results for the improvement of the wood fuel used in energy generation if conducted with the control of the factors that affect and are affected by this procedure.

In this context, the main factors that can affect storage are: the time of the year in which it is carried out, the season in which the wood fuel is harvested, how much time the wood fuel remains stored, the location in which the operation is carried out (forest, dock, industry patio, etc) and also the species, particle size and shape of the material stored.

The factors that can be affected by storage are related to intrinsic properties of the wood fuel, such as moisture content, basic density, calorific value and wood chemistry. These properties all have an impact on the use of the wood fuel for energy generation.

Therefore, considering the aspects previously mentioned, the goal of this work is to analyze the influence of the harvest season, 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 submitted to storage. The results obtained demonstrate the variations on properties such as moisture content, wood chemistry, gross and net calorific value and ash content of the material analyzed. Thus, a general view of the effect of storage on the quality of the wood fuel destined to energy generation is demonstrated.

Moreover, the combined analysis of these factors indicates the most efficient storage procedures, aiming a better productivity of the wood fuel in systems of energy generation.

2. BIBLIOGRAPHICAL REVIEW

Logging residues that are comminuted and burned directly after logging suffer no changes in energy content (THÖRNQVIST, 1984b). However, usage in this condition is not ideal due to the fact that the high moisture content of the recently produced material 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 (THÖRNQVIST (1988), NURMI (1990); THÖRNQVIST (1987), quoted by NURMI (1995). 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 at least as a buffer (JIRJIS, 1995).

While analyzing studies that evaluated the effect of storage on the wood fuel's energetic variations (THÖRNQVIST, 1984a, 1984b, 1985, 1986), 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.

The factors that are influenced by storage are related to the chemical and physical properties and characteristics of the wood fuel submitted to this operation. Woody biomass used for energy comprises many types of material that differ widely in physical and chemical properties (JIRJIS, 1995).

Studies that evaluated the characteristics of the wood destined for energy generation (BRITO and BARRICHELO (1982), THÖRNQVIST (1985, 1986, 1988), NURMI (1992), JIRJIS (1995), MARTIN (1997), GARSTANG *et al* (2002), NOGUEIRA and LORA (2003) and TEIXEIRA and LORA (2004)) and that consider storage as a factor related to the energetic gain of wood fuel (HEDING (1984), THÖRNQVIST (1984a, 1984b, 1985, 1986, 1988), NURMI (1990, 1992, 1995), GARSTANG *et al* (2002) and JIRJIS (1995, 2005)) list the following as 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; size of the particle (granulometry); calorific value; ash content; and wood species.

Regarding the chemical properties, TEIXEIRA AND LORA (2004) 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 acknowledging this property, the calorific value of the fuel can also be determined and an evaluation of the environmental impact of the burning of the biomass can be made.

The influence of the storage method in the chemical composition of particles of forest residues was evaluated by JIRJIS and THEANDER (1990), and quoted by JIRJIS (1995). In this study, the most prominent changes of the wood fuel were related to microbial activity and heating.

According to THÖRNQVIST (1982), and quoted by THÖRNQVIST (1985), decomposition by microorganisms and chemical oxidation processes causes a buildup of heat, carbon dioxide and water to occur. Piles of chipped wood accumulate heat and, under certain conditions, self-ignition can occur. Still according to THÖRNQVIST (1985), 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.

Humidity 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 (BRITO and BARRICHELO (1982), NURMI (1992), JIRJIS (1995), MARTIN (1997) and GARSTANG *et al* (2002)). This occurs because humidity decreases the useful energy for generation systems by reducing the net calorific value.

The moisture content of the fuel, being very irregular, can make the combustion process difficult, mainly in what regards its control, causing a need of constant adjustments in the air admission system of the equipments (VLASSOV, 2001). 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 fuel's quantity of water is quite evident (BRITO and BARRICHELO, 1982).

Considering this context, THÖRNQVIST (1984b) affirms that the main cause of "change is almost always originated by the moisture content of the material". An absolute dry material usually doesn't change.

THÖRNQVIST (1982), THÖRNQVIST and GUSTAFSSON (1983), quoted by THÖRNQVIST (1985) 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 (THÖRNQVIST, 1984b).

During the storage of forest fuels, moisture content affects primarily the fuel's heat value, matter loss and amount of microfungal spores. The effective heat value and matter loss directly influence the fuel's energy content (THÖRNQVIST, 1984b). 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 (HEDING, 1984).

NYLINDER and THÖRNQVIST (1981), quoted by THÖRNQVIST (1985) and NURMI (1995) agree that, along with the dissimilarity of the moisture content, the common problems of wood storage include dry matter loss. However, THÖRNQVIST (1984b, p. 17) affirms that the energy content and energy quality of forest residues are strongly dependent on these two variables during the storage period.

Therefore, the analysis of the physical and chemical properties of the wood fuel can be used to determine the most adequate forms of storage in terms of time, such as the most appropriate season for this operation, as well as in terms of evaluating the behavior to storage of different species and sizes of particles.

3. METHODOLOGY

In this work, logs with bark of the species *Pinus taeda* L. and *Eucalyptus dunnii* Maid. with various diameters[1] and average length of 2.4m were used. Besides the logs, edges[2] 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.

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 Humidity (%)	76	72	79	78	76	77	83	85	82	84	77	82	75	76	76	76	75

SOURCE: EPAGRI
NOTE: The total rainfall of 2004 was 1517mm and the averages of temperature and relative humidity were 17ºC and 79%, respectively.
The data presented reflect the climatic conditions of typical years of the region.

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, being that samples of freshly harvested wood fuel with two, four and six months of storage were collected for analysis (Table 2).

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 November March May	January April June August	May June September November	August October November February

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 10m³. Between one pile and another, a space of 3.5m was left, 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 logs' surface, according to HILLEBRAND *et al.*'s (1999) orientation.

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.

[1] The diameters of the logs used in the study varied between 8 to 40cm. This variable was not controlled in the study.

[2] Edge is the name given to pieces shaped in half-moon, obtained in the transformation of logs into blocks or semi-blocks by using primary unroll saws.

The moisture content in the wet base was verified in the chips after the 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℃ until reaching const ant 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 evaluation of the wood's quantitative 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.

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). 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.

4. RESULTS AND DISCUSSIONS

4.1 Harvest and storage season

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

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 for the stored 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).

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 didn't 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 the results obtained regarding the influence of the storage season on the wood fuel's properties important for energy generation.

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).

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, it could be demonstrated 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's 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.

4.2 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 of four months, time in which the lowest values of moisture content and highest values of gross calorific value were observed.

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).

However, BRAND (2007) correlated the storage time and 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 (1983, 1984b and 1985). However, in this study, the moisture contents at the end of six months did not equal the initial values, as observed by the author.

4.3 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, as demonstrated in 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 greater aeration in the interior of the pile, together with the larger superficial area of exchange with the environment caused a greater and faster loss of humidity in the edges. However, this same reason provided higher speed of the chemical reactions of transformation and loss of extractives, thus generating a greater chemical alteration, which, at the end of six months of storage, culminated with the beginning of the biodegradation process. This aspect was confirmed by the higher values of moisture content, hot water solubility and sodium hydroxide solubility observed in the end of the storage period, as demonstrated in Table 6.

The edge of *Pinus* was the material that lost most humidity during storage, followed by the *Eucalyptus*; it suffered greater 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.

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).

5. CONCLUSIONS

5.1 Harvest and storage seasons

The harvest and storage seasons had an effect on the properties of the wood fuel used for energy generation, being that the affected properties were: 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 the months of 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.

5.2 Storage time

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

The ideal storage time is four months, being that it may 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.

5.3 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's properties during storage than the species.

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

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