Storage and Fuel Quality of Coniferous Wood Chips

Miloš Gejdoš,[a,]* Martin Lieskovský,[a,]* Martin Slančík,[a] Miroslav Němec,[b] and Zuzana Danihelová [c]

Wood chips from Norway spruce (*Picea abies* L.) and silver fir (*Abies alba* L.) were stored for a period of 15 months (experimental pile was 4.0 m high). Atmospheric temperature and the temperature inside the pile at heights of 1, 2, and 3 m were measured in regular intervals. Samples were taken from an assortment of heights at the beginning and the end of the experimental period. Subsequently, the samples were subjected to an analysis of moisture content and other properties such as calorific value (according to the standard STN ISO 1928:2003 and ÖNORM M 7132) and ash content (according to the standard STN ISO 1171). The most significant decrease in the chips' moisture content, and increase in the calorific value from the beginning of storage, was at the height of 1.0 m. An increase in the moisture content and decrease in calorific value was recorded for samples taken from the height of 3.0 m. Samples taken from this height showed an increase in ash content after a 15-month storage period. The experiment described the influence of specific weather conditions on the development of temperature, calorific value, and ash content of coniferous wood chip piles with particle size up to 35.5 mm.

Keywords: Wood chip; Moisture content; Biomass storage; Calorific value; Ash content

Contact information: a: Department of Forest Harvesting, Logistics and Ameliorations, Technical University in Zvolen, Faculty of Forestry, T.G. Masaryka 24, Zvolen, 960 53, Slovakia; b: Department of Physics, Electrical Engineering and Applied Mechanics, Technical University in Zvolen, Faculty of Wood Sciences and Technology, T.G. Masaryka 24, Zvolen, 960 53, Slovakia, c: The Institute of Foreign Languages, Technical University in Zvolen, T. Masaryka 24, Zvolen 960 53
** Corresponding author: gejdos@tuzvo.sk*

INTRODUCTION

Forest biomass in the form of wood chips is a renewable source of energy. Immediate utilisation of biomass from wood residue is not always possible for various reasons. The majority of heat energy suppliers in Slovakia have installed technologies that require high quality wood chips. They focus mainly on the moisture content and calorific value of the fuel, mainly because of their effects on the final price. These two basic properties can also be influenced by the method and length of storage (Thörnqvist 1985; Lehtikangas and Jirjis 1998; Afzal *et al.* 2010). In the course of the first year of storage, biomass energy loss can range from 25% to 55%, caused by an increase in the relative moisture and degradation of stored chips (Thörnquist and Lundström 1982; Huber 2009). Wood chips in larger plants are stored mainly in high-capacity containers or piles.

Studies have shown that the air flowing into the piles is limited already during the creation of piles, which are 3 m high or more. This subsequently causes an increase in temperature, which in some cases also increases the moisture content inside the pile (Jirjis 1995, 2001; Afzal *et al.* 2010). The development of these basic parameters is influenced mainly by atmospheric conditions in the wood chip storage location. Known results have demonstrated that storing wood chips in piles covered by a sheet or industrial fabrics can influence the moisture content significantly (White *et al.* 1983; Thornqvist 1985; Sampson and McBeath 1987; Afzal *et al.* 2010; Barontini *et al.* 2014).

Wood chips are likely to degrade under the action of biotic agents, which negatively influence human health (Suchomel *et al.* 2014). Analyzing storage from the aspect of potential risk, the length of storage is also extremely important. Many research studies have been aimed at the analyses of the quantitative parameters of wood chips, and such studies have been carried out in small experimental piles, and in most cases with deciduous or fast-growing wood species (White *et al.* 1983; De Toro *et al.* 1994; Idler *et al.* 2005 Jirjis *et al.* 2008). Few research studies have dealt with the analysis of those parameters in the storage of wood chips using coniferous wood species in large piles (Nurmi and Hillebrand 2002).

The main aim of the present work was to determine the impact of specific weather conditions in Central Slovakia (atmospheric temperature, amount of precipitation) on the temperature changes, calorific value, and ash content in the piles of energy wood chips (of more than 100 tons). The research studied wood chip piles of Norway spruce (*Picea abies* L.) and silver fir (*Abies alba* L.) with the particle size up to 35.5 mm and storage longer than 1 year. A further aim was to compare the obtained results with research studies of other authors studying different wood species and different storage conditions. The results should provide information on the influence of specific weather conditions on the quantitative parameters of wood chips of Norway spruce and silver fir with the particle size up to 35.5 mm. This comparison can provide important information about the calorific value and ash content during a long-term storage of specific wood species.

EXPERIMENTAL

Materials

An experimental pile of wood chips was created during the period from 20 to 23 January 2012 from the wood species Norway spruce (*Picea abies* L.) and silver fir (*Abies alba* L.). The biomass of these wood species was changed into wood chips immediately after harvesting (not during the growing season). Whole trees, including the assimilation organs (needles), were chipped. A wood chip pile in the shape of a frustum was created and placed on a base sheet (waterproof woven plastic sheet) with the dimensions of 12 m x 14 m. The pile contained 163.5 tons of wood chips (68.7 tons of dry matter) altogether with total height of 4.0 m. The pile was located within the confinements of a heating plant in the town of Hriňová, Slovak Republic.

Monitoring the temperatures inside the pile was carried out using the KCP-150P temperature probes placed at the heights of 1.0 m, 2.0 m, and 3.0 m. Each probe was connected to "Datalogger" serving for storing the data in one-hour intervals. The capacity of the Datalogger is 10,000 recorded data points. The experiment was conducted from 1 February 2012 to 2 May 2013 (456 days). At the end of the experiment, the pile was gradually carried away by lorries, and every lorry was weighed; altogether, 148.3 tons were carried away.

Fig. 1. Experimental pile

Sampling Technique

One sample was taken from each height at the beginning of the experiment (T_0) and at the end of the experiment (T_{15}). Altogether 6 samples were taken. Standard methods were used to measure the various biomass properties (Afzal *et al.* 2010). The samples were also used to determine the moisture content by drying and reweighing the sample (Jirjis 2005; Afzal *et al.* 2010). The samples were dried at the temperature of 105 °C ± 2 °C until they reached a constant weight.

After reweighing the samples using laboratory scales with an accuracy of 0.01 g, the values of relative moisture content of the wood chips were calculated. The relative moisture content at the individual sampling heights was calculated as the ratio of water weight contained in the samples to the weight of wet samples, and it was expressed as a percentage.

The calorific value of the material (calorific value in MJ/kg) was determined by the bomb calorimeter IKA C200 using the standard ignition method STN ISO 1928:2003 and ÖNORM M 7132, and the ash content was determined using the standard ignition method STN ISO 1171. The ratio of the particle size in the pile was determined according to the standard STN 48 0057. The basic granulometric analysis of wood chips was carried out *via* sieving methods using an AS 200 vibratory sieve shaker (RETSCH), *i.e.*, sieving the wood chips through a set of sieves with 50 mm, 32 mm, 25 mm, 11.2 mm, and 5 mm mesh sizes.

Microbiological identification of fungi in samples was performed by examination (ISO 21527-2) in the accredited laboratory of the Regional Public Health Authority in Poprad. Exact methodology of laboratory analyses for fungi identification is described in the study (Suchomel *et al.* 2014). Fungal identification was carried out using samples taken from all height of the pile at the end of the experiment.

Weather Conditions

The temperature and relative air humidity were recorded during every day of storage at one-hour intervals using a meteorological station located in the area of the storage piles (at the distance of 3 m from the pile). The air temperature during the 456 days fluctuated between -22.0 °C (3 February 2012) to 42.0 °C (5 July 2012). The relative air humidity ranged from 98% (multiple days) to 30.3% (26 March 2012), with an average of 70.8% (Fig. 2).

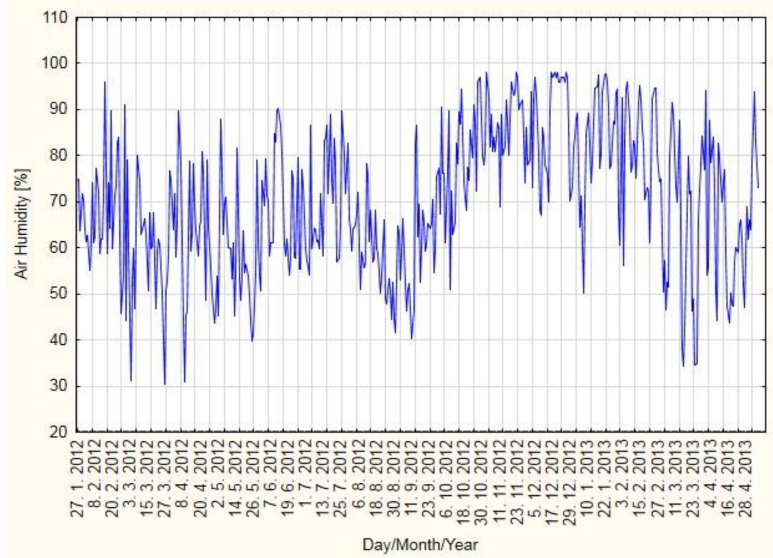

Fig. 2. Ambient air humidity during the storage period

RESULTS AND DISCUSSION

Heat Development in Pile

The temperature range inside the experimental pile and the air temperature are illustrated in Fig. 3. The median temperatures were dependent on the sampling height (1.0 m, 2.0 m, or 3.0 m). In the pile, the median temperature values ranged between 60.6 °C (1.0 m above ground) and 61.3 °C (3.0 m above ground). After an initial period of significant warming, the pile height influenced the temperature inside the pile by less than 1 °C. The minimum temperatures were recorded immediately after the beginning of the experiment, specifically in the first week after creating the storage pile. The maximum recorded temperatures were 63.4 °C at the height of 1.0 m (20 February 2013), 64.74 ° C at 2.0 m (27 June 2012), and 67.12 °C at 3.0 m (27th August 2012).

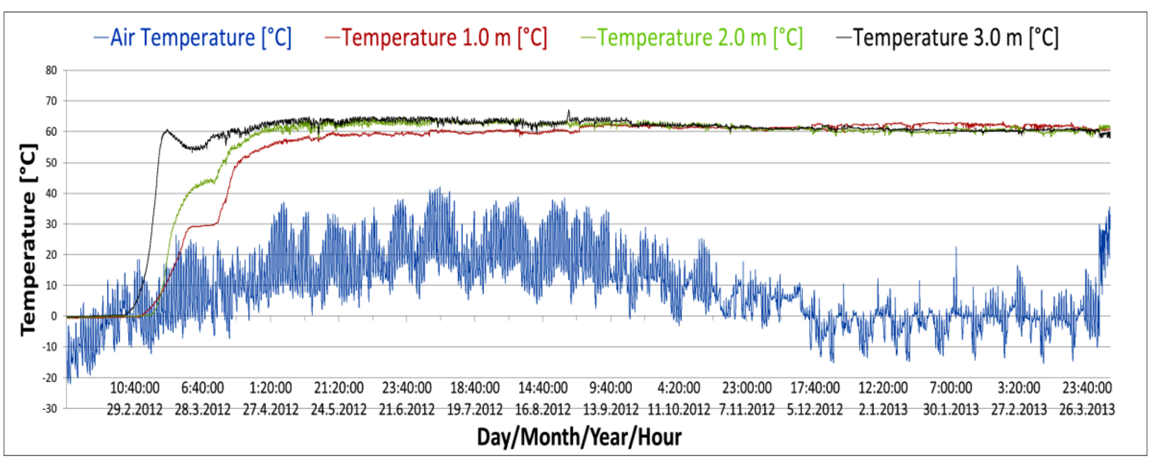

Fig. 3. Range of temperatures in the experimental pile and air temperatures

During storage, it was found out that the temperatures at the individual heights became equal 180 days after the pile was created. Similar periods of levelling the temperatures inside the wood chip pile from different wood species were recorded also in other studies (Manzone *et al.* 2013; Barontini *et al.* 2014).

Figure 3 shows that although the air temperature varied significantly, it did not affect the development of the temperature inside the pile during 6-month storage significantly. The results indicate that the temperature inside the pile at all heights increased to approximately the same level of 60 °C. Nevertheless, it did not affect the moisture content at individual heights of the wood chip pile.

Particle Size Distribution

The percentage of individual particle sizes in the experimental pile, determined according to the standard STN 48 0057, is illustrated in Fig. 4. The size of nearly 68% of all particles was 5 mm or less. The particle size was predominately influenced by chipping the whole trees and treetops. In the pile, there were no particles larger than 35.5 mm.

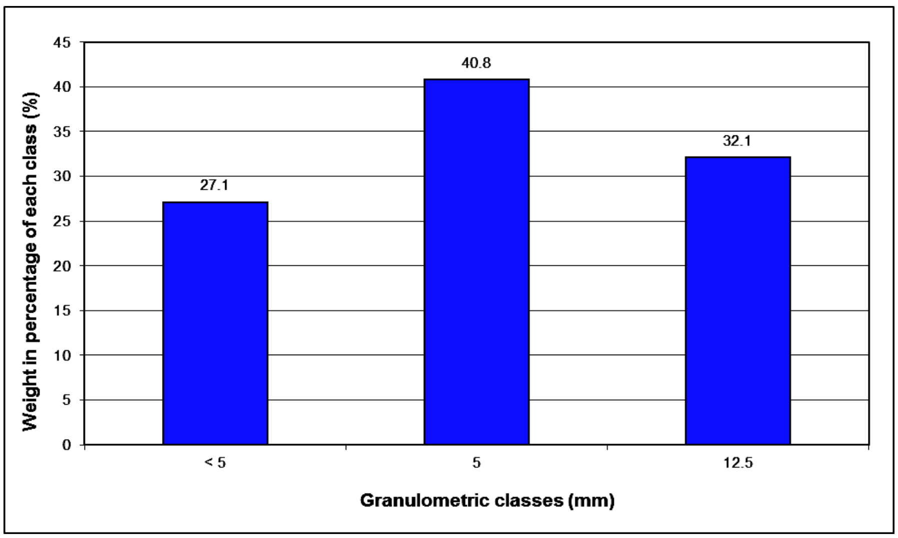

Fig. 4. Particle size distribution of wood chips

Changes in Moisture Content and Energy Content

Analysed samples between the heights of 1.0 and 2.0 m showed a decrease in the moisture content after a 15-month storage period (Table 1). The most significant fall in the moisture content during the experiment was recorded at the height of 1.0 m (13.9%). Typically, the greater the height, the lower the decrease in moisture content for coniferous wood chips. At the height of 2.0 m, the researchers recorded a 5.5% decrease in moisture content, and at 3.0 m there was an overall increase of 8.8% in moisture content. When comparing these findings with the research results of Afzal *et al.* 2010, who observed the storage effects of white birch (*Betula papyrifera* L.) wood chips stored in piles 3.0 m high over the course of one year, the decrease in moisture content for coniferous wood chips stored in a large pile is more significant. During an experiment with poplar wood chips (Barontini *et al.* 2014), the decrease in moisture content at the heights of 1.0 m, 2.5 m, and 3.5 m after 6-month storage represented the values 11.8%, 14.1%, and 16.1%, respectively (a detailed comparison and discussion about the results of studies of other authors can be seen in Table 3). During a storage experiment for spruce wood chips (*Picea abies* L.), the decrease in moisture content at the heights 0.5 m, 1.0 m, and 1.5 m was approximately 30.3 %, 27.9 %, and 25.4%, respectively (Suchomel *et al.* 2014).

The calorific value of coniferous wood chips was, at the beginning of the experiment, approximately 10 MJ/kg lower when compared to the calorific value of birch and poplar wood chips from available research studies (Afzal *et al.* 2010; Barontini *et al.* 2014). The most significant increase in the calorific value of coniferous wood chips occurred at the height of 1.0 m (increase of 2.960 MJ/kg), while at the height of 3.0 m and after 15-month storage the calorific value decreased by 1.761 MJ/kg (according to the standard STN ISO 1928).

For birch wood chips (Table 3), the most significant increase in the calorific value, after 1 year of storage, was recorded at the lowest height of an uncovered storage pile (1.770 MJ/kg). In the central and upper part of that pile, the calorific value decreased by 0.570 MJ/kg and 0.700 MJ/kg, respectively (Afzal *et al.* 2010).

If the pile has a pyramidal shape, the increasing height of the pile causes a decrease in the thickness of the pile. Therefore, the wood chips inside are influenced more by the atmospheric conditions, mainly air humidity, which can partially influence the energy values. The years 2012 and 2013 were exceptionally heavy in precipitation, and thus the effect of atmospheric precipitation on the moisture content of the wood chips stored in the upper part of the pile was significant. The moisture content and calorific value were also influenced by the particle size, which did not correspond to the standard quality requirements of this type of fuel according to the STN 48 0057 standard.

After completing the experiment, 2 species of fungi were identified in the samples (*Trichoderma viride, Penicillium* sp.). Both species pose a significant threat to human health. The production of dangerous toxins was confirmed also in genus *Penicillium* sp. causing also allergic reactions to some people (Fassati 1979). Genus *Trichoderma* sp. has been identified as the cause of infections in immunosuppressed individuals (Samuels *et al.* 2006).

Table 1. Moisture Content and Calorific Value in the Experimental Pile

Moisture Content (%)		
Sample height	**26th January 2012 (T_0)**	**2nd May 2013 (T_{15})**
1.0 m	58.0	44.1
2.0 m	56.7	51.2
3.0 m	57.1	65.9
Calorific value (MJ/kg) determined by STN ISO 1928		
1.0 m	6.472	9.431
2.0 m	6.770	7.973
3.0 m	6.647	4.886
Calorific value (MJ/kg) determined by ÖNORM M 7132		
1.0 m	6.346	9.310
2.0 m	6.787	7.850
3.0 m	6.645	4.758

Changes in Ash Content

In the lowest part of the pile, only a small change in ash content of wood chips (0.03%) was recorded after a 15-month storage period. In the higher parts of the wood chip pile, the ash content increased (in the most upper part there was an increase of 0.34%; Table 2). When storing birch and poplar wood chips for a longer period, the increase in ash content in mass percent was similar. For poplar wood chips, the ash content was increased after a 6-month storage by approximately 0.20% (Barontini *et al.* 2014), and for birch wood chips the ash content was increased by approximately 0.70% after 1 year (Afzal *et al.* 2010) (Table 3). The same increase was also recorded in the upper part of the pile.

Accordingly, one can conclude that in a bigger pile of coniferous wood chips, the calorific value would increase significantly in the lower parts of the pile, but the ash content in mass percent and calorific value would decrease slightly in the upper parts. These statements are also true for wood chips made from birch and poplar, whereby some differences were determined in the development of the calorific value and ash content (Afzal *et al.* 2010; Barontini *et al.* 2014).

Table 2. Ash Content in Different Parts of Experimental Pile

Ash Content (%)		
Sample height	**26th January 2012 (T_0)**	**2nd May 2013 (T_{15})**
1.0 m	1.36	1.39
2.0 m	1.49	1.58
3.0 m	1.30	1.64

Environmental factors also influenced ash content. Due to the accumulation of dust particles drifted in by the wind onto the chip pile, the ash content could increase significantly (Afzal *et al.* 2010). This factor could have been more significant because of the location of the experimental pile directly in the area of a heating plant.

Table 3. Comparison of Experiment Results with Results of Other Authors

Characteristics	***Picea abies, Abies alba***	***Populus x canadensis* M.** (Barontini *et al.* 2014)	***Betula papyrifera* (pile 3m high)** (Afzal *et al.* 2010)
Sample height (m)	1.0	1.0	bottom
	2.0	2.5	centre
	3.0	3.5	top
Particle size (mm)	2 – 35.5	8 - 45	2 - 25
Storage period (month)	15 month	6 month	13 month
Moisture content (%) Beginning of experiment	58	47.7 ± 2.7	60
	56.7	47.7 ± 2.8	60
	57.1	47.7 ± 2.9	60
Moisture content (%) End of experiment	44.1	35.9 ± 5.8	157
	51.2	33.6 ± 4.9	170
	65.9	31.6 ± 6.6	169
Calorific value (MJ/kg) Beginning of experiment	6.472	15.61 ± 0.64	17.69
	6.770		19.62
	6.647		20.3
Calorific value (MJ/kg) End of experiment	9.431	17.69 ± 0.34	19.46
	7.973		19.05
	4.886		19.33
Ash Content (%) Beginning of experiment	1.36	3.02 ± 0.30	0.53
	1.49		0.48
	1.30		0.51
Ash Content (%) End of experiment	1.39	3.20 ± 0.73	1.2
	1.58		1.10
	1.64		1.23

The weight of the pile after the experiment was 148.3 tons. In total, the weight of the wood chips decreased by 15.2 tons after a 15-month storage period. With this type of fuel, the recorded decrease in moisture content and weight could have been greater. Due to the small particle size and the whole tree chipping method (including assimilation organs), the experimental pile absorbed more atmospheric humidity in the upper part. The inside parts did not dry with such a high intensity as it could have been in the case of piles from other wood species and larger particle size (Afzal *et al.* 2010; Barontini *et al.* 2014). It can be said that the energy value of the stored wood chips can increase only when tree trunks without assimilation organs are chipped into particles larger than 5 mm.

CONCLUSIONS

1. The experimental pile of wood chips featured the coniferous wood species spruce and fir, and had a weight of 163.3 tons. It was discovered that the temperatures at the three heights of 1.0, 2.0, and 3.0 m reached the same value approximately 180 days after the pile’s creation. A similar time interval was also determined when studying the piles of birch and poplar wood chips.
2. The largest decrease in the pile’s moisture content after a 15-month storage period occurred in the lowest parts of the pile (height of 1.0 m, 13.9 % decrease). By increasing the height and decreasing the width of the pile, the decrease in moisture content was lower during the whole storage period. At the highest measurement level we recorded an increase in moisture content. In the upper parts of the pile, the wood chips were more likely to reabsorb the atmospheric humidity.
3. Furthermore, there were similar situations with other calorific values and ash contents. The calorific value increased most significantly in the lower parts of the pile, while in the highest part the value decreased. On the other hand, in the highest part of the stack, researchers recorded the most significant increase in the ash content. Experimental pile was located in the area of a heating plant with a chimney.
4. The experiment has described influence of specific weather conditions in Slovakia on the development of temperature inside the pile, calorific value and ash content of coniferous wood chips piles with particle size up to 35.5 mm during long-term storage. Wood chips from coniferous wood species spruce and fir show, after a long-term storage, more significant changes in studied properties than wood chips made from the wood species poplar and birch.
5. An additional negative effect of a long-term storage was the presence of moulds and fungi (*Trichoderma viride, Penicillium* sp.), which can cause health problems to workers as well as to the residents living in the vicinity of the storage location.

ACKNOWLEDGMENTS

The research described in this paper was financed jointly by the Cultural and Educational Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic (Project No. 016-TUZ-4/2012 – E-learning educational modules for processing of incidental fellings; Project No. 003TU Z-4/2015 - Development of Conceptual thinking at technical universities).

REFERENCES CITED

Afzal, M. T., Bedane, A. H., Skohansanj, S., and Mahmood, W. (2010). "Storage of comminuted and uncomminuted forest biomass and its effect on fuel quality," *BioResources* 5(1), 55-69. DOI: 10.15376/biores.5.1.55-69

Barontini, M., Scarfone, A., Spinelli, R., and Gallucci, F. (2014) "Storage dynamics and fuel quality of poplar chips," *Biomass and Bioenergy* 62, 17-25. DOI: 10.1016/j.biombioe.2014.01.022

De Toro, A., Jirjis, R., and Nilsson, D. (1994). "Cold air ventilated and sealed storage of wood-chips from willow: laboratory experiments," Monograph, Uppsala, Swedish University of Agricultural Sciences, Department of Agricultural Engineering, 192. ISSN 0283-0086.

Fassati, O. (1979). Plísně a vláknité houby v technické mikrobiologii (Moulds and filamentous fungi in technical microbiology) SNTL, pp. 211.

Huber, G. (2009). *Wessentliche Holzparameter und deren Einfluss auf die Lagerung & Verbrennung*, Vortag zum Heizwärterstammtisch, Obereggen, Italy.

Idler, C., Scholz, V., Daries, W., and Egert, J. (2005). "Loss reduced storage of short rotation coppice," *Research Papers of Žemės Ūkio Inžinerija Mokslo Darbai* 37(1), 124-134.

Jirjis, R. (1995). "Storage and drying of wood fuel," *Biomass and Bioenergy* 9(1-5), 181-190. DOI: 10.1016/0961-9534(95)00090-9

Jirjis, R. (2001). "Forest residue – Effect of handling and storage on fuel quality and working environment," *Forest Research Bulletin*, 223(1), 140.

Jirjis, R. (2005). "Effects of particle size and pile height on storage and fuel quality of comminuted *Salix viminalis*," *Biomass and Bioenergy* 28(2), 193-201. DOI: 10.1016/j.biombioe.2004.08.014

Jirjis, R., Pari, L., and Sissot, F. (2008), "Storage of poplar wood chips in northern Italy," *Conference Proceedings of the World Bioenergy*, 27th -29th Jonkoping, Sweden (1), 107-111.

Lehtikangas, P., and Jirjis, R. (1998). "Storage of logging residue in bales," *Proceedings of the 10th European Conference and Technology Exhibition, Biomass for Energy and Industry*, Würzburg, Germany, 1013-1016.

Manzone, M., Balsaria, P., and Spinelli, R. (2013). "Small-scale storage techniques for fuel chips from short rotation forestry," *Fuel* 109(1), 687-692. DOI: 10.1016/j.fuel.2013.03.006

Nurmi, J., and Hillebrand, K. (2002). "Storage alternative affect fuel wood properties of Norway spruce logging residue," *New Zealand Forest Science Journal* 31(3), 289-297.

ÖNORM (Austrian State Standard) M 7132. (1995). "Energy-economical utilization of wood and bork as fuel - Definitions and properties." Austrian Standards Institute, Vienna, Austria.

Sampson, G. R., and McBeath, J. H. (1987). "Temperature changes in an initially frozen wood chip pile," USDA Forest Service Research Note PNW-RN-454.

Samuels, G. J., Dodd, S., Lu, B., Petrini, O., Schroers, H. J., and Druzhinina, I. S. (2006). "The Trichoderma konigii aggregate species," *Studies in Mycology* 56, 67-133. DOI:10.3114/sim.2006.56.03

STN (Slovak Technical Standard) 48 0057. (2004). "Assortments of wood, Chips and sawdust of softwood," Slovak Standards Institute, Bratislava, Slovakia.

ISO 1928. (2003). "Solid mineral fuels. Determination of gross calorific value by the bomb calorimetric method, and calculation of net calorific value," International Organization for Standardization, Geneva, Switzerland.
ISO 1171. (2003). "Solid mineral fuels. Determination of ash," International Organization for Standardization, Geneva, Switzerland.
Suchomel, J., Belanová, K., Gejdoš, M., Němec, M., Danihelová, A., and Mašková, Z. (2014). "Analysis of fungi in wood chip storage piles," *BioResources* 9(3), 4410-4420. DOI: 10.15376/biores.9.3.4410-4420
Thörnqvist, T. (1985). "Drying and storage of forest residues for energy production," *Biomass and Bioenergy* 7(2), 125-134. DOI: 10.1016/0144-4565(85)90038-1
Thörnquist, T., and Lundström, H. (1982). "Health hazards caused by fungi in stored wood chips," *Forest Products Journal* 32(1), 29-32.
White, M. S., Curtis, M. L., Sarles, R. L., and Green, D. W. (1983). "Effect of outside storage on the energy potential of hardwood particulate fuels: Part 1. Moisture content and temperature," *Forest Products Journal* 33(6), 37.

Article submitted: April 1, 2015; Peer review completed: June 10, 2015; Revised version received: June 17, 2015; Accepted: July 13, 2015; Published: July 20, 2015.
DOI: 10.15376/biores.10.3.5544-5553