Monitoring Moisture Content, Temperature, and Humidity in Whole-tree Pine Chip Piles

John Klepac [1], Dana Mitchell[2], and Jason Thompson [1]

[1] Engineer, Forest Operations Research Unit, Southern Research Station, USDA Forest Service
[2] Project Leader, USDA Forest Service, Southern Research Station

Two whole-tree chip piles were monitored for moisture content, temperature, and relative humidity from October 8th, 2010 to March 16th, 2011 at a location in south Alabama. Initial moisture content samples were collected immediately after chips were delivered to the study location on October 8th for Pile 1 and October 22nd for Pile 2. During pile construction, Lascar EL-USB-2+ sensors were placed at strategic locations within each pile to monitor temperature and humidity. Samples were collected from within each pile over time through a plastic pipe that was placed near the pile center during construction. Initial moisture content for Pile 1 was 51.4%. Samples collected from the middle of Pile 1 over the drying period averaged 48.3%. Pile 2 had an initial moisture content of 46.3% and samples collected from the middle during the drying period averaged 42.2%. The maximum temperature recorded in both piles occurred at the upper location and was 146°F for Pile 1 and 137°F for Pile 2. Both piles had lower moisture contents near the center as compared to moisture contents observed 18-inches below the surface.

Keywords: Pine chips, drying, storage.

1. Introduction

Storage of wood chips is a common practice of mills for maintaining inventory when deliveries are slow. Clean chips are the most common type of wood that is stored in piles, although storing whole-tree chips is also practiced to keep a fuel source on hand. While storing chips in piles is a responsible practice and helps ensure a continuous feedstock supply, if not properly managed, it can result in degraded chip quality, loss of by-products, nematode infestations, and in extreme cases, spontaneous combustion.

Living cells in wood after it is piled consume oxygen and release heat, which provides an environment conducive for bacterial growth within the first 5 to 7 days (Fuller 1985). Chips stored in piles are at a greater risk of fungus and degradation, resulting in a lower heating value (APA 1981). APA (1981) concluded that hardwood chips and whole-tree chips produce the greatest amount of fungus. The formation of acetic acid can occur after the development of bacteria in the pile and is influenced by factors such as pile height, the degree of compaction, and the amount of chip fines and sawdust present (Springer and Hajny, 1970). The formation of acetic acid occurs when temperature reaches 140 to 160°F and results in wood deterioration by attacking the cellulose molecule (Fuller 1985). This is most common for large pile heights with a high degree of compaction. For piles with lower heights that are not compacted, wood-rotting fungi are more likely to develop when temperatures drop below 120°F (Fuller 1985).

The most prevalent species of chips used in the Southern U.S. is pine, which is high in resin content. This makes it excellent for producing by-products such as tall-oil and turpentine (Landry and Stillwell, 1984). McDonald and Twaddle (2000) surveyed mills in the U.S. and found that concerns over pile losses varied by region of the country. Size and fungal degradation were important for mills in the Northeast and North Central regions, while chip size and by-product losses were major concerns in the South. Mills in the West were most concerned with brightness loss. Piled pine chips lose turpentine more rapidly than tall-oil. Turpentine losses can reach 70 to 80% after a two-month period for piles 9 to 20 feet in height, while tall-oil losses range from 60 to 70% after two months (Fuller 1985).

Chip piles are also subject to damage caused by micro-organisms such as the pinewood nematode. The development of micro-organisms in chip piles is mainly governed by temperature, although wood moisture also has an impact on the population density of the nematode in chips (Dwinell 1986). The temperature in a chip pile depends on the ambient temperature, the size and compaction of the pile, and the fines and bark content of the chips (Bergman 1985). Dwinell (1986) determined the optimum temperature range for the reproduction of the pinewood nematode in southern pine chips was 95 to 104°F. In addition, nematode densities in chips declined as the percentage of moisture in the chips declined from 40 to 26 nematodes per gram after moisture loss reached 22% after a five-day incubation period (Dwinell 1986).

The heating value of whole-tree chips can be compromised when stored outside. Whole-tree chips stored outside, uncovered, can lose up to 25% of their potential heating value after approximately 120 days (APA 1981). Moisture content of piled chips has an effect on heating value and can vary significantly within a pile. White and Curtis found that outside layers of chip piles tend to increase in moisture content while core zones tend to lose water (APA 1981).

The objective of this study was to monitor moisture content, temperature, and relative humidity over time at various locations inside two piles of uncovered, green whole-tree pine chips. After the monitoring period, moisture content and bulk density at various locations within each pile was also of interest.

2. Methods

The project began October 8th, 2010 and was completed on March 16th, 2011. Piles were constructed on an existing concrete slab at an abandoned woodyard in Georgiana, Alabama. Two whole-tree chip piles were constructed using a John Deere[1] 120C tracked excavator (Figure 1). During pile construction, EL-USB-2+ sensors by Lascar Electronics were placed near the center of each pile at approximately 3 feet (bottom), 6 feet (middle), and 8 feet (top) from the ground. Sensors were also placed on the north and south face 18 inches deep. Each sensor was programmed to record temperature and relative humidity once every hour. Prior to the study, new batteries were installed in each sensor. Specifications for temperature and relative humidity of the sensors were 31 to 176°F and 0 to 100%, respectively.

Figure 2. Chip pile construction using an excavator.

Also during pile construction, samples were collected and placed in 5 gallon buckets and sealed with lids for later determination of moisture content, ash content, and particle size. Five samples were collected from each pile. To monitor moisture content over time a 5 foot PVC

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement of any product or service by the U.S. Department of Agriculture or other organizations represented here.

pipe was placed in each pile about 4 feet above ground ending near the center. A soil auger was inserted into the PVC pipe to collect samples at designated time frames. Moisture content was assessed as prescribed in European Standard EN 14774-2 (2009). Samples were weighed wet and placed in a drying oven at 105 ± 2°C until total mass loss differed by less than 0.2% between measurements taken one hour apart. After piles were constructed, measurements were taken on each pile and included vertical height, base circumference, and slope length. Heights were measured using a clinometer, while circumference and slope length were measured using a cloth tape. From these measurements, total volume for each pile was calculated. Bulk density was determined using procedures outlined in European Standard EN 15103 (2009).

Piles were deconstructed on March 16th, 2011. Prior to deconstruction, total height, base circumference, and slope length were measured. During deconstruction, each pile was split vertically and half removed. This was done so that an internal profile could be revealed and samples collected at strategic locations (Figure 2). Two samples were collected at each location for moisture content determination. Samples collected from locations A, B, and C were also analyzed for bulk density. In addition, three samples were collected from the surface on the north and south face of each pile. Once samples were collected, deconstruction was completed and sensors were recovered.

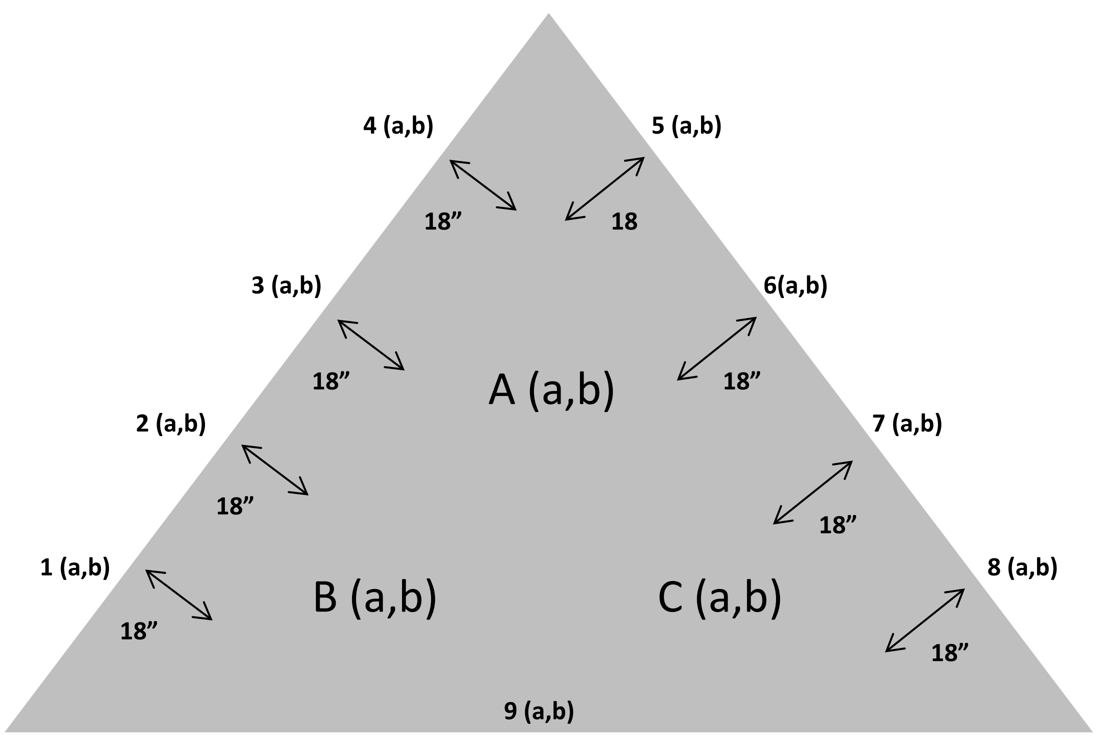

Figure 3. Sample locations during pile deconstruction.

3. Results

Climatological data are summarized in Table 1. High and low values for temperature and humidity are averages over the course of the drying period. Mean values for temperature and humidity were calculated by summing all high and low values and dividing by two times the number of drying days. For precipitation, high and low values reflect the maximum and minimum rainfall recorded on a particular day. Values for high wind speed and gust reflect averages over the drying period. A total of 18.78 inches of rainfall was recorded at the Greenville, Alabama weather station during the drying period. During the last three days of the drying period 0.47 inches of rainfall was recorded. A total of 2.71 inches of rainfall was recorded during the last week of the drying period.

Table 1. Climatological data for the drying period from October 8th, 2010 to March 16th, 2011.

Variable	High	Mean	Low	Gust	Total
Temperature (°F)	61.8	50.7	40.1	-	-
Humidity (%)	90.7	67.7	45.6	-	-
Precipitation (in)	3.2	0.12	0.0	-	18.78
Wind Speed (mph)	11.5	5.0	-	23.2	-

Dimensions of each pile are summarized in Table 2. After piles were constructed, a total of eight auger-collected samples were made prior to the end of the study period from Pile 1 and seven collections from Pile 2 for moisture content analysis over time (Figure 3). Initial moisture contents (wet-basis) from Oct. 8th for Pile 1 and Oct. 22nd for Pile 2 are also included in Figure 3. Pile 1 had an initial moisture content of 51.4%, compared to 48.3% for Pile 2. The last sample collection made through the PVC pipe occurred on March 2nd and was 51.4% for Pile 1 compared to 40.0% for Pile 2.

Table 2. Measured parameters for both piles.

Whole-Tree Chip Piles				
Pile	Vertical Height (ft)	Base Circumference (ft)	Slope Length (ft)	Volume (ft^3)
1	10	78.4	15.4	1303
2	9.5	80.0	17.0	1412

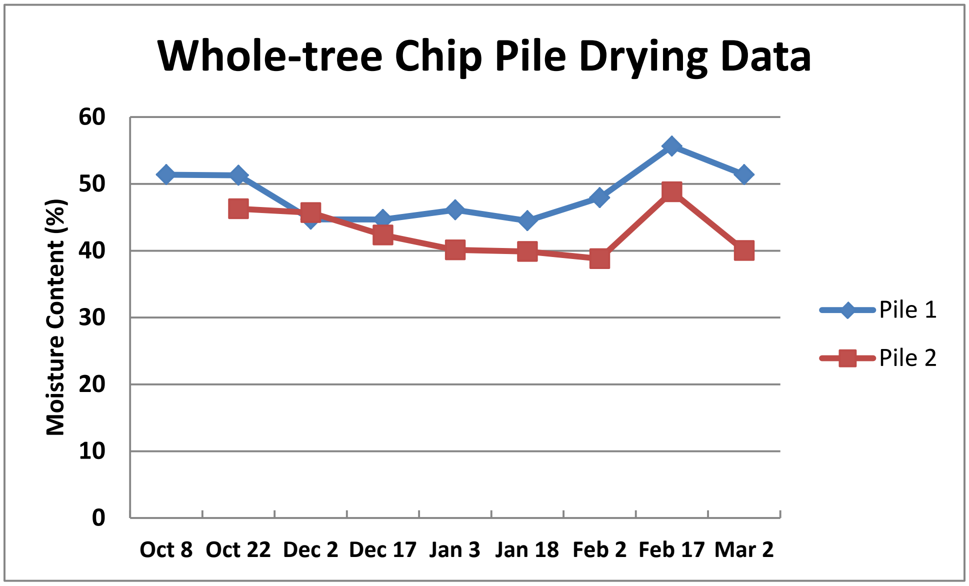

Figure 4. Moisture content trends over time for each pile.

Each sensor recorded one observation per hour; therefore, the number of observations listed in Table 3 also reflects the number of hours data were recorded. For Pile 1, the maximum data recording time possible was 3815 hours, which was achieved only by the sensor placed in the north face of the pile. All other sensors did not achieve 100% data recording during the study period. For temperature, the bottom sensor recorded 65% of the time, followed by the south sensor (53%) and the middle sensor (31%). The top sensor only recorded for 270 hours, or 7% of the time. Pile 2 had a maximum possible recording time of 3500 hours, which was achieved by both the north and south sensors. The top sensor recorded temperature 95% of the time, followed by the bottom sensor (63%) and the middle sensor (23%).

The minimum temperature recorded for both piles occurred on the north face during the month of December (36°F for Pile 1 and 32°F for Pile 2). Pile 1 also had a 36°F reading during the month of February. For both piles the maximum temperature recorded was by the top sensor during the month of October (146°F for Pile 1 and 137°F for Pile 2).

Duncan's Multiple Range Test (SAS 1988) was used to detect for significant differences (α=0.05) in temperature between piles at each sensor location. Results showed that mean temperatures were significantly different between piles at each location.

Table 3. Descriptive statistics of temperature for both Piles.

Whole-Tree Chip Piles – Temperature (°F)										
Sensor	Pile 1					Pile 2				
Location	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
Bottom	2484	94.5a[1]	15.57	63	126	2205	83.2b	14.83	61	118
Middle	1201	118.9a	17.13	73	139	771	100.9b	12.39	86	135
Top	270	127.1a	22.32	72	146	3330	79.4b	15.90	48	137
North	3815	62.7a	25.40	36	118	3500	49.7b	15.00	32	99
South	2040	71.1a	1.84	66	74	3500	67.2b	9.52	52	105

[1]Means with the same letter between piles are not significantly different using Duncan's Multiple Range Test.

Mean relative humidity was consistent for Pile 1 for the bottom, middle, top, and north locations and ranged from 98.2 to 99.9%, while the south location averaged 66.6%. Relative humidity in Pile 2 ranged from 81.6 to 99.8%.

Figures 4 and 5 display mean monthly temperatures recorded by each sensor for both piles. Overall, mean temperatures reached a minimum during the month of January and gradually increased afterwards. For Pile 1, the highest mean monthly temperatures occurred in October and were 129.5°F for the middle sensor, followed by 127.1°F for the top sensor. The bottom of Pile 1 reached a maximum temperature of 126.0°F on day nine. The middle location reached a maximum temperature of 139.0°F on day ten and remained above 100°F until day 42. The maximum temperature at the top location was 146.0°F on day nine and 144.0°F on day twelve when the sensor stopped recording. The maximum temperature was 117.8°F on day eleven for the north location and 74.0°F at day eleven for the south location.

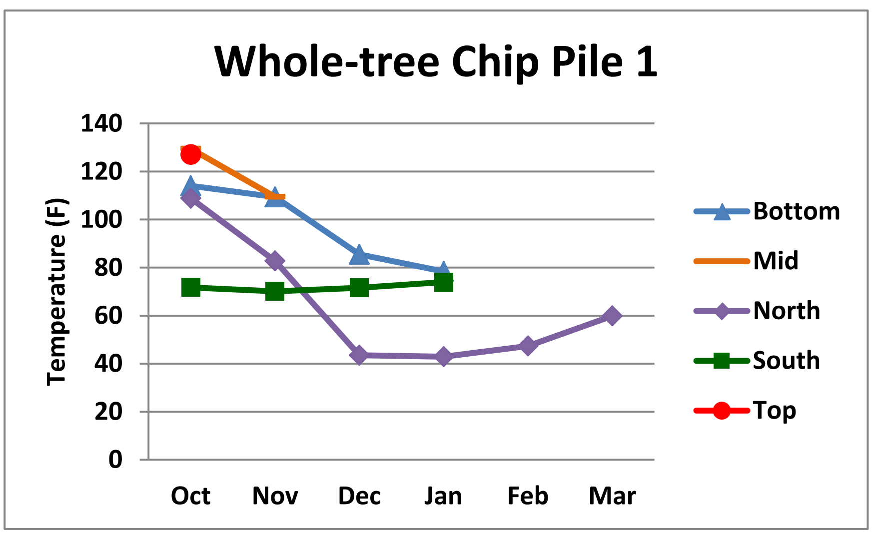

Figure 5. Mean temperature by month for Pile 1.

Temperature recorded by the south sensor in Pile 1 had a lower standard deviation as compared to the other sensors. This raised some concern about the sensor's accuracy. Testing of the sensor in a lab drying oven for five different temperatures revealed the sensor recorded temperatures with acceptable accuracy. Percent differences between the sensor and oven readings ranged from 2.4 to 5.6%.

For Pile 2 the highest mean monthly temperature was also recorded by the middle sensor during October at 111.5°F. The three highest mean monthly temperatures were recorded by the top, middle, and bottom sensors during October and differed by no more than 5.3°F (107.7°F for the top, 111.5°F for the middle and 106.2 °F for the bottom sensor). The bottom of Pile 2 reached a maximum temperature of 117.6°F on day two. Both the middle and top locations for Pile 2 reached their maximum temperature on day three (139.0°F for the middle and 135.0°F for the top). The maximum temperature for the north (96.3°F) and south (101.0°F) locations occurred on day two of the drying period.

Figure 6. Mean temperature by month for Pile 2.

Moisture contents from each sample location within each pile are summarized in Figure 6. These samples were collected during deconstruction of the piles. Both piles were much wetter around the surface and top as compared to other areas. For locations 1-8 (surface) moisture contents ranged from 60.1 to 68.1% for Pile 1 and 65.5 to 69.5% for Pile 2. At the center of the piles at locations A, B, and C moisture contents ranged from 44.2 to 48.7% for Pile 1 and 31.3 to 44.0% for Pile 2. For sample location 9 (bottom) Pile 1 had a moisture content of 45.5%, compared to 26.8% for Pile 2. Comparing moisture contents between the surface and center locations resulted in a 33% difference for Pile 1, compared to a 52% difference for Pile 2.

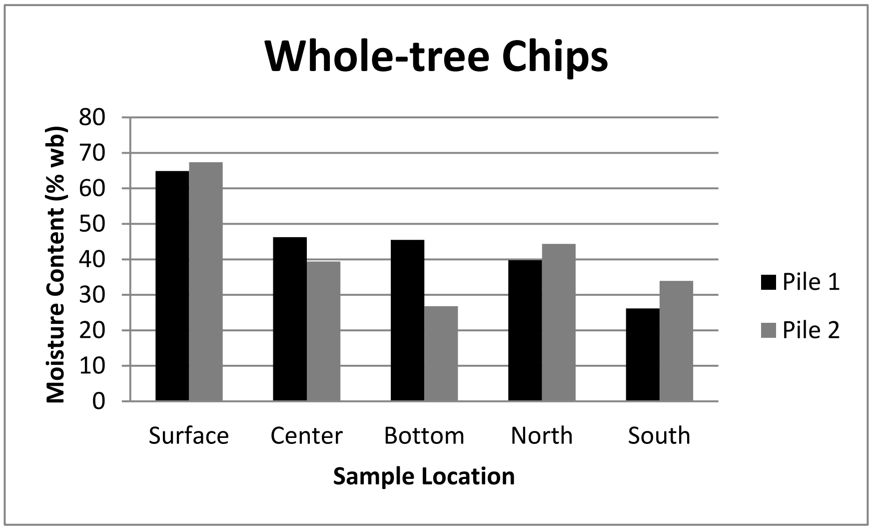

Figure 6. Moisture content by location for each pile.

Bulk density was measured from samples collected at points A, B, and C during pile deconstruction and are summarized in Figure 7. Values were consistent and ranged from 10.34 to 10.62 lb/ft3 for Pile 1 and 10.17 to 10.67 lb/ft3 for Pile 2.

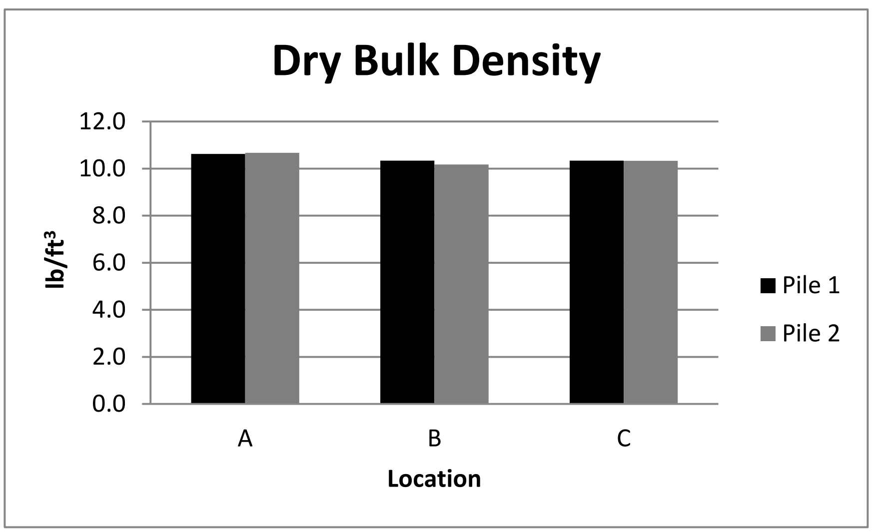

Figure 7. Dry bulk density at center locations for each pile.

4. Discussion

Both temperature and relative humidity data were recorded in both piles, however, temperature was the major focus in this paper since it is a more crucial and important variable of interest to the forest industry. Temperatures within piles were never high enough where spontaneous combustion would be likely to occur (180°F+), although they were in the range conducive for the development of wood-rotting fungi and the pinewood nematode.

The highest temperature observed of 146°F occurred at the top location in Pile 1 and only remained at that level for thirteen consecutive hours on the ninth day of the study period. The top location temperature in Pile 1 decreased slightly to 144°F by the twelfth day, at which point the sensor stopped. The maximum temperature recorded in Pile 2 was 137°F at the top location during day two of the study period.

For smaller, non-compacted piles wood-rotting fungi is more probable when temperatures drop below 120°F. For Pile 1, three of the sensors (bottom, north, and south) recorded more than 50% of the time for the total study period. Both the north and south sensors recorded temperatures of less than 120°F for 100% of their recording time. The bottom sensor recorded temperatures of less than 120°F for 90% of its recording time. Pile 2 had four sensors (bottom, north, south, and top) that recorded more than 50% of the time for the total study period. The bottom, north, and south sensors all recorded temperatures less than 120°F 100% of the time, while the top sensor recorded temperatures in this range 98% of the time.

The pinewood nematode has been found to thrive when temperatures are between 95 to 104°F. Of the three sensors in Pile 1 that recorded more than 50% of the time, the bottom sensor had the highest percentage (29%) of time with temperatures within this range. The north sensor only recorded temperatures within this range 3% of the time, while the south sensor recorded no temperatures within this range. Of the four sensors in Pile 2 that recorded more than 50% of the time, the bottom sensor also had the highest percentage (22%) of time with temperatures within this range. The top sensor recorded within this range approximately 15% of the time.

Statistical analysis showed that mean temperatures between piles at each location were significantly different. This implies that temperature within piled chips can be highly variable, even with the same type of material.

5. Conclusions

It appears that storing whole-tree pine chips in small piles 10 feet in height are not susceptible of reaching internal temperatures high enough to cause spontaneous combustion. At the end of the drying period piles were higher in moisture content along the surface as compared to the center. Pile 1 had a 33% difference in moisture content between the surface and center compared to a 52% difference for Pile 2. Duncan's Multiple Range Test indicated there were significant differences in recorded temperatures between piles for each sensor location. Temperature data revealed that chip piles of this type are more susceptible to wood-rotting fungi than they are to the pinewood nematode under these conditions.

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