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David L. Nicholls, and Yonggang Feng, Michigan Energy Conservation Program for Agriculture and Forestry, and MSU Department of Forestry
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MOISTURE CONTENT AND TEMPERATURE CHANGES OF WOOD FUEL DURING OUTSIDE STORAGE

By
David L. Nicholls
Research Associate
and
Yonggang Feng
Graduate Research Assistant
Michigan Energy Conservation Program
Wood Energy Demonstration Project
Michigan State University
Department of Forestry

INTRODUCTION

The Viking Energy Facility of McBain, Michigan, cooperated with the Michigan Energy Conservation Program's Wood Energy Demonstration Project to evaluate alternative methods of outdoor storage for wood fuel. Viking Energy is an 18 megawatt (MW) (16.4 MW net output) electrical generating facility using wood as a fuel source to provide electricity for the equivalent of 4,000 residential households.

Wood fuel requirements for the facility average approximately 600 tons of green fuel per day. The primary fuel source is on-site residues from forest management and tree improvement activities, which include harvest residues and trees of unmerchantable size. Small amounts of manufacturing residues are obtained from local sawmills. The facility maintains an average on-site fuel supply of 7 - 10 days (4,200-6,000 tons).

Although most incoming fuel is stored for less than 2 weeks, storage periods of more than 2 months are sometimes necessary. The objectives of this study were to evaluate changes in temperature and moisture content of wood fuel under conventional storage methods vs. storage with a venting system to accelerate drying. Results of the study will help plant managers adopt specific strategies for optimizing fuel inventory conditions, including pile height, storage time, and use of accelerated drying systems.

MECP is a cooperative effort of the:
Michigan Department of Agriculture - Michigan Soil Conservation Districts - USDA Soil Conservation Service
Michigan State University's Agricultural Experiment Station and Cooperative Extension Service

Procedures

Storage Piles

The facility constructed two experimental fuel piles, a control and ventilated pile, to monitor changes in wood moisture content and temperature over a 3 1/2-month storage period. The storage piles were constructed as uncompacted cones, each about 20 feet high. In one pile, a venting system was installed to accelerate natural air-drying of wood chips during outdoor storage. The vent consisted of a culvert (30 ft. long, 2 ft. in diameter) placed vertically through the center of the pile to act as an exhaust stack. One-inch diameter holes were drilled in the culvert to increase air flow through the wood chips. Holes were drilled more frequently throughout the lower section of the culvert, where the pile was the widest, than at the upper level. Screening material was wrapped around the entire culvert to prevent wood chips from entering.

The control pile had no modifications. The size, shape, and species composition of the two piles were matched as closely as possible. Species composition for the two piles was at least 80 percent softwoods, primarily red pine. The remainder was mixed hardwoods, including aspen and red oak.

Temperature Samples

Temperatures within the pile were monitored with thermocouples which were placed at selected pile locations during formation (Figure 1). Thermocouples were located in four regions of each pile: ground level and upper locations in both the north and south aspects. Temperature sample gradients for lower locations were approximately 3 ft. above ground level at 2-, 4-, 7-, 15-, and 20-ft. depths from the pile surface. Thermocouples for upper pile locations were about 12 ft. above ground level and were placed 2,4,7, and 10 ft. from the pile surface. Eighteen temperature sampling points were established for each pile.

Each thermocouple was encased in a 1/2-inch chlorinated polyvinyl chloride (CPVC) tube. The interior tube ends were insulated with expanding polyurethane foam insulation to within 6 inches of each thermocouple sensor. Insulation around each sensor ensured that air temperatures were monitored from specified depths of the pile. Type J, iron-constant thermocouples with PVC coatings were used. Temperature readings were taken with a hand-held digital thermometer.

Moisture Content Samples

Samples to determine the fuel moisture content were taken from lower pile locations at depths up to 15 ft. from the pile surface. Samples were taken on north and south aspects at depths of 1/2, 4, and 15 ft. from the surface of each pile. Six moisture content samples were taken at each sampling date.

Figure 1:

Temperature sample locations for control pile

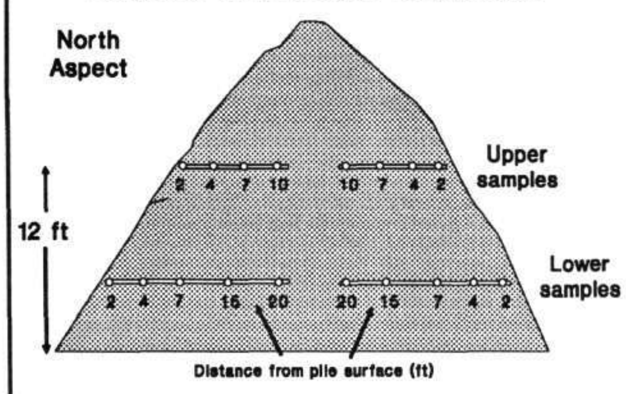
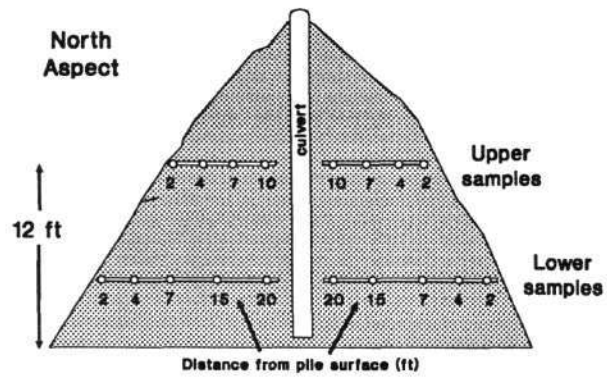


Figure 2:

Temperature sample and vent locations for vented pile



Surface samples were taken at a depth of 1/2 ft. from the surface to avoid sampling wood chips that may have experienced uneven drying and wetting from atmospheric conditions. Interior samples at 4 ft. and 15 ft. were collected with a segmented steel probe that was pushed to the desired depth with a front-end loader. The probe included an end bucket chamber to ensure that each sample was removed from only one location. All specifications for the probe, including design of the collection chamber were based on work by M.S. White, et al. (1980).

Sampling Procedures

Piles were constructed in early September 1990 and monitored until December 1990. Temperature and moisture content samples were taken about once per week at the beginning of the study and less frequently as the study progressed. Samples were taken on days 5, 12, 19, 26, 40, 57, and 96 of the 3 1/2-month study.

Results

Temperature

Temperature data is presented in Figures 5 - 8. Because temperatures of the north and south aspects of both piles did not vary considerably, only south aspect temperatures were evaluated. Temperature results and sampling locations are referred to in this bulletin as interior (15-and 20-ft. depths), intermediate (7-ft. depth), and surface (2- and 4-ft. depths).

Initial pile temperatures

Pile temperatures were greatest during the first few weeks of the study, and then decreased (Figures 5 and 6). The highest temperatures of the study were recorded on the first sampling date (day 5) at interior locations. At this sampling, temperatures ranged from 100 to 120 degrees F greater than ambient (outside) air temperatures.

On the final sampling date (day 96), interior pile temperatures had decreased by as much as 117 degrees F from the initial sampling date.

For surface zones, temperatures decreased an average of only 49 degrees F from the initial to the final sampling date of the study (Figure 2, Graph 2). For the last 3 sampling dates (days 40, 57, and 96) surface zone temperatures closely matched outside air temperatures.

Surface vs. interior temperatures

Temperatures within the piles varied considerably early in the storage period. After 5 days of storage, temperatures at interior regions were as much as 92 degrees F greater than at surface regions (Figures 5 and 6). By day 40, the maximum temperature difference between interior and surface regions was only 65 degrees F (Figures 5 and 6). This

Figure 3:

Moisture content sample locations for control pile

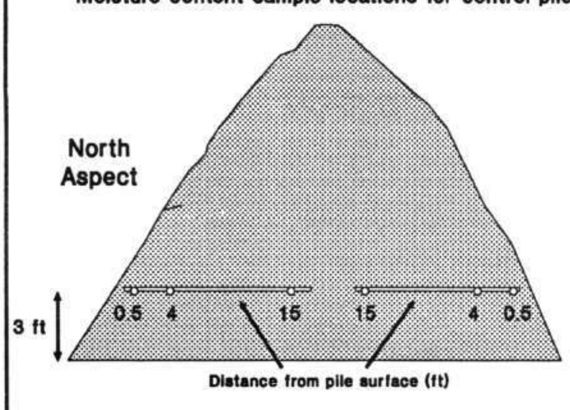
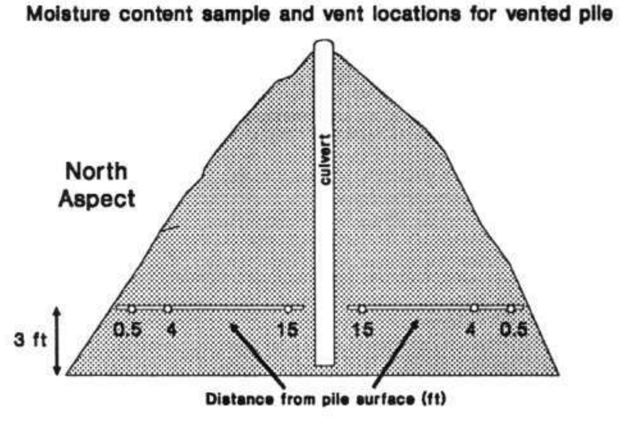


Figure 4:

Moisture content sample and vent locations for vented pile



temperature difference was only 46 degrees F by day 96 of the study. The differences between the temperature at interior and surface regions decreased in both the control and vented pile after extended outdoor storage.

Control pile vs. vented pile temperatures

Temperatures in the vented pile were considerably warmer than in the control pile early in the storage period. For the first sampling date, temperatures at the 4-ft. and 7-ft. depths were at least 50 degrees F greater in the vented pile than in the control pile (Figure 6). Initial temperatures were only moderately higher for interior regions of the vented pile as compared to the control pile.

During the 2nd half of the storage period, interior temperatures were lower in the vented pile than in the control pile. After 96 days of storage, half of the pile was removed to reveal a profile of the interior region (page 1 photo). A thin vertical zone of saturated material parallel to the culvert suggests that precipitation entered through the top of the vent. This saturated zone represented a small percent of the total pile volume. Lower interior pile temperatures may have been a result of this wetting.

Surface zones of the vented and control piles followed similar temperature patterns from day 26 to the end of the study (Figure 6). Surface zones were generally 10 degrees warmer than ambient air temperatures for the final 3 sampling dates.

Moisture content (MC)

Moisture content changes were evaluated for the north and south aspects of the control and vented piles. For the following discussion of moisture content results, surface samples were located 0.5 ft. and interior samples 15 ft. from the pile surface, respectively.

MC changes over time

The overall wood fuel moisture content averaged 52.9 percent moisture content green basis (MCGB) at the initial sampling date. MCGB is the weight of water as a percentage of the total weight of the sample (wood + water). The average moisture content of surface samples increased throughout the study, while it decreased for interior samples. Samples 4 ft. from the surfaces of both piles exhibited moderate changes in moisture content (Figure 11). Wood chips at the intermediate depth of the vented pile became somewhat dryer as the study progressed, while samples from the control pile showed that its moisture content increased during this time.

MC variations within piles

After 12 days of storage, the moisture content of wood chips sampled from the surface region of both piles was already considerably higher than at the interior locations (Figure 9). For the remainder of the storage period, the moisture content continued to increase for surface samples and decrease for interior samples. On the final sampling date, the control pile surface was 69.1 percent MCGB while the interior sample was only 27.2 percent MCGB (Figure 10).

Control vs. vented pile MC

There was no accelerated drying effect for interior regions of the vented pile as compared to the control pile (Figures 10 and 11). Moisture contents of interior regions were moderately lower for the control pile than the vented pile. Interior samples (15 ft. from the pile surface) from the vented pile were apparently not close enough to the culvert to be part of the wet zone caused by precipitation entering the vent.

Local Precipitation Records

Local precipitation records were obtained from two weather stations, located about 10 and 15 miles from the McBain site. High surface moisture on day 19 of the study was the result of a recent rainfall of approximately 0.4 inches. High surface moisture on day 96 was influenced by mixed snow and rain for two days prior to the sampling. It is unlikely that interior measurements were greatly influenced by precipitation events.

Figure 11

Moisture content of wood chips in control and vented piles during 3 months of outside storage at the Viking Energy Facility

Location	Sampling Date (Days of Storage) 12	19	26	40	57	96
	Moisture Content (Green Basis)					
C-L-S-0.5	52.1	59.8	55.3	64.8	63.6	69.1
C-L-S-4	46.1	52.1	45.3	45.0	45.5	51.4
C-L-S-15	44.4	38.7	38.2	37.3	34.2	27.2
V-L-S-0.5	56.4	63.4	62.2	62.5	58.6	67.8
V-L-S-4	46.4	43.0	44.1	43.7	38.7	40.0
V-L-S-15	47.0	45.1	44.6	37.9	40.9	36.8

C: Control	U: Upper
V: Vented	S: South
L: Lower	N: North

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Summary

Overall pile temperatures were highest during the first few weeks of storage, and decreased as the study progressed. Temperatures within the pile varied considerably early in the study, with interior regions warmer than surface regions. Initially, the vented pile was considerably warmer than the control pile; however, during the 2nd half of the storage period, interior temperatures were lower in the vented pile than in the control pile.

Average moisture content tended to increase throughout the study for surface samples, and decrease for interior samples.

Moisture contents of interior regions were moderately lower in the control pile than in the vented pile. A high moisture content zone, which developed adjacent to the culvert of the vented pile, was probably caused by precipitation entering the culvert.

References

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Wood Energy Demonstration Project

The Michigan Energy Conservation Program has been established to help farmers and wood energy users reduce energy costs by practical conservation methods. Reduced dependence on fossil fuels will enable more productive management of agricultural and forest resources in Michigan.

The Wood Energy Demonstration Project is designed to help wood fuel users establish wood energy systems, providing model demonstrations for other organizations. All businesses, governmental units, and not-for-profit organizations within Michigan were eligible for the grant program. A total of $300,000 has been allocated to 8 wood energy demonstration sites. The Viking Energy Facility is participating in the program on a voluntary basis. Their activities have included facility tours and the wood energy demonstration project described in this report.

Figure 5

Temperatures of interior samples from control and vented piles of wood chips during 3 months of outdoor storage at the Viking Energy Facility

Location	5 (Sept 18)	12	19	26	40	57	96 (Dec 18)
	Sampling Date (# days storage)						
	Temperature (degrees F)						
C-L-S-15	141	126	118	117	89	89	61
C-L-S-20	154	141	135	133	110	105	84
V-L-S-15	159	149	130	96	72	68	42
V-L-S-20	155	141	144	120	78	74	55
Air temp		57	48	36	46	33	31

Figure 6

Temperatures of surface and intermediate samples from control and vented piles of wood chips during 3 months of outdoor storage at the Viking Energy Facility

Location	5 (Sept 18)	12	19	26	40	57	96 (Dec 18)
	Sampling Date (# days storage)						
	Temperature (degrees F)						
C-L-S-2	75	46	67	66	45	34	38
C-L-S-4	70	47	63	86	50	51	41
C-L-S-7	75	50	73	97	56	72	43
V-L-S-2	67	58	49	46	42	33	32
V-L-S-4	128	70	68	64	45	37	34
V-L-S-7	155	128	98	84	61	55	37
Air temp		57	48	36	46	33	31

C: Control	U: Upper
V: Vented	S: South
L: Lower	N: North

Figure 7

Temperatures of wood chips in control and vented piles after 5 days of outside storage at the Viking Energy Facility

	Horizontal Depth from Surface (ft)					
	2	4	7	10	15	20
Region	Temperature (degrees F)					
C-L-S	75	70	75	-	141	154
C-U-S	45	49	105	156	-	-
V-L-S	67	128	155	-	159	155
V-U-S	69	123	89	139	-	-
Air temp	43					

Figure 8

Temperatures of wood chips in control and vented piles after 96 days of outside storage at the Viking Energy Facility

	Horizontal Depth from Surface (ft)					
	2	4	7	10	15	20
Region	Temperature (degrees F)					
C-L-S	38	41	43	-	61	84
C-U-S	31	32	41	71	-	-
V-L-S	32	34	37	-	42	55
V-U-S	31	34	34	36	-	-
Air temp	31					

C: Control	U: Upper
V: Vented	S: South
L: Lower	N: North

FIGURE 9

Moisture content of wood chips in control and vented piles after 12 days of outside storage at the Viking Energy Facility

REGION	Horizontal Depth from Surface (ft) 0.5	4	15
	Moisture Content (Green Basis)		
C-L-S	52.1	46.1	44.4
C-L-N	59.5	44.2	44.2
V-L-S	56.4	46.4	47.0
V-L-N	60.9	48.1	44.3

FIGURE 10

Moisture content of wood chips in control and vented piles after 96 days of outside storage at the Viking Energy Facility

REGION	Horizontal Depth from Surface (ft) 0.5	4	15
	Moisture Content (Green Basis)		
C-L-S	69.1	51.4	27.2
C-L-N	67.7	42.3	35.6
V-L-S	67.8	40.0	36.8
V-L-N	60.6	42.0	34.3

C: Control	U: Upper
V: Vented	S: South
L: Lower	N: North