PULP AND PAPERMAKING PROPERTIES OF GYPSY MOTH-KILLED TREES

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(Received September 1987)

ABSTRACT

A study was undertaken to evaluate the pulp and papermaking properties of gypsy moth-killed trees. Red oak (*Quercus rubra*), white oak (*Quercus alba*), and red maple (*Acer rubrum*) trees dead 1, 2, 3, 4, and 5 years were harvested, chipped, kraft pulped, and compared to pulped live control trees. No statistical differences ($P \leq 0.05$) in total kraft pulp yields were measured with time after tree death for the species evaluated. Handsheet strength evaluations were conducted using these pulps and they were compared at four CSf levels. With but a few exceptions, no statistical differences ($P \leq 0.05$) in handsheet tear and tensile properties were measured; however, wide variations in MIT fold and burst properties were observed. The differences observed in sheet properties over the freeness levels tested could not be related to wood degradation that may have occurred with time after tree death.

Evaluation of the top, middle, and bottom sections of pulped red and white oak trees dead five years was conducted and no statistical differences in total pulp yields were measured. Significant differences in pulp yields due to advanced wood decay were measured in red maple; however in most cases no differences in handsheet strength properties were measured for all species within the freeness range tested.

On the basis of the results observed in this study, it was concluded that neither the total pulp yields nor the papermaking properties would be drastically affected by the introduction of gypsy moth-killed trees into the kraft pulping process.

Keywords: Pulp, papermaking, red oak, white oak, red maple, gypsy moth-killed trees.

INTRODUCTION

Over the past decade the gypsy moth (*Lymantria dispar* L.) has defoliated millions of acres of Northeastern hardwood forests. In 1986, the gypsy moth caused 2.4 million acres of defoliation in the Northeastern United States, and since 1970, defoliation has exceeded 500,000 acres annually (McManus 1980; USDA Forest Service 1986). Presently, heavy infestations have been reported in the states of New York, Pennsylvania, New Jersey, Rhode Island, Massachusetts, and Connecticut (USDA Forest Service 1986). Oaks are the most susceptible to defoliation and tree mortality. However, high tree mortality has been observed in forest stands containing such species as red maple, hickory, and ash.

A number of researchers have reported on the pulping of dead/decayed softwood species (Minerowicz et al. 1982; Werner et al. 1983; Hatton 1978; Hunt 1978a, b). Previous studies indicated that little to no drop in sulfite or kraft total pulp yields could be expected for softwood species killed by the spruce budworm

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[1] This paper was presented in part at the 40th Annual Meeting of the Forest Products Research Society, June 1986, in Spokane, Washington. This study was supported by State McIntire-Stennis funds and has been approved as Journal Series No. 7755.

The authors wish to thank Westvaco Corporation for the use of their paper testing facilities and Hammermill Paper Company for their contribution to this study.

(Wilson and Johnston 1985; Werner et al. 1983) or southern pine bark beetle (Ifju et al. 1979). Residual lignin content in pulps followed no consistent trends with time after tree death.

Limited information is available concerning the use of dead/decayed hardwoods in the paper industry. Swanson (1983) reported that the use of decayed wood in an alkaline pulping process could result in increased wood loss during harvesting, reduced wood density, increased chemical usage, reduced pulp yield, and paper strength. Most recently, DeCrease et al. (1985) pulped gypsy moth-killed red oak by a soda process and observed that pulps obtained from trees dead up to five years gave slightly higher Kappa numbers and similar yields when compared to live tree pulps. No significant losses in pulp or handsheet quality were observed for pulps made from decayed wood. Similar observations were reported by Labosky and Baldwin (1984), who in a preliminary study kraft pulped dead red oak and reported that no large reductions in total pulp yield occurred with time after tree death. However, reductions in strength properties were observed and prompted a call for further studies to verify their observations.

Therefore, a study was undertaken to investigate the pulp and papermaking properties of selected gypsy moth-killed Northeastern hardwoods as related to time after tree death. The species examined were red oak, white oak, and red maple that had been killed and left standing from zero (living trees) up to five years following tree death. In addition, a tree dead for five years was selected from each species, divided into top, middle, and bottom bole sections, chipped, and pulped; and the resultant handsheets were evaluated. This study was designed to evaluate within-tree species variation in pulp yield and papermaking properties.

MATERIALS AND METHODS

Wood source

The trees for this study were harvested from an established tree stand containing marked dead trees in a Forest Service study site in Clinton County, Pennsylvania, from land managed by Hammermill Paper Company. The species examined included red oak (*Quercus rubra*), white oak (*Quercus alba*), and red maple (*Acer rubrum*). Three dead trees from each species group were randomly harvested each year. Time of tree death was established using data obtained from Forest Service study plots.

Trees were harvested in October. Dead one-year and two-year trees were harvested during the first year of study. Control (live) and trees dead three years were harvested during the second year. Trees dead four and five years were harvested in October, 1985 and 1986, respectively. After felling, bolts were removed from the top, middle bole, and butt sections of each tree. These small bolts were debarked, if necessary, chipped and combined to form a composite sample for each harvested tree. A total of 45 dead wood chip composites (3 trees•3 species•5 years) in addition to nine controls (3 trees•3 species) gave a grand total of 54 chip composites. In addition, sufficient samples were taken from the top, middle, and butt portions of a randomly selected tree, dead five years, for a within-tree study. This sample was chipped and pulped separately by section in an effort to determine if chip location in the bole affected pulp yield and papermaking properties.

TABLE 1. *Kraft pulping conditions used on gypsy moth-killed trees.*

Minutes to temperature	50
Minutes at temperature	120
Pulping temperature (C)	172
Chip charge (grams, oven dry basis)	500
Effective alkali (%)	17
Sulfidity (%)	25
Liquor : wood	5:1
Minutes for cool-down	30

To maintain chip thickness and size, each bole was cut using a band saw and chipped by hand. Chip size was kept at approximately 1.25•1.00•0.125 inches. Prior to pulping, the chipped composites were stored in a double-layered plastic bag in a freezer maintained at a temperature of −5 C. Although all of the bark was removed before chipping; no effort was made to remove the cambium or decayed sapwood. Inevitably, some of the decayed wood was lost during chip preparation. DeCrease et al. (1985) in their study with gypsy moth-killed red oak used a drum debarker that produced essentially sound wood from the chipper; however in this study some decayed wood was included in the pulp and paper evaluation.

Pulping preparation

Wood chips were pulped in a M/K Systems Mini-Mill digester using the kraft process. The pulping conditions used in this study are summarized in Table 1.

The digested chips were washed with hot water and passed through a Bauer single-disc refiner to enhance washing and fiber separation. The washed pulp was placed in a screen box to drain and later hand-squeezed to remove as much water as possible. The moisture content was calculated to determine total pulp yield. Permanganate number was determined as described by TAPPI standard T 214 m-50. A minimum of two kraft cooks were prepared from each chipped tree composite.

Handsheet preparation and testing

The replicate kraft cooks from each tree composite were combined to provide enough pulp for a valley beater charge. Pulps were beaten according to TAPPI standards T 200 ts-66, with the exception that no British disintegrator was available. Pulp samples for Canadian Standard freeness (CSf) testing and handsheet formation were removed from the valley beater after intervals of 0, 5, 15, 25, and 35 minutes beating. Pulp freeness was determined using TAPPI standard T 227 m-58, while handsheets were prepared according to TAPPI standard T 205 os-71. The handsheets were tested at the Westvaco Corporation's Tyrone Papermill paper testing facility for tensile, tear, burst, and MIT fold according to TAPPI standard T 220 os-71. A Tinius Olsen automatic horizontal tester was used to measure tensile strength.

Strength values were plotted against CSf and average values determined by extrapolating at the 600, 500, 400, and 300 CSf levels. The extrapolated values were analyzed using two-factor analyses of variance described by Neter et al.

TABLE 2. *Total kraft pulp yields (%) and permanganate numbers obtained from gypsy moth-killed trees at selected times after tree death.*

Species	Total pulp yield (%)					
	Years dead					
	Control	One	Two	Three	Four	Five
Red oak	48.3 B[1]	51.6 A	49.4 AB	47.9 B	49.8 AB	50.4 AB
White oak	49.8 AB	51.3 B	49.3 A	50.3 AB	51.3 B	50.0 AB
Red maple	51.4 AB	51.9 AB	51.9 AB	50.9 A	52.4 B	51.3 B
	Permanganate number[2]					
Red oak	13.7 AB	13.9 AB	12.9 A	12.7 A	15.0 B	15.3 B
White oak	16.9 B	15.2 A	12.8 C	16.5 B	16.5 B	14.9 A
Red maple	12.3 A	13.9 AB	15.2 B	13.2 A	14.3 B	13.8 B

[1] Means with the same capital letter in a row are not significantly different at the 0.05 significance level.
[2] Based on 25 ml of potassium permanganate—TAPPI Standard T 214 m-50.

(1985). All statistical calculations were accomplished using Minitab (Ryan et al. 1986).

RESULTS AND DISCUSSION

Total pulp yields and permanganate numbers

Total kraft pulp yields and permanganate numbers obtained from pulping gypsy moth-killed red oak, white oak, and red maple trees are summarized in Table 2. Data show that under identical pulping conditions, no statistical differences in total kraft pulp yield were observed between white oak and red maple control trees and those trees dead up to five years. Statistically higher pulp yields were observed in pulping dead one year red oak compared to control trees. Red oak pulp yields ranged from a low of 47.9% (trees dead three years) to a high of 51.6% (trees dead one year). These results were comparable to pulp yields obtained from red oak live control trees (48.3%). In this study, pulp yields ranged from a low of 47.9% to a high of 52.4% for all species and dead age classes examined.

No consistent trends in pulp permanganate number and pulp yield could be established amongst species and time following tree death. For example, kraft digested white oak control chips produced pulps with an average permanganate number of 16.9, whereas trees dead two years produced pulps with an average permanganate number of 12.8. Since a higher permanganate number was measured in control pulps, it was expected that a higher pulp yield would be obtained. This was not observed and comparable pulp yields were measured (49.8% versus 49.3%).

Within-tree pulp yields and permanganate number

Since visual differences in chip quality (resulting from stain and fungal decay) were observed among species and time of tree death, an additional study was conducted to determine if differences in pulp yield occurred within a dead tree. A tree dead five years was randomly selected from each species, divided into the top, middle, and bottom bole sections and kraft pulped. The within-species total kraft pulp yields and permanganate numbers are summarized in Table 3. No within-species differences in total kraft pulp yield and permanganate number were observed in dead five year red oak and white oak; however, differences were

TABLE 3. *Total kraft pulp yields (%) and permanganate numbers obtained from top, middle, and bottom bolts of trees dead five years.*

Species	Specimen location	Pulp[1] yield (%)	Average $KMnO_4$[2]
Red oak	Top	48.5 a[3]	13.7 a
	Middle	48.6 a	13.4 a
	Bottom	49.6 a	13.9 a
White oak	Top	51.1 a	15.2 a
	Middle	50.7 a	12.4 b
	Bottom	51.3 a	11.6 b
Red maple	Top	51.5 a	13.2 a
	Middle	50.0 a	13.2 a
	Bottom	45.1 b	14.0 a

[1] Based on two replicate cooks.
[2] Based on 25 ml of potassium permanganate, TAPPI Standard T 214 m-50.
[3] Means with the same small letter in a column are not significantly different at the 0.05 significance level.

observed in red maple. A lower pulp yield (45.1%) with a higher permanganate number (14.0) was obtained for the pulped bottom bole section of red maple compared to the other portions of the tree.

Pulping results

Pulping results show that pulp yield and permanganate number variation occurred; however, no significant decrease in total pulp yield was observed with time following tree death. In most cases, higher total pulp yields were obtained from pulped dead trees compared to pulped control trees.

Pulp yield variations and random residual lignin patterns of pulped dead oak and maple trees could be due to the amount and type of decay fungi present at the time of pulping. As observed in an earlier study, if the bark remained intact on the bole of the dead tree, sufficient moisture was present to promote wood decay even five years after tree death (Garges et al. 1984). Hunt (1978a, b) pulped dead hemlock and western redcedar trees and found permanganate numbers to be higher for pulps infected by brown rot fungi compared to those trees infected with white rot fungi. Since both white and brown rot fungi invade dead oaks (Karasevicz 1987), the degree and amount of degradation by each type fungi within a tree could contribute to the pulping variations observed in this study. Karasevicz (1987) found the biodeterioration of red oak dead following gypsy moth defoliation to follow a successional pattern of degradation types; stain-white rot-brown rot. The white rot fungi left behind cellulose rich wood, which was utilized later in succession by brown rotters. The variation in degradation rates on tree components (cellulose, lignin) could explain why higher pulp yields were obtained in dead trees compared to live control trees.

The pulping observations made in this study support earlier findings. DeCrease et al. (1985) soda-pulped gypsy moth-killed red oak trees and found no statistical differences to occur in pulp yield for trees dead up to four years. No trends in brownstock Kappa numbers could be found based on time following tree death. Similar observations were reported by Ifju et al. (1979), who found no statistical differences in kraft pulp yield as well as no constant trends in permanganate numbers for pulps obtained from beetle-killed southern yellow pine dead up to

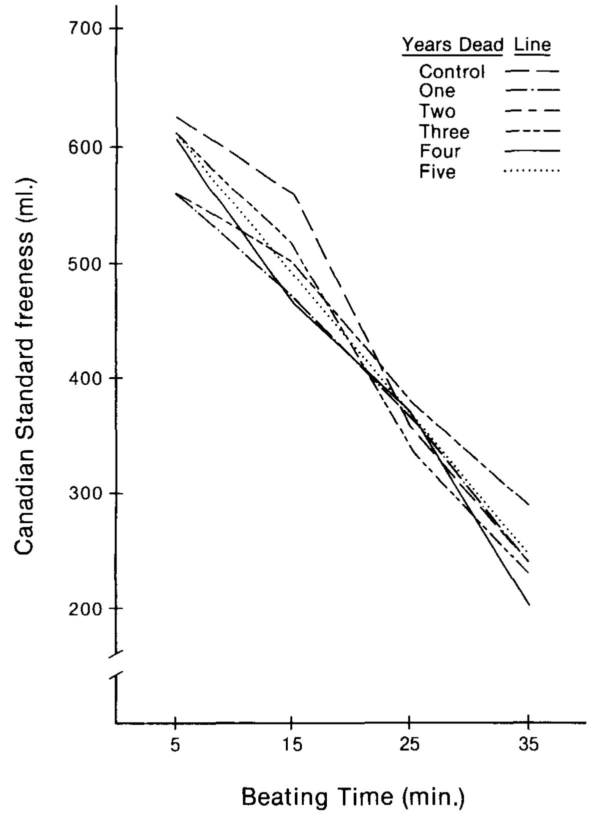

FIG. 1. Influence of beating time on CSf development for pulps obtained from white oak trees at selected times after tree death.

two years. Hunt (1978a, b) had drawn similar conclusions pulping decayed western hemlock, western redcedar, and alpine fir. Lowry et al. (1977) concluded that yield and kraft pulping properties of lodgepole pine dead seven years were similar to green wood. From the observations made in this study, it was concluded that satisfactory pulp yields can be obtained from gypsy moth-killed oak and maple trees dead up to five years.

Beating characteristics

The influence of beating time on CSf development for pulps obtained from dead white oak trees is shown in Fig. 1. No consistent trends in CSf values were observed in pulps with time after tree death. However, for some pulps less time was required to reach a given freeness level. It was expected that as more decayed chips entered the digester, less refining energy would be required to reach a given freeness (Hunt 1978a). Apparently, the amount of decayed fibers in pulp was minimal and had little effect on the beating rates of pulp in this study.

Handsheet strength evaluations

Handsheet strength evaluations studies of gypsy moth-killed trees are summarized in Tables 4, 5, and 6. With but a few exceptions, no statistical differences

TABLE 4. *Handsheet strength properties of pulps obtained from gypsy moth-killed red oak trees at selected times after tree death.*

Time of death (years)	CSf															
	Tear (g)				Tensile (kg/m)				MIT fold				Burst (kN/m)			
	600	500	400	300	600	500	400	300	600	500	400	300	600	500	400	300
Zero	71 a[1]	67 a	65 a	60 a	339 ab	482 b	571 a	589 a	28 a	195 a	438 a	813 a	159 b	310 b	352 a	393 a
One	50 a	69 a	74 a	70 a	268 a	357 ab	428 a	482 a	5 b	22 b	82 b	138 b	76 a	179 a	248 ab	297 a
Two	59 a	75 a	74 a	72 a	286 a	357 a	428 a	500 a	4 b	23 b	71 b	152 b	90 a	172 a	241 b	310 a
Three	66 a	69 a	72 a	70 a	375 b	428 ab	536 a	571 a	40 a	105 c	367 c	631 a	186 b	297 b	324 ab	379 a
Four	72 a	75 a	77 a	80 a	304 ab	446 ab	536 a	536 a	9 b	85 c	205 c	369 ab	145 b	241 ab	324 ab	359 a
Five	59 a	57 a	55 a	51 a	500 b	732 c	714 b	732 b	32 a	113 c	285 c	449 ab	214 b	310 b	366 a	393 a

[1] Means with the same small letter in a column are not statistically different at the 0.05 significance level.

TABLE 5. *Handsheet strength properties of pulps obtained from gypsy moth-killed white oak trees at selected times after tree death.*

Time of death (years)	CSf															
	Tear (g)				Tensile (kg/m)				MIT fold				Burst (kN/m)			
	600	500	400	300	600	500	400	300	600	500	400	300	600	500	400	300
Zero	71 a[1]	76 a	78 a	78 a	321 a	428 a	482 ab	517 a	52 a	120 a	227 ab	394 ab	186 b	262 ab	310 ab	359 a
One	44 a	58 a	69 a	81 a	268 ab	304 b	393 a	482 a	4 b	20 b	89 a	243 b	76 a	159 a	241 a	297 a
Two	60 a	67 a	74 a	77 a	179 b	375 ab	464 ab	536 a	3 b	17 b	104 a	255 b	97 a	186 a	276 ab	366 a
Three	60 a	68 a	71 a	56 a	286 ab	268 b	446 ab	500 a	10 b	84 c	275 ab	498 ab	138 ab	221 ab	290 ab	331 a
Four	78 a	74 a	77 a	46 a	304 a	357 ab	464 ab	500 a	7 b	68 c	496 b	820 a	138 ab	228 ab	338 ab	359 a
Five	81 a	71 a	77 a	48 a	375 a	482 a	554 b	589 b	10 b	168 a	413 b	731 ab	221 b	297 b	366 b	345 a

[1] Means with the same small letter in a column are not statistically different at the 0.05 significance level.

TABLE 6. *Handsheet strength properties of pulps obtained from gypsy moth-killed red maple trees at selected times after tree death.*

Time of death (years)	CSf															
	Tear (g)				Tensile (kg/m)				MIT fold				Burst (kN/m)			
	600	500	400	300	600	500	400	300	600	500	400	300	600	500	400	300
Zero	37 a[1]	57 a	52 a	51 a	339 ab	357 ab	464 ab	536 a	4 a	22 a	194 a	567 a	90 a	179 ab	283 ab	352 b
One	28 a	29 a	57 a	62 a	214 a	304 a	410 ab	714 b	3 a	12 ab	51 b	153 b	76 a	117 a	214 ab	283 ab
Two	37 a	37 a	52 a	73 a	304 ab	357 ab	464 ab	536 a	3 a	6 b	83 b	93 c	62 a	138 ab	255 ab	262 ab
Three	28 a	43 a	58 a	56 a	250 a	321 ab	339 a	357 c	6 a	21 a	137 ab	217 b	97 a	124 a	179 a	152 a
Four	25 a	44 a	44 a	46 a	321 ab	428 ab	517 bc	607 ab	4 a	28 a	148 ab	425 d	41 a	193 ab	269 ab	352 b
Five	40 a	41 a	33 a	48 a	375 b	446 b	607 c	679 b	4 a	43 c	189 a	373 d	110 a	214 b	303 a	366 b

[1] Means with the same small letter in a column are not statistically different at the 0.05 significance level.

TABLE 7. *Handsheet strength properties of pulps obtained from the top, middle and bottom boles of gypsy moth-killed trees dead five years.*

Species and section	CSf															
	Tear (g)				Tensile (kg/m)				MIT fold				Burst (kN/m)			
	600	500	400	300	600	500	400	300	600	500	400	300	600	500	400	300
Red oak																
Top	40 a[1]	40 a	40 a	46 a	354 a	512 a	472 a	551 a	20 a	60 a	190 a	330 a	152 a	234 a	255 a	310 a
Middle	51 a	58 a	53 a	56 a	354 a	393 a	512 a	590 a	14 a	62 a	140 a	250 a	145 a	207 a	276 a	338 a
Bottom	52 a	52 a	51 a	52 a	393 a	472 a	551 a	629 a	17 a	50 a	170 a	276 a	193 a	248 a	310 a	372 a
White oak																
Top	56 a	64 a	60 a	41 b	354 a	512 a	590 a	590 a	18 a	18 a	845 b	525 a	166 b	166 b	407 a	324 b
Middle	56 a	61 a	65 a	67 a	433 a	590 a	590 a	629 a	45 a	5 a	300 a	58 b	255 a	345 a	372 a	407 a
Bottom	57 a	76 a	73 a	76 a	393 a	551 a	551 a	590 a	110 b	420 b	170 a	710 a	234 a	345 a	379 a	414 a
Red maple																
Top	23 a	27 a	30 a	32 a	354 a	433 b	512 a	551 a	6 a	15 a	75 a	43 a	172 a	193 a	228 a	248 a
Middle	33 a	30 a	29 a	24 a	276 a	315 a	393 a	393 b	4 a	7 a	190 b	270 b	152 a	159 a	186 b	90 b
Bottom	44 a	35 a	20 a	20 a	236 a	197 a	472 a	590 a	5 a	13 a	35 a	153 a	124 a	179 a	255 a	303 a

[1] Means with the same small letter in a column are not statistically different at the 0.05 significance level.

in handsheet tear and tensile properties were observed in red oak, white oak, and red maple pulp with time after tree death over the freeness range evaluated. MIT fold tests were very erratic as indicated by the variations observed at selected times from tree death. Variations in burst properties were also observed over the freeness range examined. Burst properties appeared to be highest from pulps obtained from trees dead for five years compared to the other dead age classes.

Handsheets were prepared and tested from pulps obtained from the top, middle, and bottom bole sections of trees dead five years and evaluated at the various CSf levels for each species group. The results are summarized in Table 7. With but a few exceptions, no statistical differences in handsheet properties were measured for handsheets made from pulps obtained from top, middle, or bottom boles of trees. Surprisingly, although yield differences were measured, no reductions in sheet properties were observed for pulps obtained from the bottom bole of red maple.

Discussion of handsheet strength properties

The introduction of some decayed wood chips into the papermaking process appeared not to have drastically affected the strength properties of handsheets. In some instances, statistical differences in sheet properties were measured, but no consistent trends in reduction of sheet properties based on time following tree death could be established. It was expected that handsheet tear and tensile strength would decrease with an increase in time following tree death due to the introduction of fungally degraded fibers (Ifju 1979). Handsheet prepared from trees dead one and two years appeared to have followed this trend as evidenced by a slight decrease in handsheet tensile, MIT fold and burst properties for all species relative to the control pulps. However, handsheets prepared from pulps obtained from trees dead for three to five years were usually higher in strength compared to the other pulps.

The slight decline in handsheet strength properties after tree death may be in part due to the extent and amount of wood decay associated with trees dead one and two years. As shown by earlier studies (Karasevicz 1987), decay was not too far advanced in the red oak sapwood zone. During chip preparation, it was found that this decayed wood was not easily removed or lost as it was for trees dead three years or longer. Nearly all of the advanced decayed wood in the sapwood zone was lost during chip preparation for those trees dead three years or more. Therefore, it was possible that the proportion of decayed wood that was charged into the digester was more for trees dead one and two years compared to the other dead age classes. This condition in part could explain the variations observed in handsheet properties with time following tree death. While the amount of decayed wood was not thought to have been greater than 10% of the chip charge, this situation could have contributed to the variations in both pulp yield and handsheet properties observed in this study.

The handsheet strength results were in general agreement with that observed by other investigators. DeCrease and coworkers (1985) found no discernible trends in loss in red oak handsheet strength properties with time following tree death. Lowry et al. (1977) reported paper strength properties of dead lodgepole pine were satisfactory and that paper quality differences were insignificant. However, Ifju and coworkers (1979) found both tear and tensile properties to decrease with an increase in time of death for beetle-killed southern pines. Hatton (1978) concluded in his study that the burst index and breaking length of pulps obtained from spruce budworm-killed wood dead up to four years were similar to those of sound wood.

In general, hardwood pulps are inherently weak and would produce a weaker sheet of paper compared to long-fibered softwood pulps. Therefore, any small change in strength properties associated with an increase in time following tree death may have been masked by the inherent weakness of hardwood pulps. Perhaps more sensitive testing or measuring methods of decayed wood chips into the digester would have shown different results.

CONCLUSIONS

From the results of this study, the following conclusions were drawn:

1. No statistical differences in total kraft pulp yields were observed with time following tree death, although variations in pulp yields were measured among the species examined.
2. Handsheet strength property variations were observed, but reductions in sheet properties could not be related to time from tree death.
3. No within-species difference in total kraft pulp yields were observed in red and white oak trees dead five years; however, pulp yield differences were measured in red maple. With but a few exceptions, no within-species differences in handsheet properties were observed among the species examined.
4. Based on the results observed in this study, neither the pulp yield nor papermaking properties would be drastically affected by the introduction of dead trees into the kraft papermaking process.

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