BEETLE-KILLED SPRUCE UTILIZATION IN THE KENAI PENINSULA[1]

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ABSTRACT

Infestation of the *Dendroctonus rufipennis* beetle has resulted in large stands of dead and dying timber on the Kenai peninsula in Alaska. Tests were conducted to evaluate the value of beetle-killed spruce as pulpwood. The results showed that live and dead spruce wood can be pulped effectively. The two least deteriorated classes and the most deteriorated class of logs had similar characteristics when pulped; the remaining class had somewhat poorer pulpability. The more deteriorated wood required the same or slightly less refining energy to achieve a certain level of freeness. The presence of sap rot decay was found to be an important indicator of pulping efficiency and resultant pulp quality. Log deterioration had mixed effects on paper properties.

INTRODUCTION

Infestation of the *Dendroctonus rufipennis* beetle has resulted in large stands of dead and dying timber on the Kenai Peninsula in Alaska. White spruce *(Picea glauca* (Moench) Voss) is the major species affected along with the hybrid lutz spruce *(Picea lutzii* Little). Once infested, the trees are attacked by decay organisms such as fungi and other microorganisms. Because post-infestation time may affect the palpability of the wood and resultant paper properties and because the beetle has killed a large amount of timber, tests were conducted to evaluate the value of the beetle-killed material as pulpwood. This study is part of a larger project investigating the recovery of beetle-killed material for a variety of end uses (l).

A primary effect of beetle infestation is the elimination of a tree's natural defenses against fungal decay. Hundreds of species of fungi have been identified in wood. These have been broadly categorized as brown rot, white rot, soft rot, and sapstain or sap rot fungi (2). Brown rot fungi preferentially attack cellulose and hemicellulose (carbohydrates), which leads to reduction in pulp quality and yield. Soft rot fungi tend to attack both carbohydrates and lignin, discoloring and softening the wood; pulp quality is generally degraded. White rot fungi also tend to attack both lignin and carbohydrate components, but some of these fungi preferentially attack lignin. Thus, yield and quality may not be as affected by the presence of these fungi. Sapstain fungi are usually found in the sapwood of softwoods; these fungi mainly attack stored carbohydrates, but they may also cause some chemical degradation of the wood. The initial fungal attack on the wood ("incipient decay") is often invisible and difficult to detect.

Several previous studies examined the pulpability of dead, dying, and decayed trees. In a kraft pulping study of standing white spruce killed by spruce beetles in south-central Alaska, Werner and others (3) found no difference in pulp yield between live trees and trees that had been dead for as long as 50 years. Paper strength properties also remained nearly unaffected, being on par with those of pulp from recently dead trees. The report provides several references on the effect of decay on pulp qualities for true firs *(Abies* spp.), hemlock *(Tsuga* spp.), balsam fir *(Abies balsamea),* and jack *(Pinus banksiana)* and southern *(Pinus* spp.) pines.

Lowery (4) studied dead timber, both down and standing, in the Rocky Mountains. The species included Engelmann spruce *(Picea engelmannii),* Douglas-fir *(Pseudotsuga menziesii),* western larch *(Larix occidentalis),* and lodgepole pine *(Pinus contorta).* The results indicated that the lower moisture content of the dead wood required the use of more power for chipping and resulted in the production of more fines. Kraft pulping of lodgepole pine yielded pulp suitable for paper and board products.

The sulfite pulping process and its effect on wood infected with various types of decay was studied by Björkman and

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[1]This information was previously published as Pulpability of beetle-killed spruce. Res. Pap. FPL-RP-557. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory (1996).

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others (5). The authors classified the decay as either firm or soft rot, depending on the effects on the wood, and as light or dark, depending on the discoloration of the wood. Firm light rot is the same as white rot decay, whereas the other categories represent various types of soft and brown rot decay. The authors found that firm light rot did not cause significant deterioration of pulp quality. However, the other types of decay (soft dark rot, soft light rot, and firm dark rot) reduced pulp quality and yield. The discoloration caused by decay increased the amount of pulping and bleaching chemicals compared to that required for sound wood.

Samples of green wood and dead wood from insect-killed lodgepole pine in Montana were chemically (kraft and sulfite) and mechanically pulped (6). For kraft pulping, the green wood and sound dead wood had very similar pulping and papermaking characteristics. The decayed dead wood pulped more quickly and had lower residual lignin content, lower yield, and slightly lower strength. Chemical analysis of the wood indicated lower holocellulose and α–cellulose content. The palpability of beetle-killed southern pines (*Pinus taeda* L. and *Pinus echinata* Mill.) was evaluated for the kraft process (7). The logs were evaluated for pulp Kappa number and yield, and paper strength properties based on time since death of the tree. Although no decline in yield was observed, there were slight increases in Kappa number. Tear strength of pulp from recently dead wood was observed to decrease slightly whereas tensile strength increased slightly. A loss of tensile strength was observed after longer periods. The authors concluded that the beetle-killed material was usable for kraft pulping up to 2 years after the death of the tree.

EXPERIMENTAL PROCEDURE

The trees were harvested from six locations on the Kenai Peninsula in Alaska. The logs were obtained from trees that had been classified by visual inspection into four deterioration classes, ranging from live or recently dead trees (class 1) to trees exhibiting major deterioration such as sloughed bark and large weather checks (class 4) (Table I). After the trees were felled, the log and defect volumes were estimated using Scribner rules (8) and cubic rules (9). Gross volumes were estimated using Bruce's formula for butt logs and Smalian's formula for all other logs. Specific details for each log can be found in Scott and others (10).

The logs were shipped to the Forest Products Laboratory in Madison, Wisconsin, where they were debarked using draw knives, chipped in a four-blade chipper, screened, bagged, and stored at 5°C. During screening, the amount of oversized and undersized chips was not noted. The moisture content (dry basis) was determined. The chips were pulped in a 23-L, stainless-steel digester with pumped liquor circulation and indirect steam heating. The charge was 2.5 kg of ovendry chips with a 4:1 liquor-to-wood ratio. The chemical charge was 18 percent active alkali on wood for the low Kappa cooks and 16 percent active alkali on wood for the high Kappa cooks; 25 percent sulfidity was used for both cooks.

Table I—Deterioration classes of beetle-killed spruce

Deterioration class	Description
1	Trees green or infested; needles green, but attacked by beetles
2	Trees recently dead; red–brown needles; retention of fine branches and twigs; bark still tight
3	No fine branches and twigs; gray crown; tight bark or at least 90 percent of bark remaining; small weather checks
4	Trees dead for a long time; some large branches broken off; bark loosened and more than 10 percent sloughed away; large weather checks apparent in many trees

Each log was pulped to two Kappa levels: nominal 30 and 80 Kappa. For each cook, temperature was ramped from 80°C to 170°C over a period of 90 to 100 min. For the low Kappa level, the cook was held at constant temperature for 40 min. For the high Kappa level, the cook was held at constant temperature for 90 to 100 min. The liquor was drained, and the chips were washed in the digestor and then fiberized in an atmospheric refiner. The pulp was screened in 0.3-mm slotted plates, dewatered shredded and stored for papermaking and testing. Screened yield and Kappa number were determined (Tappi test method T 236) (11).

Some samples from deterioration classes 1 and 4 were further tested for papermaking properties because we expected that these samples would show the greatest differences. Beater curves were generated by refining the pulps to various Canadian standard freeness (CSF) values to detemine papermaking properties. The pulps were refined in a PFI mill, a laboratory refining apparatus, according to Tappi test method T 248. The following properties were measured: CSF (Tappi test method T 227). Kajaani fiber length (T 271), thickness (T 220), moisture content (T 412). burst strength (T 220). tensile strength (T 220), and tear strength (T 220) 11).

EXPERIMENTAL RESULTS

The overall results indicate that deterioration classification alone does not have a great effect on pulpability of the wood. However, we were able to make several general observations:

- The amount of decay in the logs was not necessarily a function of the deterioration class: the amount of decay varied widely in each deterioration class, ranging from 0 to at least 80 percent. The individual samples represented the variation observed throughout the entire sample, but did not reflect deterioration from beetle-kill alone. While introduction of sap rot fungi can be attributed to beetle activity, the amount of heart rot seen in those trees indicated that it was present prior to attack by beetles.
- The amount of deterioration did not affect wood pulpability or properties of the resultant paper to a great extent. Other factors seemed to have a greater effect on pulp quality.
- The presence of sap rot tended to increase the Kappa number of resultant pulp while decreasing the yield.

Pulping Properties

Table II summarizes the pulp yield and Kappa results for the high and low Kappa cooks. The specifics for each cook can be found in Scott and others (1996). The high Kappa vaIues class 3 had the highest Kappa number. For the low Kappa represent a linerboard grade of paper and the low Kappa cooks, a bleachable grade of pulp (the low Kappa cooks were divided into two subgroups based on H-factor). Note that for both high and low Kappa cooks, the results for deterioration classes l, 2, and 4 were very similar on the basis of yield. The high Kappa results (H-factor of 611) showed that the last deteriorated class had a slightly lower Kappa number that the other classes and that deterioration results (H-factors of 1375 and 1528), a similar trend was apparent for deterioration class 3: lower yield and higher Kappa number in both cases. Deterioration classes l, 2, and 4 produced similar results in these cooks. However, statistical analysis among the groups revealed no significant differences.

A closer look at the class 3 samples indicates that one log had a much lower yield and higher Kappa number for both the high and low Kappa cooks. This log was only 68 percent sound; all the defect was a result of sap rot, which can lead to inferior pulps. Other logs in deterioration classes 2, 3, and 4 also contained sap rot. Table III shows the effect of sap rot on pulp yield and Kappa number for all deterioration classes. For the high Kappa cooks, the Kappa number increased with the presence of sap rot by 11 points; pulp yield decreased slightly. For the low Kappa cooks, Kappa number rose slightly, but there was a greater decrease in pulp yield. The presence of sap rot also increased the variation between the samples, as evidenced by the larger standard deviations.

Table II—Average pulp yield[a]

H-factor	Deterioration class	Number of samples	Net volume (%)	Yield (%)	Kappa number
611[b]	1	2	58.2	53.89 (0.12)	71.93 (3.44)
	2	3	84.1	53.94 (2.91)	75.04 (9.98)
	3	4	74.9	51.89 (2.10)	86.12 (10.31)
	4	3	87.1	54.67 (0.84)	75.81 (8.43)
1375[c]	1	3	55.5	48.50 (0.63)	26.48 (1.22)
	2	3	84.1	47.63 (2.49)	25.48 (1.20)
	3	3	75.6	45.08 (2.57)	30.51 (1.04)
	4	3	87.1	47.12 (1.32)	25.52 (0.82)
1528[c]	1	2	58.2	47.36 (3.78)	22.81 (0.11)
	2	2	76.1	46.89 (2.62)	22.33 (1.17)
	3	1	85.9	45.93 (NA)	26.11 (NA)

[a]Numbers in parentheses indicate standard deviation.
[b]High Kappa number.
[c]Low Kappa number.

Table III—Effect of sap rot decay for all deterioration classes[a]

H-factor	Condition	Number of samples	Yield (%)	Kappa number
611[b]	Logs with sap rot	5	52.77 (2.17)	84.81 (10.61)
	Logs without sap rot	7	53.90 (2.00)	73.84 (6.40)
	All logs	12	53.43 (2.06)	78.41 (9.76)
1375[c]	Logs with sap rot	4	45.51 (2.43)	28.21 (2.48)
	Logs without sap rot	8	47.86 (1.54)	26.39 (2.18)
	All logs	12	47.07 (2.11)	27.00 (2.35)
1528[c]	Logs with sap rot	1	45.04 (NA)	23.16 (NA)
	Logs without sap rot	4	47.35 (2.46)	23.31 (1.97)
	All logs	5	46.89 (2.37)	23.28 (1.70)

[a]Numbers in parentheses indicate standard deviation.
[b]High Kappa number.
[c]Low Kappa number.

The presence of decay in logs and chips can have several deleterious effects on the chemical pulping of wood. Fungal degradation itself can result in yield losses and changes in Kappa number as a result of the relative amount of degradation of carbohydrates and lignin by the organisms. Additionally, if the carbohydrates are preferentially attacked, the Kappa number will rise as the lignin to carbohydrate ratio increases. Also, the presence of the fungus and its metabolites can neutralize the pulping chemicals, leading to less availability of chemicals for pulping and resulting in higher yields and Kappa numbers for the same cooking time. Additional effects, such as the opening of the cell wall structure by fungal growth, can increase liquor penetration into the cell wall. The relative extent to which these effects take place, which depends on the type of fungus and the exposure conditions, affects the final pulping results

Refining and Papermaking Properties

Figure 1 shows the number of PFI mill revolutions compared to CSF values for the high Kappa number pulps. The number of revolutions indicates the amount of refining energy needed to reduce CSF, a measure of pulp drainability. Comparison of the curves shows a wide variation in the amount of refining necessary to reach a certain freeness level. On average, less refining energy was needed for the more highly deteriorated class 4 logs than the class 1 logs. However, differences in amount of refining energy seemed to be more dependent on the logs themselves rather than the deterioration class. Variations within a deterioration class may have caused the type of decay (e.g., sap as opposed to heart) found in each log, with environmental factors presenting a secondary influence.

Figure 2 shows the effect of the high Kappa cook on strength properties. Only slight differences occurred between deterioration classes. For the same CSF, tensile indices were in general slightly higher for class 4 than for class 1. These results may be due to the relative amount of decay noted in each log; log 407-1 (class 4) showed the highest tensile indices at all CSF levels and no signs of decay. The higher net volume for the class 4 logs compared to class 1 logs (87.1 versus 58.2 percent, respectively) may have contributed to the higher strength values. The burst indices showed similar trends. The tear index was primarily a function of the average fiber length (10).

The number of PFI revolutions as a function of CSF for the low Kappa pulp is shown in Figure 3. Again, the differences among classes seemed less significant than the variation among logs. Log 132-2 required the least energy for refining, possibly as a result of the great extent of decay in the log. Similar to the high Kappa pulp, the tensile strength indices for the low Kappa pulp were slightly higher for the more deteriorated logs (Fig. 4). However, as for the high Kappa pulps, these values were strongly dependent on the amount of decay present. Regardless of the deterioration class, the lower the net volume measured, the lower the tensile indices. As for the high Kappa pulp, the tear index showed strong dependence on fiber length.

These results should be interpreted as indicative of expected trends for pulping this kind of material. As mentioned earlier, the samples had different parameters that could not be accounted for in the interpretation. For example, there were significant variations in the breast height diameter of the logs, height of the sample from the ground, and growth location of the tree. More significantly, the net volume of sound wood in the logs varied between the classes, which seemed to have a significant effect on paper properties. The variation in location was especially important since

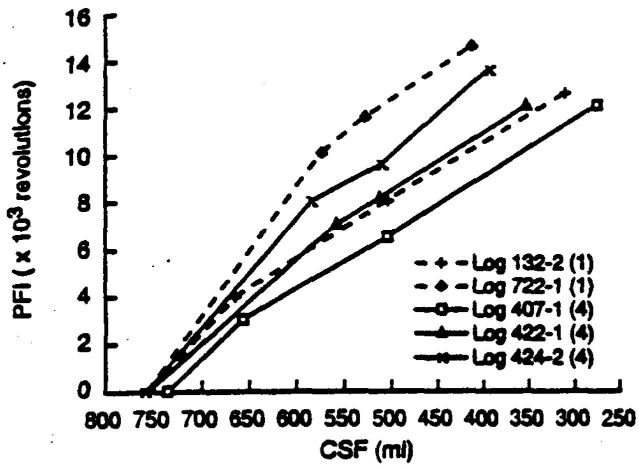

Figure 1—Revolutions of PFI mill as a function of Canadian standard freeness (CSF) for high Kappa value cook. Number of revolutions is a measure of energy needed to refine fibers. Numbers in parentheses are deterioration classes.

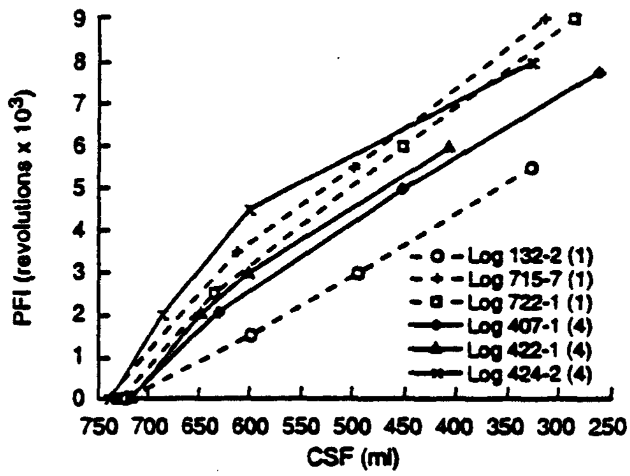

Figure 3—Revolutions of PFI mill as a function of CSF for low Kappa cook.

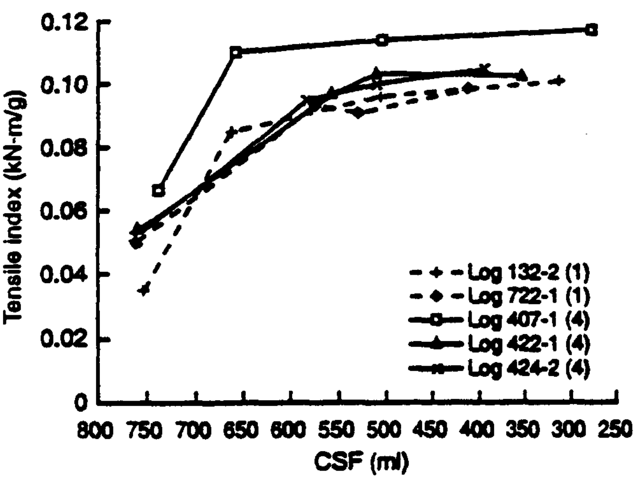

Figure 2—Tensile index of paper made from high Kappa cook as a function of CSF.

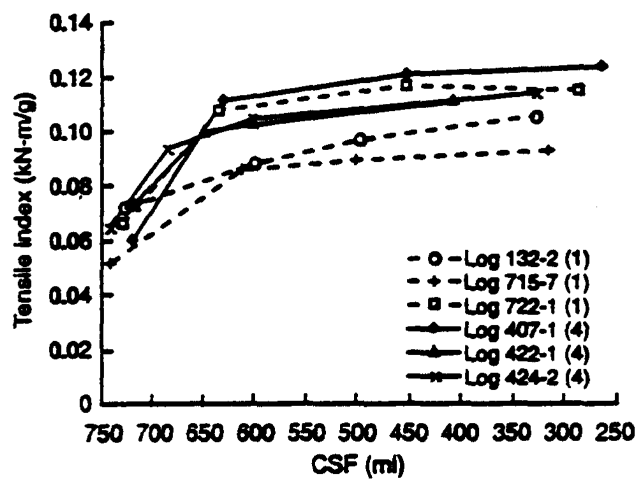

Figure 4—Tensile index of paper made from low Kappa cook as a function of CSF.

exposure, soil conditions, and other environmental factors may have contributed to wide variations in the quality of the resultant fiber irrespective of the effect of deterioration. In addition, the height at which the tree section was taken may have significantly affected the amout of juvenile wood in the sample. Juvenile wood is known to have a significant effect on the kraft pulping process, typically resulting in a decrease in yield and an increase in liquor consumption (10).

CONCLUSIONS

The results of this study indicate that beetle-killed spruce can be pulped effectively. Our conclusions are as follows:

- Beetle-killed spruce can be pulped effectively with the kraft pulping process. Pulp yield from deteriorated logs was similar for high and low Kappa levels.
- Extent of log deterioration has little effect on pulping. There was little apparent difference between deterioration class 1 (control) and classes 2 and 4. Class 3 seemed to have slightly less favorable pulping characteristics.

However, the sample sizes and numbs of uncontrolled variables and environmental factors were such that no rigorous statistical interpretation of these data was possible.

- Refining energy is the same or slightly less for pulp produced from more deteriorated wood. This is to be expected since the cell wall structure would be weakened by the action of fungi and other organisms. The refining energy was strongly dependent on the presence of decay-logs with lower net volume required less refining energy.
- Log deterioration has mixed effects on paper properties. In general, tear strength was slightly lower and tensile strength slightly higher for the more deteriorated wood. Burst and tensile strength were strongly dependent on the amount of log decay, as measured by the net cubic volume of sound wood. Tear strength was strongly dependent on fiber length, which tended to be shorter in the more severely deteriorated wood. However, strength properties were still of an acceptable quality when compared to the control.

RECOMMENDATIONS

This study should be used as a preliminary indication that deteriorated wood is pulpable by the kraft process. However, variations in parameters, especially the region from which the logs are obtained and environmental factors, need to be carefully taken into account to isolate the effect of log deterioration from other variables.

Two methods of obtaining statistically reliable data am (1) to investigate a large number of samples such that the effects of uncontrolled parameters can be taken into account and the data subjected to statistical analysis, and (2) to investigate selected samples from a restricted area such that environmental factors are similar for all samples; the sample logs should also be of similar sizes and cut from the same distance above ground.

If a particular area or stand of trees is to be harvested for pulping, we suggest that option 2 be utilized to evaluate the trees for pulpability. This method would be the most cost-effective in terms of amount of research needed to produce high quality data. However, since the presence of decay seems to be a key factor in the suitability for pulping, an assessment of the harvested logs using the net cubic volume as the parameter should also give a good indication of the quality of the material for pulp and paper manufacture.

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Book 1

May 5-7, 1997
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