DECAY RESISTANCE OF OUT-OF-SERVICE UTILITY POLES AS RELATED TO THE DISTRIBUTION OF THEIR RESIDUAL CREOSOTE CONTENT
(Ketahanan Tiang Listrik Bekas Pakai terhadap Kerusakan Biologis yang Dihubungkan dengan Sisa Kandungan Bahan Pengawet Kreosot didalamnya)\(^1\)

By / Oleh

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Ringkasan


Kata kunci: percobaan simulasi, jamur Neolentinus lepideus Fr., uji petak tanah, tiang listrik bekas pakai, dan jenis southern yellow pine.

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Summary

Decay resistance of weathered, creosote-treated southern yellow pine poles which have been out-of-service was investigated through a simulation trial (soil-block test) to evaluate their effectiveness against biodegradation for possible utilization of these poles into useful products, such as solid-wood structures and wood composites. It turned out that the decay resistance in 5- and 25-year weathered as well as in freshly treated poles was related to their creosote content and its distribution inside the poles. Weathering of the poles caused reduction in creosote content such that the residual content of the outer and upper portions of the poles was lower than the inner and bottom portions. Overall residual creosote content in the 5-year poles was lower than in freshly treated poles, but still higher than in 25-year poles. Above 14 percent level of residual creosote content, the decay resistance of weathered poles was still high. Below that level, the decay resistance decreased dramatically; and therefore, the 14 percent creosote content was regarded as the critical level. Further, when linked to the 14 percent critical level, decay resistance of 5-year poles was mostly still comparable to freshly treated poles: whereas, the decay resistance of 25-year poles, especially in the outer portions, was much lower and approaching that of untreated southern yellow pine. In reutilization of out-of-service poles for useful products (i.e. solid-wood structures and wood composites), consequently, their residual creosote content should be considered. Portion of these poles with the creosote content at 14 percent or higher is suitable for solid-wood structures in exterior applications. For wood composites, pieces of the poles with the creosote content below 14 percent should be placed in the interior, while those with the content greater than 14 percent are more suitable for the outer part.

Keywords: simulation trial, fungus *Neolentinus lupidens* Fr., soil-block test, out-of-service weathered utility poles, and southern yellow pine species.

I. INTRODUCTION

In the United States, there are about 150 million wooden poles in service carrying electrical transmission and distribution lines. Each year the ever-expanding basic electric and communication industries consume about six million treated poles. Approximately 75 percent of the annual consumption of the poles consists of southern yellow pine, which are usually treated with creosote (Mickelwright 1991). One to two million poles are to be replaced each year, mostly due to mechanical wear rather than biodegradation. Most of these replaced poles are considered no longer serviceable (Bull and Lindheim 1990). As a result, utility companies are faced with a dilemma regarding the disposal of out-of-service poles which still contain residual creosote. Popular waste disposal options are becoming more and more difficult due to diminishing land-fill spaces, limited capacity of incineration, and strictly environmental regulations.

Reutilization of waste poles, by among others, their conversion into useful products, such as solid-wood structures and wood composites can be regarded as a one way to solve their disposal problems. In addition, the remaining creosote content in the poles can still have the preserving capability against wood decay. About two cubic meters per year of weathered utility poles treated with creosote are available for recycling (Feltion and DeGroot 1996). However, the standing poles during their service are affected by long-term weathering, such as heat from the sun, water-leaching from the rain, and gravitational force, thereby causing some changes in their...
creosote content and its distribution inside the poles. As a result, these changes may affect the effectiveness of the weathered poles and their converted wood products as well, against biodegradation.

The soil-block test is commonly used to evaluate the effectiveness of preservatives in freshly treated as well as weathered wood products (Hunt and Garrat 1967). This test can measure the decay resistance of treated poles at a given level of preservative retention. In this case, a fungus is introduced to infect and then degrade the wood substances (Duncan 1954). In creosote-treated wood, such as utility poles and crossties, the wood-rotting fungus Neolentinus lepideus Fr. is often used. It is a brown-rot fungus which destroys cellulose and hemicellulose, leaving lignin in the form of fine brownish residue. When wood is decayed by this fungus, it becomes dark in color with whitish mycelium and a strong aromatic odor (Hickin 1971).

The fungus Neolentinus lepideus Fr. is resistant to creosote and commonly found in railway ties, utility poles, and other treated wood which has received insufficient preservatives during pressure impregnation treatment (Hunt and Garrat 1967; and Richardson 1978). Therefore, weathered treated wood, such as railway sleepers and utility poles may be vulnerable to the biological attack by this fungus. The objective of this study was to evaluate the decay resistance of weathered out-of-service, creosote-treated utility poles as intended for useful wood products. This was done by performing decay simulation (soil-block test) on those corresponding poles using the fungus Neolentinus lepideus Fr. and afterwards the extent of their biodegradation was examined with respect to their residual creosote content and its distribution inside the poles.

II. MATERIALS AND METHODS

The study was divided into two: Distribution of residual creosote content in weathered poles, and Decay resistance of the corresponding poles.

A. Distribution of residual creosote

Weathered out-of-service southern yellow pine (Pine sp.) poles of two service duration groups (5- and 25-years) were selected. In addition, freshly treated poles of the same species were used for comparison purpose. Five different poles from each group were taken as replicates. These poles were obtained from the Entergy Gulf States Utility Company and brought to Lee Memorial Forest near Bogalusa, Louisiana for processing. All the poles were passed through a metal detector to remove metal objects. After metal removal, the poles were cut into 8- to 10-ft long bolts. Three bolts (top, middle, and bottom) were selected from each pole. Each bolt was sawn into experimental specimens of lumber using a portable Wood Mizer at horizontal distances of 0.5-, 1.5-, 2.5-, and 3.5-inches from pole surface, respectively (Figure 1). During sawing, sawdust samples obtained from various vertical and horizontal locations in the poles were collected for creosote content determination, while the lumber portions were used for the decay test.
Creosote content (% of dry, extracted wood) was determined using toluene extraction in accordance with AWPA Standard A6-83 (1984\(^a\)), as follows:

\[
100 \times \frac{(W_1 - W_2 - W_3)}{W_2} \tag{1}
\]

where \(W_1\) is weight of wood samples before extraction; \(W_2\) is weight of oven-dry extracted sample; and \(W_3\) is weight of water in sample.

**B. Decay resistance**

The same as in the residual creosote distribution, visually defect-free samples were obtained from a lumber at several vertical and horizontal locations in the poles. The samples were further sawn into blocks measuring 0.75 by 0.75- by 0.75-inches. They were stored in an environmental chamber at a constant temperature (80°F) and relative humidity (70 percent) for 24 hours, and weighed at equilibrium moisture content. Decay resistance was performed by the soil-block method, using a sandy loam soil with a water-holding capacity of 22-25 percent, in accordance with AWPA Standard M10-77 (1984\(^b\)). Block samples were subjected to decay with the fungus *Neolentinus lepideus* Fr., which were obtained from the American Type Cultural Collection with specification No. 12653 (Madison 535). For comparison purposes, 20 blocks of untreated southern yellow pine (SYP) as reference were also prepared. After air-drying and weighing, they were conditioned and subjected to decay in the same manner as treated test samples. SYP feeder strips measuring 0.125- by 0.125-
by 1.275-inches with the grain parallel to the long dimensions were used for each block.

Each of the feeder strips was added into a bottle, containing the sandy loam soil, and then inoculated with fungus inoculum. The inoculated bottles were incubated in a conditioned room at 80°F and 70 percent relative humidity for about three weeks until the feeder strips were covered with mycelium. The bottles were then ready to receive the test blocks from either treated poles or untreated SYP. They were placed in the incubation room.

At the end of 12-week incubation period, the blocks were removed from the bottles, and the mycelium was carefully brushed-off. The blocks were reconditioned again and then weighed at equilibrium. The following formula was used to determine the weight loss (WL) in per cent, as follows:

\[ \text{WL} = \frac{W_i - W_f}{W_i} \times 100 \]  

where \( W_i \) and \( W_f \) are the initial and final weights of block samples, respectively.

**III. RESULTS AND DISCUSSION**

**A. Distribution of creosote content**

The analysis of variance reveals that the effects of main sources of variances (service duration, vertical locations, and horizontal locations) and the interaction of these three variables were significant (Table 1). The significant interaction shows that at a given pole service duration and vertical location, the creosote content had specific patterns of changes with respect to horizontal location (Figure 2). Creosote content in freshly treated poles was much higher than in weathered poles. In weathered poles with 5-year service duration, the residual creosote content was still greater than with 25-year duration. In both 5- and 25-year old poles, creosote content tended to increase horizontally from the surface to the pith, and vertically from the upper to the bottom portions. On the contrary, the horizontal trend in freshly treated poles was inversely of weathered poles; whereby, the creosote content was highest in the outer portion, and was lowest in the interior. The vertical trend, however, showed no significant changes.

The decreasing trend in residual creosote from the pith to the surface of 5- and 25-year old poles is mainly due to the effect of bleeding and leaching of creosote during service (Schneider, et al. 1995). In long-term weathering, the surface of poles was more exposed to high temperature than the interior, causing the evaporation mostly of low-molecular weight (more volatile) fractions of the creosote. As a result, outward movement of creosote occurred due to the pressure gradient between the surface and the interior of the poles. Higher residual creosote content inside the weathered poles beyond 2.5-in. distance from the surface could be attributed to the presence of pit aspiration and bulking effect of extractives, inhibiting the passage of creosote to move out from the interior. However, pit aspiration is less common near the pole surface, since it consists mainly of sapwood. Also, steaming in the pre-treatment method tends to relieve pit aspiration in the sapwood. These phenomena
also explain the decreasing trend of creosote content from the outer to the inner portions of freshly treated poles. The higher creosote content in the bottom of 5- and 25-year old poles was mainly due to gravity which caused the downward movement of the creosote in standing poles during service.

Table 1. Analysis of variance on creosote content and percent weight loss in treated poles

<table>
<thead>
<tr>
<th>Source of variation (Sumber keragaman)</th>
<th>df (db)</th>
<th>F-values (-nilai)</th>
<th>F-tables</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Creosote content (Kandungan kreosot)</td>
<td>Weight loss (Kehilangan berat)</td>
</tr>
<tr>
<td>Service duration (Masa paka), S</td>
<td>2</td>
<td>24.57**</td>
<td>24.92**</td>
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<tr>
<td>Vertical location (Kedudukan vertikal), V</td>
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<td>19.43**</td>
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<tr>
<td>Horizontal location (Kedudukan horizontal), H</td>
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<td>16.96**</td>
<td>8.74**</td>
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<td>Interaction (Interaksi), S<em>V</em>H</td>
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<td>2.98**</td>
<td>3.94**</td>
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<tr>
<td>Means (Rata-rata), Y</td>
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<td>15.49</td>
<td>8.22</td>
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<td>Unit (Satuan)</td>
<td>%</td>
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<td>%</td>
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<td>Coeff. of variation (koefisien keragaman), %</td>
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<tr>
<td>Remark (Keterangan)</td>
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B. Decay resistance

The analysis of variance on weight loss of treated poles (Table 1) shows that the effect of all sources of variation (i.e. service duration, and vertical and horizontal locations) were significant as well. Poles with longer service duration had higher weight loss, indicating more intensive decay (Figure 3). Weathering which caused reduction in creosote content (Figure 2) made the exposed part of wood poles less protected, and therefore more vulnerable to biodegradation by fungi. In untreated SYP, the weight loss was much higher than in overall treated poles. As shown visually in Figure 4, decay activity by fungi was more pronounced by the more extensive growth of mycelium in untreated SYP and 25-year old poles, but was less and least in 5-year and freshly treated poles, respectively.
In freshly treated poles, weight loss in the outer portion was negligible (Figure 3) since the creosote content near the surface was high (Figure 2). The weight loss somewhat increased toward the pith due to the inward gradual decrease in creosote content. With respect to vertical location, the weight loss in freshly treated poles shows no significant changes. In 5- and 25-year old poles, the weight loss was greater in the upper and outer portions than in the bottom and interior, while the residual creosote content in the same locations decreased horizontally outward and upward. This indicates that the loss of creosote in the outer and upper portions of weathered poles enhanced the decaying activities of the fungus.

![Diagram showing weight loss and creosote content at different locations](image)

**Figure 2. Distribution of creosote in treated poles**

*Gambar 2. Penyebaran kreosot dalam tiang listrik diawetkan*

It is interesting to note that the fungus-induced weight loss was negligible at creosote content above 14 percent level (Figure 5). It increased dramatically with the reduction in creosote content starting from this critical level, indicating that at low creosote content, there was much greater activities by the fungus. For example, the weight loss in the outer portions of 25-year poles ranged from 31.9 to 34.8 percent (Figure 3), while the creosote content in the corresponding portions ranged from 2.7 and 2.8 percent; on the other hand, weight loss in the inner portions of these poles was much lower (3.2 - 5.0 percent) since the creosote content was still close the 14 percent critical level (11.4 - 12.9 percent). This might be linked to the reduction of creosote content in the outer portion, which was accompanied by some loss of its more volatile (i.e. low molecular weight) fractions, as described in the distribution of residual creosote inside the weathered poles. Stasse (1955) stated that creosote of low molecular weight fractions tended to have greater partial solubility in water than high-molecular weight fraction creosote. Therefore, fractions of high-water solubility could more seriously damage the body fluid of organisms they were intended to inhibit.
Figure 3. Weight loss with respect to vertical and horizontal locations in treated poles (SYP = untreated southern yellow pine wood)

Gambar 3. Kehilangan berat pada kedudukan vertikal dan horizontal tertentu dalam tiang listrik diawetkan (SYP = kayu southern yellow pine yang tidak diawetkan)

Figure 4. Decay activity by the fungus in creosote-treated pole woods, as shown by the extent of mycelium growth, was enhanced by the decreasing level of creosote content (creosote content levels: A>B>C>D), mycelium growth: A>B>C>D, and A, B, C, and D are freshly treated, 5-year poles, 25-year poles, and untreated southern yellow pine (as a control), respectively

Figure 5. Relationship between creosote content and weight loss
_Gambar 5. Hubungan antara kandungan kreosot dengan kehilangan berat_

When pole averages are considered, the weight loss in freshly treated poles at 0.5- and 3.5-in. horizontally from the pole surface was 0.6 - 1.3 percent, respectively. For weathered poles, the weight loss at the corresponding horizontal distances was 6.4 and 1.9 percent in 5-year poles; and 32.1 and 4.2 percent in 25-year poles, respectively. For untreated SYP, the weight loss was the greatest (42.9 percent). It is apparent that the decay resistant of 5-year poles was mostly still high and closer to freshly treated poles; meanwhile, low decay resistance in the outer portions of 25-year poles was comparable to untreated SYP.

The results of this study suggest that, when out-of-service weathered poles are reutilized for useful products (i.e. solid-wood structures and wood composites), their residual creosote content should be considered. In establishing solid-wood structures for outdoor or exterior applications, portions from the weathered poles with low decay resistance (at residual creosote content less than 14 percent) should not be used; rather, those with high decay resistance (at creosote content above 14 percent) are more reliable. Further, in the processing of wood composites, pieces with the low decay-resistance wood poles (mostly at 25-year service) should be located in the inner part of the corresponding products; whereas, pieces from the high decay-resistance poles (mostly at 5-year service) are more suitable for the outer part. The overall reason is that solid-wood structures and the outer part of the wood composites, in their exterior application, are more likely exposed to ground contact and other decay-inducing environmental factors.
IV. CONCLUSIONS

Weathering affected the distribution of residual creosote content in weathered out-of-service poles, such that longer service duration of the corresponding poles caused reduction in creosote content. The content in the upper and outer portions of the corresponding poles was lower than the bottom and the inner portions.

The variation in decay resistance of weathered poles was related to their residual creosote content. Reduction in decay resistance in 25-year poles, which was comparable to untreated southern yellow pine timber, was greater than in 5-year poles. Decay resistance of most portions in 5-year poles was still closer to freshly treated poles.

In weathered poles, the residual creosote content at 14 percent was regarded as critical level. Above the critical level, decay resistance of the poles (mostly at 5-year service) was still high. However, below this level (mostly at 25-year service) the decay resistance decreased drastically.

Significant relationship between decay resistance and residual creosote content in weathered out-of-service poles should be considered when these poles are reutilized for other useful products such as solid-wood structures and wood composites. Among others, portions of the weathered poles with residual creosote content above 14 percent critical level are more suitable for exterior-application solid-wood structure and for the outer part of wood composites, while those with the residual creosote below the critical level are for the interior of the composites.

LITERATURE CITED


