Performance Evaluation of Tall Oil Pitch Emulsion for Stabilizing Unpaved Forest Road Surfaces

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In British Columbia's central interior, production of tall oil-based road-surface stabilizers, which are coproducts of the kraft pulping process, began in 1990. One product, a tall oil pitch (TOP) emulsion, was applied as a test to a 5.1-km section of unpaved forest road near Prince George, British Columbia, in May 1992. The Forest Engineering Research Institute of Canada cooperated with the British Columbia Ministry of Forests' Prince George Forest District to evaluate the emulsion's performance on the forest road. Road-surface conditions and dustfall were monitored, and information about application procedures and costs, aggregate gradation, climate and traffic conditions, and maintenance procedures was collected.

Maintenance of a high-quality running surface on unpaved forest roads is an ongoing challenge for forest companies and government agencies. A stabilized surface made up of correctly graded aggregate can lower road and vehicle maintenance costs, lengthen the interval between resurfacing treatments, improve road safety and public goodwill by reducing dustfall, and reduce sediment in runoff water. However, because it is difficult to quantify these benefits monetarily, forest companies are often reluctant to invest in road-surface stabilization projects.

The forest industry in British Columbia has used calcium and magnesium chlorides, calcium and sodium lignosulfonates, asphalt emulsions, seal coats, and other products to stabilize unpaved road surfaces and control dust. Recently several lesser-known compounds, some of them proprietary, have emerged in North America as alternative treatments. They are referred to as "nonstandard stabilizers" and include compounds such as tall-oil based emulsions, bioenzymes, electrolytes, and pozzolans (*1*). Of the numerous conventional and nonstandard stabilizers available, most have shortcomings that limit their use to particular climate, soil, and traffic conditions.

In 1990, B.C. Chemicals Ltd. of Prince George, British Columbia, began producing tall-oil-based road-surface stabilizers. In a trial of one such product, a tall oil pitch (TOP) emulsion was applied to an unpaved 5.1-km section of the Willow Forest Service Road in the central interior of British Columbia in May 1992. The Forest Engineering Research Institute of Canada (FERIC) cooperated with the Prince George Forest District of the British Columbia Ministry of Forests (BCMOF) on a project to assess the emulsion's performance as a forest road-surface stabilizer.

The objectives of the project were to document site preparation and product application procedures and

costs, and to evaluate the impact of the treatment on road-surface conditions and dustfall. A secondary objective was to formulate long-term cost projections for TOP emulsion treatment and selected alternatives.

PROJECT AND SITE DESCRIPTIONS

Tall oil, usually used as a raw material in the chemical industry (*2*), is manufactured from the soap skimmings generated by kraft pulping of resinous softwoods. If pulp mills cannot dispose of this material, the alternative is to burn it within the mill. Internal disposal is discouraged because it reduces pulping productivity and increases air pollution (H.S. Norman, General Manager, B.C. Chemicals Ltd., Prince George, British Columbia, personal communication, September 1992). B.C. Chemicals Ltd. has manufactured tall oil since 1975, and currently receives soap from five pulp mills in the central interior of British Columbia.

Because demand for the product is limited, B.C. Chemicals Ltd. explored alternative uses and markets for tall oil products, including road-surface stabilizers. In late 1990, B.C. Chemicals Ltd. began producing two chemically different compounds from tall oil; TOP and depitched tall oil. TOP is processed into an emulsion known as TOP emulsion. It is marketed for road-surface stabilization under the trade name Dustrol E. In 1993 some modifications were made to the original formulation of the TOP emulsion. This alternative product is marketed as a dust palliative under the trade name Dustrol EX.

TOP, dark brown in color, is soluble in organic solvents; it has excellent cementitious and waterproofing properties (*3*). TOP stabilizes an unpaved road surface by cementing aggregate particles together. This is in contrast to the extensively used calcium and magnesium chloride treatments, which are hygroscopic and stabilize a road surface by drawing moisture into the aggregate. The TOP emulsion used in the study contained a 25 percent concentration of pitch solids. Some preliminary applications were done in the region with concentrations of 40 and 50 percent, but thorough blending with the surfacing aggregate proved difficult to achieve.

There have been several trial applications of tall oil-based emulsions in North America (*1*) using products from the southeastern United States. These are by-products of the pine pulping process and are sometimes referred to as "pine tar derivatives" or "tree sap." Their chemical properties differ from B.C. Chemical Ltd.'s emulsions because a combination of both spruce and pine wood is used in the pulp manufacturing process in the Prince George area. Several cursory trials of tall-oil-based emulsions have occurred in the interior of British Columbia. In this study, FERIC monitored the performance of TOP emulsion (Dustrol E) only. A 5.1-km test section was established on a heavily traveled unpaved portion of the Willow Forest Service Road near Prince George. This route has a specified maximum gross vehicle weight rating of 82 t and is subject to off-highway log-hauling traffic. Road-maintenance costs are allocated proportionally to a group of industrial users (Willow-Ahbau Road Users Committee) based on the cumulative tonnage of products hauled over the road. Level grades predominate and the running surface averages 9 to 10 m wide.

STUDY METHODS

Currently, no standard assessment procedure exists for evaluating road-surface stabilizers, although a variety of procedures has been proposed in the literature (*4,5*). After a review of various options, some procedures from UMA Engineering Ltd. were adapted for this project.

The application process was monitored to document techniques for mixing the emulsion with the aggregate, compaction procedures, emulsion transport and handling, and application costs. Visual assessments of road-surface conditions and dustfall were conducted at regular intervals from the time of application in May 1992 until the end of September 1992. Intermittent observations of road-surface conditions were made until May 1993. The 5.1-km treated section and an adjacent 5-km untreated section were monitored and compared.

One individual conducted all the assessments to ensure consistency in estimates of road-surface conditions and dustfall. Road-surface condition was evaluated for potholes, washboarding, surface ravelling, and ride quality for drivers. The frequency and severity of the surface condition indicators were ranked on a scale of 1 to 4, with preferred and severely deteriorated conditions represented by 1 and 4, respectively. Because conditions varied over the length of the test road, a weighted average was calculated for each observation date. The dust plumes created from passenger vehicles and log trucks were ranked on a scale of 0 to 5 against dust volume and driver visibility criteria. Dust-free and extreme dust conditions were represented by 0 and 5, respectively. Dust plumes generated by passing vehicles were photographed at two stations in the treated and control sections. Initially the assessments were conducted weekly, and then biweekly after the first 2 months of the trial.

Data about factors expected to influence product performance were collected. Grain size analyses were done on samples of the surfacing material. Local precipitation and temperature records were obtained from the Prince George Airport weather station, located 6 km from the study site. A traffic counter was installed for

a 1-week period to provide estimates of traffic volume. Driving habits and speeds were noted during the regular site inspections. Records for the weight of logs and wood chips hauled by the user companies over the test section were also obtained. Finally road-maintenance procedures and costs for the treated and control sections were documented and described.

Procedures for Applying Top Emulsion

B.C. Chemicals Ltd. employed a contractor (Lobol Enterprises Ltd., Prince George, British Columbia) to apply the emulsion to the test road during two 12-hr periods on a weekend. A 25 percent water solution of TOP emulsion was specified for the trial. Two tanker trucks with capacities of 16 000 L and 35 000 L and one quad-axle tanker trailer carrying 19 000 L were used to transport a 50 percent solution to the work site from the Prince George plant. Water was added at the site to dilute the emulsion to the required concentration. The tankers, equipped with spray bars (Figure 1), applied the emulsion to the road surface and refilled from the trailer before returning to the plant 23 km away to reload.

Two motor-graders prepared the road surface and blended the emulsion into the aggregate. One grader, equipped with carbide-tipped picks on the cutting edges, worked ahead of the application equipment, recovering material from the road shoulders and blading the surfacing aggregate into two windrows, one on each side of the road. The second grader, equipped with straight cutting edges, retrieved a portion of material from the windrow and spread a thin layer of aggregate in preparation for each spray coat of emulsion (Figure 2). To minimize disruption of traffic, the application was completed on successive subsections approximately 1 to 1.3 km long.

FIGURE 1 Emulsion application.

FIGURE 2 Motor grader spreads aggregate before each spray coat.

Several coats of emulsion were required to reach the targeted surface layer thickness of 5 to 7 cm. To bond the surface layer with the underlying base course, the first coat of emulsion, or primer coat, was sprayed onto the exposed base course at a rate of 1 L/m^2. Production coats were applied at 2 L/m^2 to successive 2-cm layers of surfacing aggregate until the desired surface layer thickness was reached. An average accumulation of 8 L/m^2 was planned; however, the actual rate varied from 8.5 to 12.4 L/m^2 depending on subsection requirements. Some subsections appeared to contain a larger proportion of fines in the aggregate and thus required more emulsion to achieve complete aggregate coating. In total, 453 000 L of emulsion was applied to the 5.1-km test road, resulting in an average application rate of 9.4 L/m^2.

A multiwheel pneumatic-tire roller completed the application process by kneading and compacting the emulsion-coated aggregate. The kneading action produced by this type of compactor helps create a more stable, less permeable surface layer. As with other phases in the process, procedures for compaction were developed empirically and no density criteria were specified. The surface was rolled repeatedly until firm and smooth. Initially some of the emulsion-coated aggregate stuck to the compactor's tires, but this was alleviated by adding 1000 kg of water ballast to the machine and by reducing its tire pressure. Vibratory steel drum rollers are unsuitable for this application because pitch-coated aggregate sticks to the drum.

The manufacturer established a unit cost of C$0.10/L (mid-1992) for the TOP emulsion product, including application, for roads within British Columbia's central interior region. If the target application rate of 8 L/m^2 can be sustained, the cost to stabilize the surface on a 9- to 10-m-wide forest road is approximately $7,000/km for the complete process.

RESULTS AND DISCUSSION

Monitoring Performance of TOP Emulsion

The results of performance monitoring are summarized in Figures 3 and 4. Inferences about TOP emulsion performance can be made from trends shown in the charts. When comparing observations of the treated and untreated road sections, note that the untreated section was graded regularly and received lighter traffic volumes. No grading occurred on the treated section during the study period.

Four indicators of road-surface condition are presented in Figure 3. Light potholing was observed over some subsections of the treated road. Potholes formed in groups, oriented longitudinally, and were attributed to road surface geometry, drainage, and how well the emulsion blended with the aggregate. Early in the trial, potholes were patched by hand with an aggregate-emulsion mixture. Potholes also developed on the untreated section during the summer and were repaired by regular blading. In late summer and fall, and coinciding with higher rainfall levels, the incidence and severity of potholing were higher on the untreated road although this section was subject to regular maintenance.

Washboarding of the road surface before treatment was a recurrent problem even on level grades and tangent road sections. Performance monitoring showed that washboarding was eradicated with the application of TOP emulsion. Washboarding continued to be a problem on the untreated section, although some observation dates coincided with blading maintenance and resulted in a low rating.

Surface ravelling, and the resulting accumulations of float gravel on roadsides and between wheel tracks, is a condition that was effectively controlled on the treated section. The incidence of surface ravelling on the

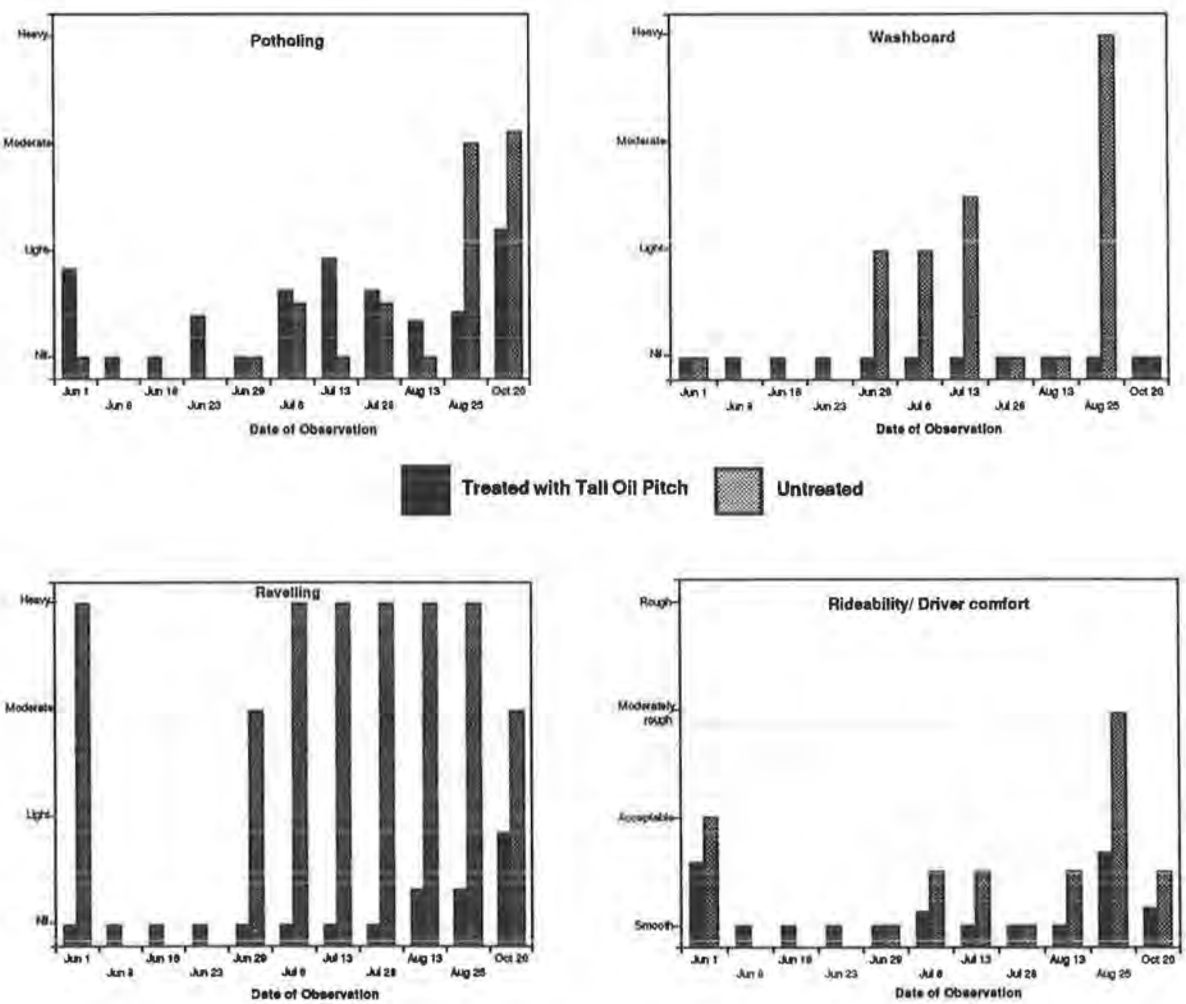

FIGURE 3 Results of performance monitoring.

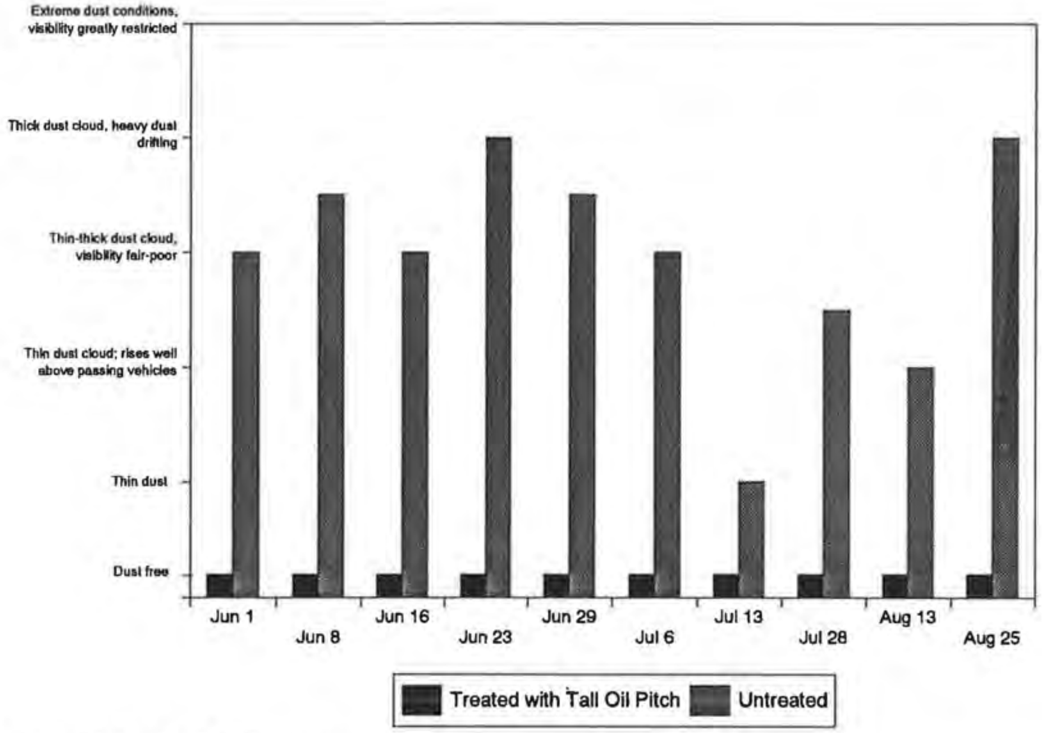

FIGURE 4 Dustfall observations.

untreated road remained high and was especially acute on curves.

The fourth indicator of surface condition, rideability or the level of driver comfort experienced while traveling on the road, is a subjective evaluation often used as an indicator of surface quality. The quality of ride for the treated section was usually smooth and superior to that for the untreated road. This opinion was corroborated by FERIC in interviews with many regular users of the road.

The study showed that dustfall was consistently and effectively controlled on the TOP-treated road (Figure 4). Maintenance managers found that industrial and public users appreciated the dust-free driving conditions. Figures 5 and 6 illustrate the differences in dustfall generated by vehicles passing over the treated and untreated sections on the same day.

In June 1993, after more than 1 year of service, strips of potholes had formed over much of the road surface of the treated section. Rather than attempting repairs, much of the treated section was ripped up and reshaped with a motor grader. However, the surface of one 500-m subsection remained remarkably smooth and well stabilized and was left intact (Figure 7).

FIGURE 5 Treated road surface.

FIGURE 6 Adjacent untreated road section.

FIGURE 7 **Surface performing well after 14 months of treatment.**

Grain Size Analysis

A key factor influencing road-surface stability is surfacing aggregate gradation. Aggregate with an insufficient fines fraction (i.e., material passing a 0.074-mm sieve) will not have the necessary binding properties; conversely, a large proportion can retain too much moisture, thus leaving the surface susceptible to frost damage. Acceptable results for any treatment should not be expected unless gradation has been analyzed and adjusted to meet specifications.

The grain size chart in Figure 8 shows the grain size distributions for two samples taken from material windrowed during the application process. The samples fall within the British Columbia Ministry of Transportation and Highways' acceptable range for surfacing aggregate (represented by the shaded area). The proportion, by weight, of fines in the two aggregate samples was 5.0 and 5.7 percent. Nine months before application, six samples were retrieved from ravelled material accumulated on roadway shoulders. Fines content for these samples ranged from 9.2 to 18.4 percent. Although not representative of the surface layer subsequently formed and treated with TOP, the results suggest that variations in gradation existed over the road. This finding concurs with the contractor's experience during application: the aggregate on some subsections had a high proportion of fines and was difficult to coat totally with emulsion.

Climatic Conditions

Climatic conditions were extraordinarily challenging to the performance and lifespan of the treatment. Figures 9 and 10 summarize precipitation and temperatures during the study period. Total precipitation, including

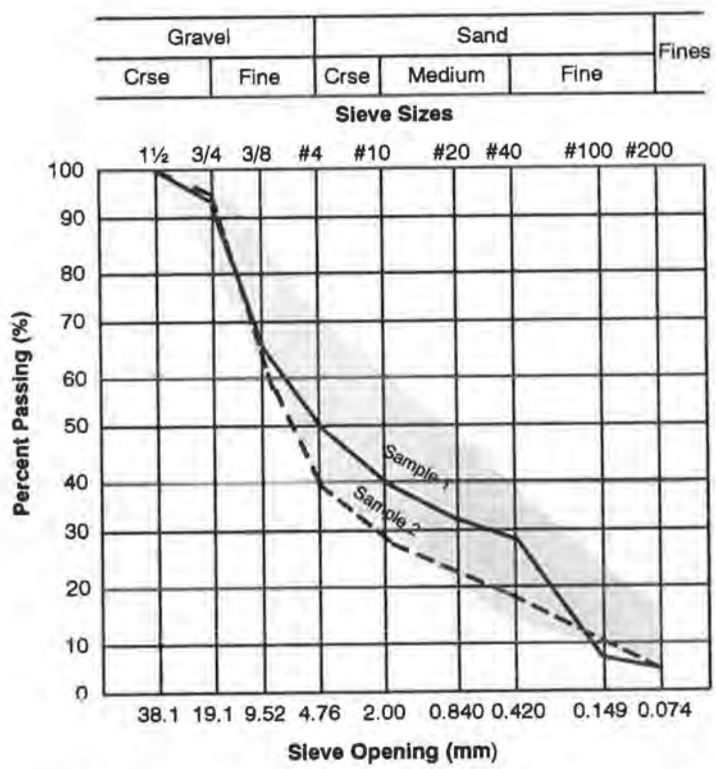

FIGURE 8 **Gradation of surfacing aggregate.**

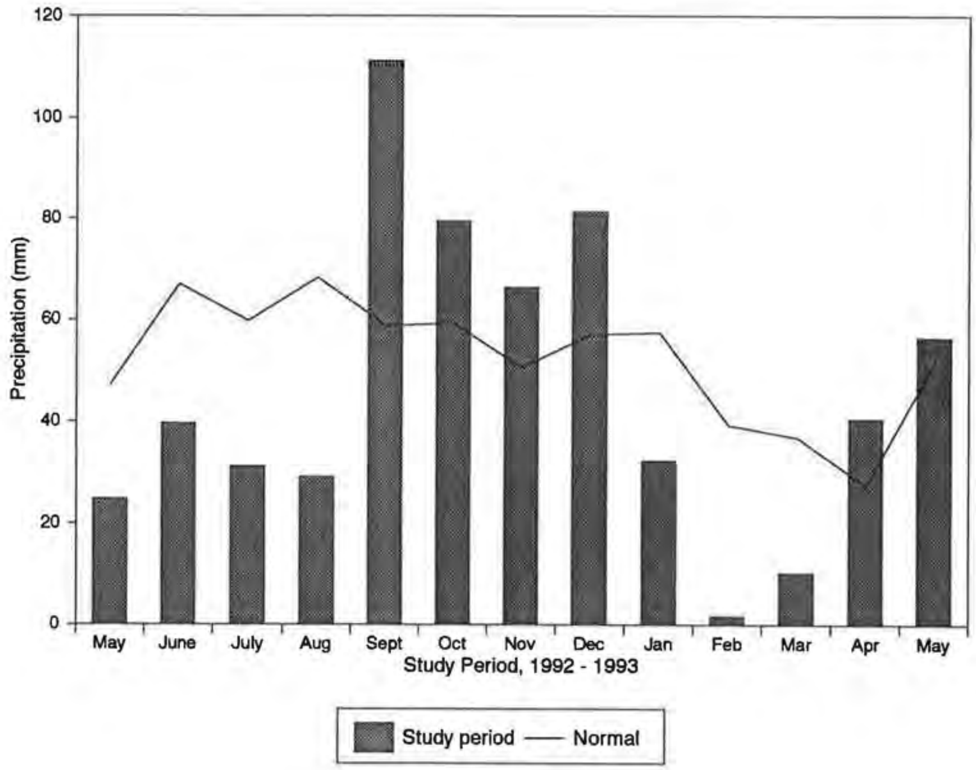

FIGURE 9 Precipitation record.

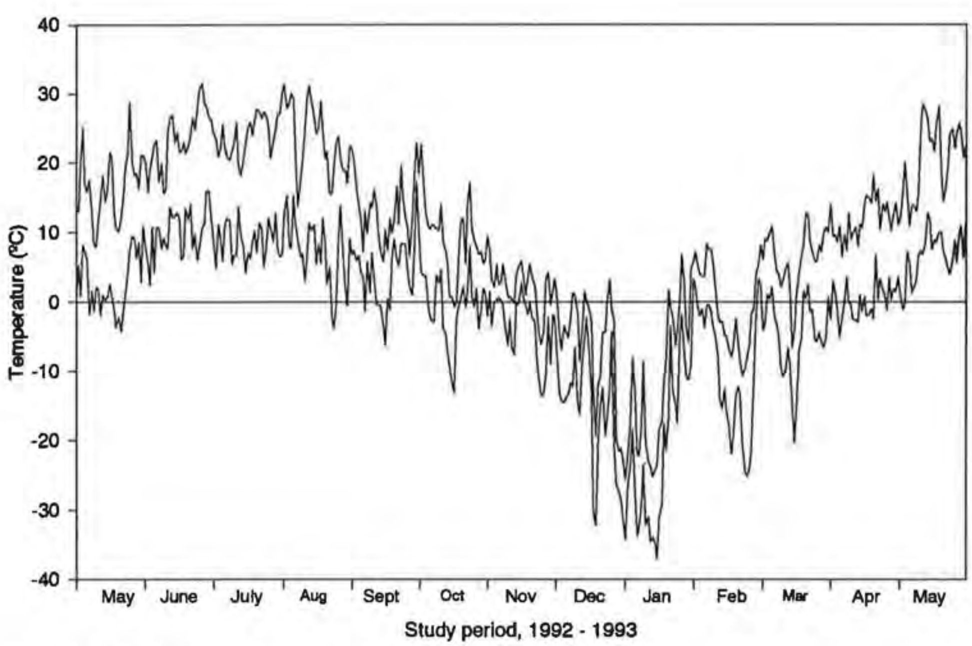

FIGURE 10 Daily maximum and minimum temperatures.

rainfall and snowfall, for the 12-month period of May 1, 1992, to April 30, 1993, was 548 mm. The pattern of precipitation varied considerably from the pattern normally experienced in the area. The summer was unusually dry and preceded a wetter-than-normal fall. The unusually wet fall period strongly tested stabilizer performance because the propensity for potholing and product leaching increased in these weather conditions.

Snowplowing usually leaves a compact snow surface, which is sanded to provide traction for vehicles. However, snowfall accumulations in January, February, and March were below normal. As a result, during the winter the treated road was usually exposed, leaving it subject to precipitation, temperature fluctuations, traffic, ice blading, and sanding. In the absence of a protective snow layer, it is probable that the quality of treated surface continued to deteriorate during the winter, thus shortening treatment life.

Temperatures ranged from +32 to −37°C during the study period (Figure 10), and numerous fluctuations above and below freezing occurred during the transition periods (spring break-up and fall freeze-up). In British Columbia's central interior there are usually summer and winter log-hauling seasons separated by 2- to 4-week intervals of freeze-up and break-up in the spring and fall. During these transition periods the road surface is more susceptible to damage from heavy traffic because the strength of the underlying base course and subgrade is reduced.

Traffic Conditions

Three sawmills, one wood remanufacturing plant, and two aggregate and asphalt production facilities contribute to the heavy, multiaxle vehicle traffic on the treated and untreated road sections. These vehicles include on- and off-highway log trucks, B- and super B-train chip vans, lumber carriers, gravel trucks, and many other types of heavy industrial carriers. Plant workers and local residents contribute to light passenger vehicle traffic. Undoubtedly the control of dust during dry periods contributed to the excessive driving speeds observed on the treated road.

Table 1 summarizes traffic data from an automatic hose count system for the period of August 28 to September 3, 1992, inclusive. For an unpaved forest road, a very high volume of heavy industrial and light passenger vehicle traffic was experienced during weekdays. Log-hauling traffic fluctuated depending on the season and on the location of the mill's log sources. During spring break-up and fall freeze-up, log hauling was suspended until road conditions stabilized. However, the treated road sustained continued use by chip vans, lumber carriers, and other heavy vehicles throughout these periods when the surface was prone to damage.

Records from Willow-Ahbau Road Users Committee indicate that approximately 650 000 t of logs, wood chips, and gravel were hauled over the test road section from May 1, 1992, to April 30, 1993. Weights of other products, including lumber, were not available. FERIC estimates that the tonnage for recorded materials alone translates into more than 15,000 one-way trips. These figures concur with FERIC's observations that the road sustains very high volumes of heavy industrial and light passenger traffic.

Maintenance Procedures

After the TOP emulsion was applied and follow-up patching completed, no blading maintenance with motor graders was done on the treated section during the 1-year evaluation period. Although it becomes increas-

TABLE 1 Traffic Volume: August 28 to September 3, 1992, Inclusive

Type of vehicle	Average daily traffic[a]	
	Weekdays (no. vehicles)	Weekends (no. vehicles)
Light passenger vehicles	310	189
Heavy industrial multi-axle vehicles	402	35
Total	712	224

NOTE: Summarized from Carol L. Smith, P.Eng., Transtech Data Service (1992), Victoria, British Columbia; unpublished report, September 1992.

[a]Total traffic volume obtained from hose count installation. The breakdown between light passenger and heavy industrial traffic was estimated from industrial user records.

ingly malleable in hot weather, the emulsion-coated aggregate forms a consolidated layer that cannot be rebladed. Before being treated, the road often required twice-weekly grading. One occasion warranted full grading with four to six passes to complete a road section, and the other occasion usually required light patch-grading. The lower traffic volume on the untreated section resulted in a grading frequency of approximately once per week.

Supervisory personnel noted that without the TOP stabilization treatment, the dryer-than-normal summer conditions would have necessitated daily watering of the road surface to control dust, thus adding significantly to road-maintenance costs (C. Andreschefski, Area Supervisor, Canadian Forest Products Ltd., Netherlands Division, Prince George, British Columbia, personal communication, September 1993).

Other Observations

Identification of the physical and chemical processes that define the soil-emulsion interaction is a necessary first step in the development of superior emulsion formulations and application procedures for road-surface treatment. B.C. Chemicals Ltd., in collaboration with Arbokem Inc. of Vancouver, British Columbia, is conducting research to determine how tall-oil-based emulsions interact with the surfacing aggregate and how to accelerate the curing process.

TOP emulsions require 1 to 3 days to cure, depending on weather conditions. A faster curing rate is needed to allow normal traffic flow to resume promptly. Immediately following application, vehicle tires will often pick up some of the emulsion-coated aggregate and deposit it on vehicle surfaces. Some drivers become annoyed if they are not forewarned about these conditions because emulsion-coated aggregate is difficult to clean from vehicle surfaces. Once the precise curing mechanism is identified, emulsion additives may be proposed that can speed up the process.

Tests have shown that the leachate of road materials treated with TOP emulsion is nontoxic (H.S. Norman, General Manager, B.C. Chemicals Ltd., Prince George, British Columbia, personal communication, September 1992).

Thorough blending of the emulsion with the aggregate is the most challenging aspect of product application and requires repeated passes with a motor grader and spray truck. One possible explanation for the difficulty of mixing is that the pitch solids in the emulsion may be intercepted by the upper surface of the aggregate layer, where they accumulate. Initially each spray coat appears to saturate the aggregate. However, if the pitch component of the emulsion is filtered out at the surface, only dark-colored water penetrates through to the lower portion of the aggregate layer. Thus the product must be applied over several thin lifts of aggregate.

The hot, dry weather during the application period caused the water in the aggregate to evaporate quickly. Sometimes light- colored streaks in the aggregate, indicating low pitch content, were revealed after the surface layer dried. This puzzling phenomenon was perhaps due to an uneven distribution of TOP within the emulsion after water was added on site. Also, high interfacial tensions between the emulsion and soil particles may be a contributing factor (H.S. Norman, General Manager, B.C. Chemicals Ltd., Prince George, British Columbia, personal communication, May 1994). When the streaks appeared, the surface was reworked with the motor grader and additional emulsion was applied.

TOP emulsion treatment is not intended to create a permanent road surface. As expected, some road sections gradually deteriorated during the year-long study. Three processes of the surface failure were observed. The predominant type of failure was potholing, and predictably it was observed most often on sections with negligible crowning and poor drainage. Another failure process was spalling of the fine emulsion matrix at the surface. This was not a serious concern and occurred only intermittently. Interestingly, potholing or spalling failures were not associated with vehicle wheel tracks. The third failure process was deformation of the surface in the wheel tracks. It occurred sporadically and was observed on the road sections that remained saturated for a lengthy period following application. TOP emulsion had been applied to these sections late in the day, under shaded conditions, when the rate of evaporation had slowed. The surface and base course likely did not develop sufficient strength before regular traffic resumed.

Several sections of the test road performed extraordinarily well during the trial. In particular, one 500-m section, including a curve, remained in excellent condition beyond the year-long study period and was used through a second summer hauling season without any maintenance. Interestingly, this road section had received the lowest application rate of emulsion, at 8.5 L/m^2. However, this 500-m section was also the subject of a cursory TOP trial one year prior to this study. A 40 percent concentration of TOP was lightly applied at that time.

The superior performance of this 500-m section suggests that residual amounts of pitch persisted from the cursory trial and that the effects of tall oil-based emulsion applications may be cumulative. It is likely that another contributing factor was the well-drained road base on this particular section.

Alternative Treatments

Expenditure profiles over a common 5-year planning period were prepared for three alternatives: Dustrol E, Dustrol EX, and no treatment. Costs are estimated for the 5-km-long, 9-m-wide test road and are thus site specific. The first year of profiles is shown in Table 2. A summary of the annual costs and the expenditures by work phase is presented in constant-worth dollars in Tables 3 and 4, respectively. The present worth of each expenditure profile was calculated. Information about the Dustrol EX alternative was collected through discussions with users and visits to several roads where the product was being tested in north central British Columbia. The maintenance regime for the no-treatment option was derived from the road-maintenance records of the Willow-Ahbau Road Users Committee.

Dustrol E is marketed as a road-surface stabilizer, and Dustrol EX as a dust control agent. Perhaps emphasis on the latter distinction is unwarranted because reduced dust emissions are the result of a well-stabilized road surface. The two products provide different degrees of surface stabilization. The depth of stabilization within the surface, the chemical properties and process of interaction with the aggregate, and the application techniques vary between the two products.

At present, a more rigorous procedure, and therefore a more expensive one, is being used to apply the Dustrol E product than the Dustrol EX product. The initial cost of Dustrol EX treatment is considerably less because it is usually applied to a road surface with little preparation in only one or two spray coats. Dustrol EX is applied at a rate of 3 L/m^2 and costs $2,800/km for a 9-m-wide road. Observations indicate that only a thin upper layer of the road is treated and that surface deterioration occurs more rapidly than the road treated with Dustrol E. It is likely that a mid- to late-summer reapplication of Dustrol EX would be necessary on the heavily used industrial road chosen for this study. Additional costs for surface patching and grading can be anticipated for the Dustrol EX option and are included in the cost profiles. The no-treatment alternative includes the cost of watering to reduce dust during the summer months and the cost of resurfacing to replace aggregate lost after five years of heavy traffic and continual blading activity.

TABLE 2 Estimated Expenditure Profiles for Alternative Treatments (Year 1 of 5-Year Planning Period)

		Dustrol E Emulsion[a]		Dustrol EX emulsion		No treatment	
End of year	End of month	Work performed	Constant worth ($/km)	Work performed	Constant worth ($/km)	Work performed	Constant worth ($/km)
0	May	Application	7000	Application	2800	Grading	500
	June	Patching	80	Patching & grading	240	Grading	500
	July			Grading	160	Watering & grading	1000
	August	Patching & grading	160	Re-application	2000	Watering & grading	1000
	September			Patching & grading	200	Grading	500
	October					Grading	500
	November	Grading	160	Grading	160	Grading	500
	December						
	January						
	February						
	March	Grading	160	Grading	500	Grading	500
	April	Grading	160	Grading	500	Grading	500
1	May	Application	7000	Application	2800	Grading	500

Note: Road maintenace costs in December, January, and February are omitted because they are common to all the alternatives. Estimates apply to the 9-m wide test road section monitored in the study.

[a]Assume that residual TOP will accumulate in the surface layer, thus reducing application costs to $4000/km in Years 2 to 5.

TABLE 3 Estimated Annual Road-Surfacing and Maintenance Expenditures for Alternative Treatments

End of year	Dustrol E emulsion ($/km)	Dustrol EX emulsion ($/km)	No treatment ($/km)
0	7 000	2 800	500
1	7 720	6 560	5 500
2	4 720	6 560	5 500
3	4 720	6 560	5 500
4	4 720	6 560	5 500
5	4 720	6 560	25 000
Present worth	28 569	29 499	36 365

NOTE: Road maintenance costs common to all the alternatives are omitted. The assumptions for the analysis are: 5-year planning period, 8% discount rate, and monthly compounding. The measure of effectiveness is the present worth method applied to constant worth, before-tax cash flows. Estimates apply to the 9-m wide test road section monitored in the study.

TABLE 4 Estimated Total Expenditures over 5-Year Planning Period by Maintenance Activity

Work performed	Dustrol E emulsion ($/km)	Dustrol EX emulsion ($/km)	No treatment ($/km)
Annual product applications	30 000	16 800	-
Re-applications within each year	-	10 000	-
Regular grading	2 800	7 100	22 500
Surface patching	800	1 700	-
Watering for dust control	-	-	5 000
Resurface with new aggregate	-	-	20 000
Present worth	28 569	29 499	36 365

See footnote for Table 3.

Analysis shows that the treatment alternative with the largest initial application costs may prove to be the most cost-effective over an extended planning period when ancillary costs and the time value of money are considered. When assessments of nonmonetary factors (such as the quality of the surface created and the improvement to road safety) are made, the Dustrol E alternative compares favorably with other options.

CONCLUSIONS

The test road treated with TOP emulsion performed well during the year-long study, and local road users were pleased with the results. Climatic conditions and traffic patterns were very challenging for product performance, yet a maintenance-free surface was retained during the year-long study. One section in particular performed extraordinarily well, pointing to the good potential of TOP emulsion for road-surface stabilization. An advantage of TOP emulsion over some alternative nonpermanent treatments is its ability to act by cementing aggregate particles together, thus forming a water-resistant surface. Because it is not a hygroscopic agent, performance can be maintained over extended dry periods. TOP emulsion potential would be enhanced if practical repair procedures could be developed to enable patching of isolated sections of potholing while leaving the acceptable road surfaces intact.

The relatively high initial costs and difficulties in application demand that potential users conduct long-term economic analyses to determine the benefits of us-

ing TOP emulsion in a road-surface stabilization program. When analyzing alternatives with more attractive start-up costs, users are reminded that overall maintenance costs are likely to decrease and the quality of the surface produced is likely to improve as the level of initial investment is raised.

Note that two chemically different tall-oil-based emulsions are produced in British Columbia's central interior and marketed as road-surface treatments: Dustrol E and Dustrol EX. Application procedures for the E and EX emulsions have developed through a process of trial and error. Detailed scientific study is required to refine formulations and application methods and to produce more consistent results. B.C. Chemicals Ltd. has undertaken important research to better understand how the locally produced tall-oil-based emulsions stabilize unpaved road surfaces. Without information about the product's interaction with different soil types and the process of curing the product when it is applied to the road surface, it will be difficult to improve product performance and expand on the potential for commercialization.

Preparation of the road surface is perhaps the key phase of a stabilization program. Correctly graded aggregate must be in place and properly shaped to form a well-crowned road surface. Positive drainage over an entire road surface is critical to maintaining it. Blading practices affect surface quality, and should be monitored to ensure that the geometry of the road surface is preserved. The benefits of applying a chemical stabilizer will not be fully realized unless resources are invested in preparation.

Forest-road-maintenance managers will sometimes be skeptical of a nonstandard stabilizer until it can demonstrate clear benefits and consistent performance. Although some product formulations may be proprietary, it is incumbent upon producers and marketers to describe the nature of their product and explain how it will work to stabilize a road surface. With the proliferation of surface treatment compounds, road-maintenance managers need concise and complete information about a product to decide if an investment is warranted.

It is often difficult for road-maintenance personnel to choose the most cost-effective product or decide whether trial of an alternative is warranted. The decision remains a site-specific one. A product must be matched to local climate conditions, type of traffic, and the type and gradation of surfacing material. The best decision will result from a comparison of alternatives over a planting period of several years, coupled with the sound judgment of experienced managers concerned with both the quantitative and nonquantitative aspects of investment alternatives (6).

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