Relative Effectiveness of Road Dust Suppressants

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Abstract

The relative effectiveness of commercially available road dust suppressants in abating fugitive dust emission and loss of fines from unpaved road surfaces was assessed in a field based research project. The dust suppressants studied, lignin derivatives and chloride based compounds, were used on unpaved road test sections during the severe dusty months (late spring to fall) of 1993 and 1994 in Colorado.

To measure the relative effectiveness of the different dust suppressants, comparative fugitive dust emission studies were conducted on several unpaved road test sections using the Colorado State University Dustometer, a dust sampling device developed in this research. In addition, total aggregate loss from the surfaces of the test sections was measured. Based upon the prevailing costs, analyses were performed to determined the economics of using the different dust suppressants.

The research indicated that the use of the three dust suppressants studied reduced fugitive dust emission from the unpaved roadways by 50-70%. The total aggregate losses from the treated test sections were 42-61% less than that of the untreated control test section. The cost savings of retaining aggregate on the treated test sections more than offset the costs of the dust suppressants, resulting in an estimated cost savings of 30-46% over the untreated control test section.

Introduction

While unpaved roads carry a small portion of the nation's traffic, they provide a vital first link in the nation's economy. Of the nearly 4 million miles (6.5 million kilometers) of road network in the continental U.S., it is estimated that about 65% are unpaved (Eaton, et al., 1988). One major problem associated with unpaved roads is traffic generated fugitive dust. To residents living along unpaved roads, the airborne dust penetrates their homes causing nuisances and health problems such as hay fevers and allergies. The fine suspended dust particles contribute significantly to the particulate matter loading in the atmosphere. According to air pollution studies, nearly 34% of the particulate matter in the atmosphere originates from unpaved roads nation wide, making unpaved roads one of the major man-made sources of fugitive dust (Barnard et al., 1992). In addition to environmental degradation, the generation of dust means loss of aggregate and subsequent road surface deterioration as the loss of road surface fines in the form of dust leads to the formation of ruts, potholes and corrugations. These conditions represent a significant material and economic loss.

The severity of the dust problem is determined primarily by the volume of traffic using an unpaved road as well as the speed, weight, number of wheels of each vehicle, the abrasive resistance of the road surface material and the amount of fines in the initial road surface material mix. The climatic condition of the region is also an important factor affecting the generation of dust from unpaved roads. Long dry spells that often occur in semiarid and arid regions aggravate the road dustiness.

The high maintenance cost of unpaved roads in terms of aggregate replacement, the increased public awareness of pollution problems and the high road user cost has led agencies responsible for the maintenance of roads to have a renewed interest in dust control measures. Frequently used dust control methods include reduction of vehicular speed, application of water and use of dust suppressing chemicals. Although dust suppression has been in practice for decades, quantitative studies on the effectiveness of the different road dust suppressants and their environmental impact have been virtually nonexistent. Some field testing of dust suppressants have been done by the Midwest Research Institute (MRI) Bohn, et al., (1978), PEDco (1974) and Hoover et al.,(1973). Hoover et al.,(1973) and Lane et al.,(1984) also used laboratory methods to quantify dust suppressants effectiveness.

The research reported in this paper summarizes a study conducted to evaluate, under field conditions, the relative effectiveness of some of the more commonly used road dust suppressants. Three commercially available dust suppressants were evaluated in the study: lignosulfonate, (a byproduct of the paper making industry), calcium chloride and magnesium chloride (both deliquescent and hygroscopic compounds). The road surface material used was crushed gravel mix from a local gravel pit.

Experimental Design

The tests were performed on four unpaved road sections, each 1.25 miles long, in the Loveland area of Larimer County, Colorado. Three of the test sections were treated with the different dust suppressants, namely: lignosulfonate, calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$), while one of the sections was left untreated to serve as the control. All four test sections were part of the same stretch of an existing unpaved road.

Virgin crushed gravel material was used for the construction of the road surfaces. The gravel can be classified by the general name of scoria, according to the American Association of State Highway Officials Standard Specification (Casagrande, 1948). A sieve analysis was performed on the aggregate mix according to ASTM Test No. C-136. The results of the analysis are represented in Figure 1. The quantity of the material passing the No. 40 (425 μm) standard sieve referred to as fine sand/silt is 9.6%. The fines fraction is noted to be directly related to the amount of dust emission from an unpaved road surface. Other tests to determine the engineering properties of the aggregate were also performed. They included: Atterburg limits to determine the plasticity of the road surface material; Los Angeles abrasion to determine the abrasive resistance of the aggregate mix and specific gravity. The tests and the results are listed in Table1.

Table 1— Aggregate Property Results

Test	Results
Atterburg Limits (ASTM No. D-423 & D-424)	Nonplastic and no cohesion
Los Angeles Abrasion Test (ASTM No. C-131)	30%
Soundness (ASTM No. C-88)	Not Determined
Specific Gravity (ASTM No. D-845)	2.6

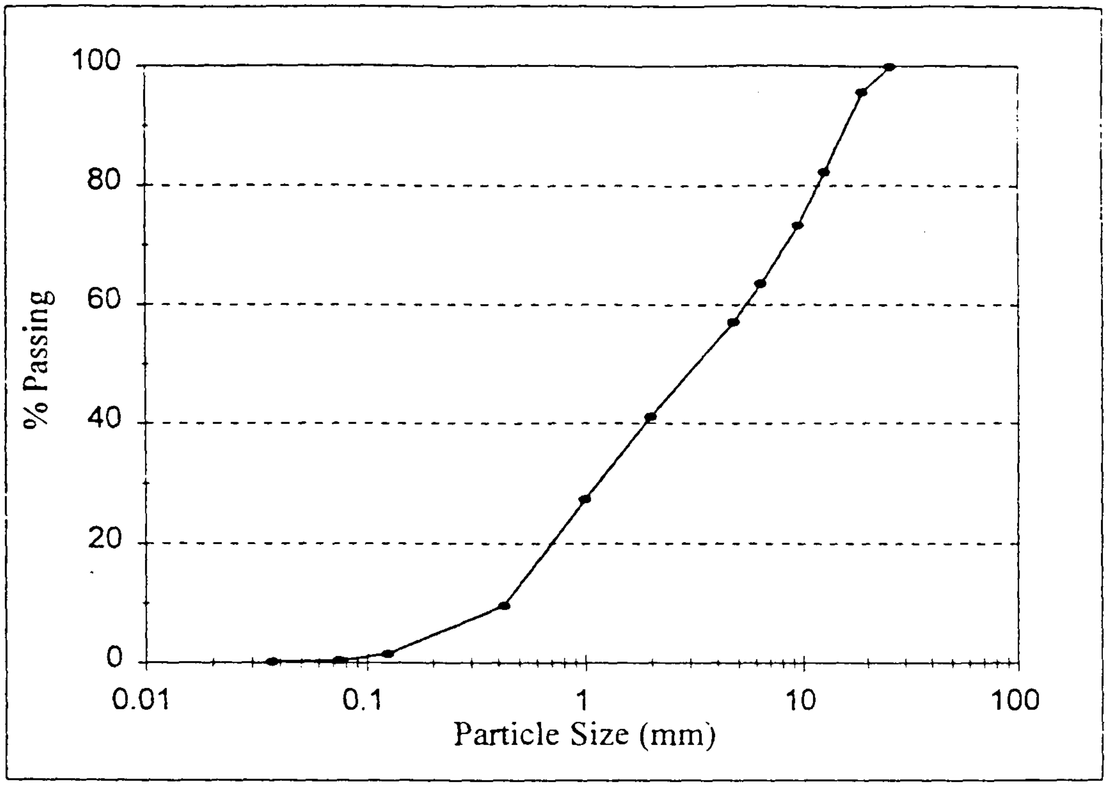

Figure 1— Cumulative Distribution of Aggregate Particle Size

Test Sections

The construction of the road test sections followed the procedures recommended in the highway engineering literature and that of the dust suppressants suppliers. "Important application techniques for most dust suppressants include: a) road surface scarification, b) adequate grading and smoothing of the road surface, c) application of the dust suppressants in quantities sufficient for effective dust control, d) proper road finish procedure that includes the forming of the surface crown, optimum compaction of the road surface and proper drainage" (Lane, 1984). Approximately 4 inches (10.2 cm) of the virgin gravel material was laid on the existing roadway.

The primary equipment involved in the test section construction include: 1) water trucks for adding water to the road surface material, 2) motor graders for grading, mixing and shaping the roadway, 3) a distributor truck with power spray bar for applying dust suppressant and 4) a vibratory steel drum compactor for compacting the road surface. The application rate for the lignosulfonate as suggested by the supplier was 1/2 gal/yd^2 (2.3 lit/m^2) of road surface and the method of application was mixed-in-place. The application rates for the $CaCl_2$ and $MgCl_2$ were the same at 1/2 gal/yd^2 (2.3 lit/m^2) of road surface and the method of application was surface sprayed. The mixed-in-place application method involves the addition of the dust suppressant to the road surface material in-situ by mechanically mixing the suppressant with the road surface material. The surface sprayed application, on the other hand, involves the spraying of the dust suppressant under high pressure on the road surface after the road surface has been maintained (bladed, shaped and compacted).

Measurements

Three fundamental field measurements were made. They were traffic counts, fugitive dust emissions and total aggregate loss. The traffic survey of each of test section was carried out by installing traffic counters at the beginning and end of each test section. The counters were left in place throughout the duration of the field measurements which started in late May and ended in early October 1994.

The dust emission from each test section was measured throughout the test period using the Colorado State University Dustometer. The Dustometer is simply a moving dust sampler developed, field tested and used in this research. The device consists primarily of: 1) a fabricated metal box containing a 10 in. by 8 in. (25.4 by 20.3 cm) glass fiber filter paper, mounted to the bumper of a 1/4 ton pickup truck on the driver's side rear tire, 2) an electric generator and 3) a high volumetric suction pump. The fabricated filter box has a 12 in. by 12 in. (30.5 by 30.5 cm) opening that is covered with a 450 micron mesh sieve which faces the tire. The micron screen prevents any non dust particles from being drawn onto the filter paper during dust measurement.

As the truck is driven at a constant speed of 45 mph (72.6 kph) a portion of the dust generated is collected on a preweighed filter paper in the filter box mounted on the bumper of the truck. At the end of a test run the filter paper is gently removed and stored. The filter box is refitted with a new preweighed filter paper and another test is run. The dust laden filter papers are later weighed in the laboratory. Figure 2 shows a schematic diagram of the Colorado State University Dustometer setup.

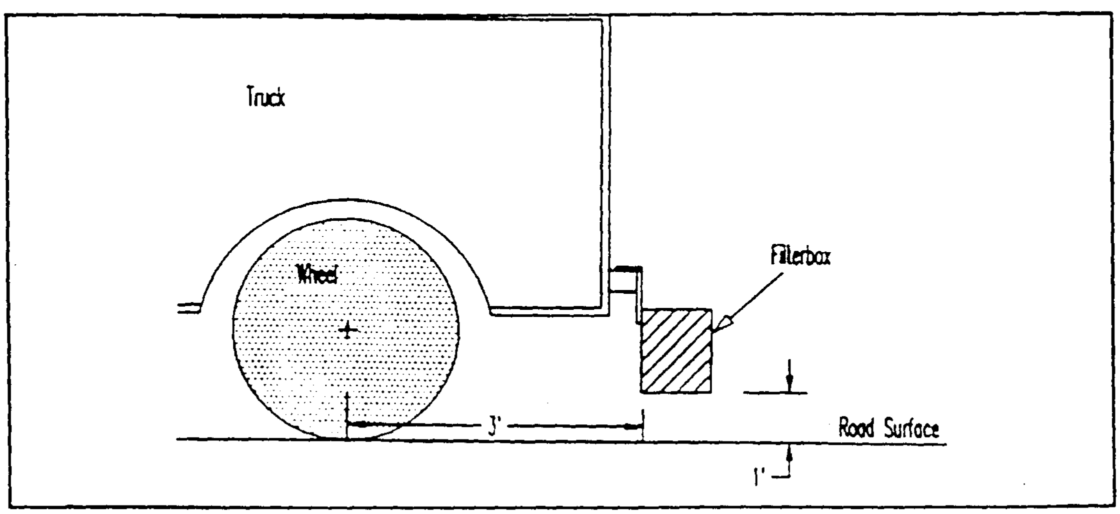

Figure 2 — Schematic Diagram of the Colorado State University Dustometer Setup

The total aggregate loss from each test section over the test period as a result of vehicular activity and erosion (wind and rain) was measured by documenting the elevations of the test sections right after construction and at the end of the test period after the test sections had received periodic maintenance. The initial elevations of the test sections were compared with the final elevations of the test sections and the differences represented the total aggregate loss.

The aggregate loss estimates were made at one-quarter mile points along each test section. Each one-quarter mile transect was divided into 3 ft (0.9 m) intervals starting from the crown. Using a dumpy level, levels were taken at the 3 ft intervals to document the initial elevations of the roadways immediately after construction. The test sections were then open to traffic for 4.5 months (duration of the test period) after which they received period maintenance without additional aggregate or dust suppressants. Following the same procedure used in taking the initial elevations, the final elevations were taken and the difference between the two elevations was used to estimate the total aggregate loss.

Research Results and Discussion

Traffic Survey

The results of the traffic counts for each of the four test sections are presented in Table 2. There is a direct correlation between the number of vehicles using a roadway and the degradation of the roadway. The extensive traffic survey done was to measure as accurately as possible the number of vehicles using each test section so that aggregate loss can be expressed as per vehicle per mile.

Although, all four test sections were part of the same stretch of unpaved county road, it appears that the sections at the ends of the stretch, the lignosulfonate treated and the untreated test sections had higher traffic counts than the $CaCl_2$ and the $MgCl_2$ test sections located in the middle of the road. The lignosulfonate and the untreated test sections had Average Daily Traffic (ADT) of 515 and 538 respectively compared to 421 for the $CaCl_2$ and 448 for the $MgCl_2$ test sections.

Table 2— Traffic Survey on Test Sections

Test Section	**Beginning**	**End (# of Vehicles)**	**Average**	**ADT**
Lignosulfonate	85,326	59,746	72,536	515
$CaCl_2$	59,746	58,659	59,203	421
$MgCl_2$	58,659	67,680	63,170	448
Untreated	67,680	83,895	75,788	538

Duration of Test: 141 days (app. 4.5 months)

Dust Measurement

The results of the fugitive dust measurements from each of the four test sections are shown in Figure 3. In all, 15 dust sampling measurements from each test section were made during the research period. Each data point in Figure 3 is an average of three measurements made by driving the Dustometer in the same driving lane in the same direction. The length of each test section was one mile. The dust measurements were initiated 16 days after the completion of the test sections. During the test period the treated test sections did not received any periodic maintenance, while the untreated control test section received two periodic maintenances.

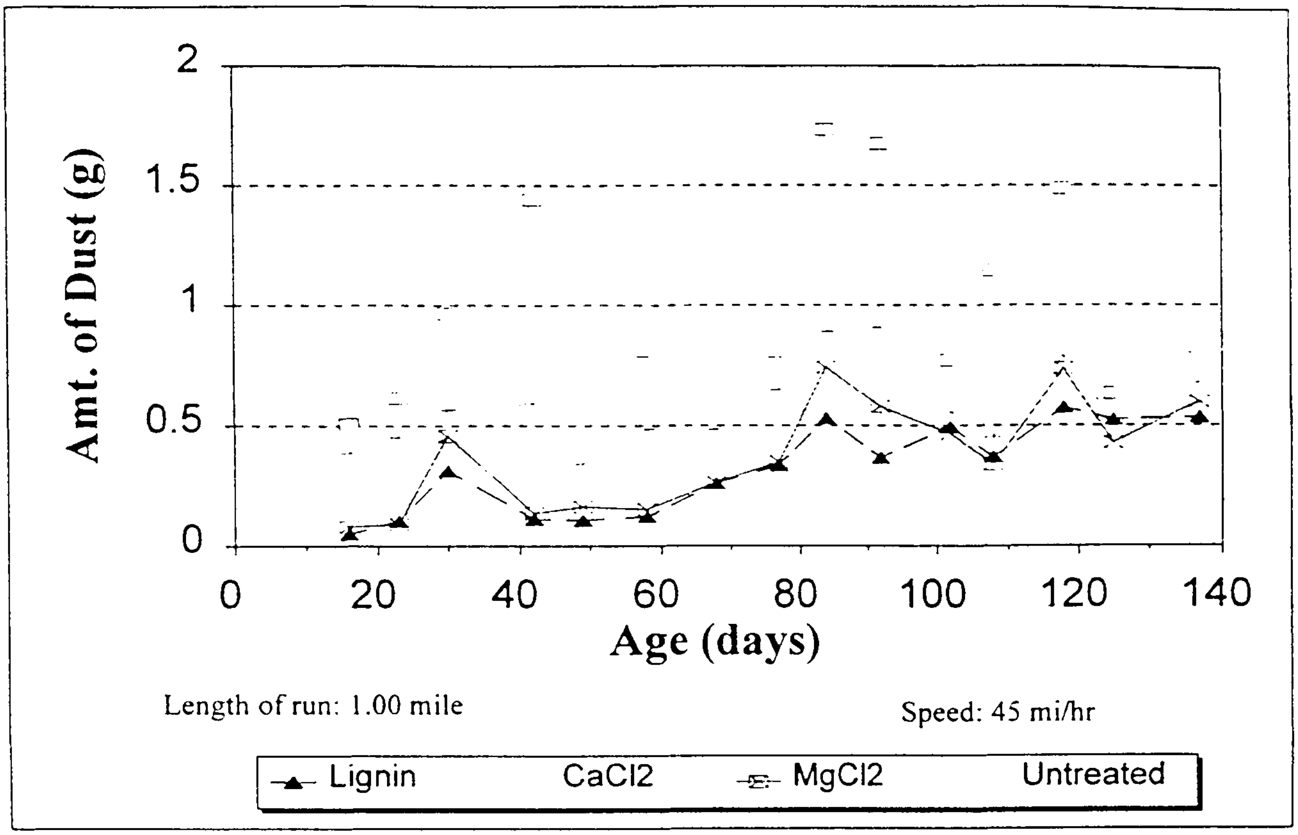

Figure 3--- Dust Measurement from Test Sections

The average ambient temperature and relative humidity during the test period was approximately 88°F (31°C) and 24%, respectively. The amount of dust sampled from the lignosulfonate treated test section varied from a low of 0.05 gms when the treatment was new to a high of nearly 0.6 gms measured towards the end of the test period. The $CaCl_2$ treated test section started with approximately 0.4 gms of dust and had a high of about 0.9 gms, while the $MgCl_2$ test section measured 0.08 gms of dust at the onset and had a high of approximately 0.7 gms measured towards the end of the test period. The untreated test section, however, averaged about 1.0 gm of dust measured each sampling period. It should be noted that the amounts of dust measured was only a portion of the dust generated by the left back wheel. Therefore, the dust measurements indicated only the relative effectiveness of each dust suppressant. It did not measure the amount of dust generated per vehicle.

From Figure 3, it is apparent that all the dust suppressants were effective in reducing the amount of dust generated when compared to the amount of dust from the untreated section. In addition, as the treated test sections aged the amount of dust emissions increased. This is indeed expected since, with time, the treatments lose their effectiveness and the continuous vehicular activities accelerate the loss of road surface fines. Figure 3 also shows variations in the amount of dust sampled, these variations could be due to many factors, significant among them is the rainfall pattern during the test period. Depending upon the amount of rainfall and the prevailing weather condition prior to a dust measurement, higher or lower dust amounts could be measured. Rainfall events that did not produce runoff but gave the road surface just enough moisture to help vehicular compaction of the road surface and the rejuvenation of the dust suppressants in the case of the treated test sections, caused lower dust measurements. On the other hand, rainfall events that produced substantial runoff were noted to wash off the dust suppressants in the immediate top portion of the road surface allowing the fines to be become loose and thus lost in the form of dust.

Aggregate Loss Measurement

Table 3 shows the measured aggregate loss from each of the test sections over the 4.5 month period in which the study was done. The table also contains the estimated annual loss based on the measured loss.

Table 3— Aggregate Loss Measurement

Test Section	Measured Aggregate Loss (mm)	(inches)	(ft)	Estimated Aggregate Loss in One Year (inches)
Lignosulfonate	5.80	0.228	0.019	0.604
$CaCl_2$	7.01	0.276	0.023	0.731
$MgCl_2$	5.18	0.204	0.017	0.541
Untreated	15.55	0.612	0.051	1.622

Initial thickness of surface wearing course: app. 4 inches (102 mm)
Duration of measurement: 4.5 months

The aggregate loss from the treated test sections were measured as 0.228 in. (5.80 mm) for the lignosulfonate, 0.276 in. (7.01 mm) for $CaCl_2$ and 0.204 in. (5.18 mm) for $MgCl_2$. The untreated test section loss was 0.612 in. (15.55 mm) which is approximately 3-times more than that of the $MgCl_2$ treated test section, 2.7-times more than the lignosulfonate treated test section and about 2-times more that the $CaCl_2$ treated test section. These measurements are consistent with results of other studies. Hoover, et al. (1973) reported aggregate pullout from treated unpaved road surfaces as approximately 25-75% that of untreated test sections; this research showed a 33-45% aggregate pullout.

Aggregate pullout from unpaved road surfaces is due primarily to vehicular movement and therefore, the volume of traffic using the road test sections would affect the total aggregate loss from the road test sections within a given time period. Since the traffic volumes for the road test sections evaluated were different, the aggregate loss from each test section can only be compared on a per vehicle basis. Table 4 shows the estimated total aggregate loss from each test section in tons/mile/year/vehicle. The estimated losses were computed considering a 33 ft (10 m) wide road and compacted density of 1.6 tons/yd^3 (note: road width does not have an impact on the amount of total aggregate loss).

The estimated total aggregate loss based on the 4.5 months measurement is 1.01 tons/mile/year/vehicle for the lignosulfonate treated test section, 1.49 and 1.04 tons/mile/year/vehicle for the $CaCl_2$ and $MgCl_2$ treated test sections respectively. The untreated test section on the other hand, loss an estimated total aggregate of 2.59 tons/mile/year/vehicle, 42-61% more than the treated test sections. Note that the estimated loses include: loss of fines in the form of vehicular-generated-dust and loses due to erosion (wind and rainfall).

Table 4--- Estimated Total Aggregate Loss

Length of test section: 1.00 mi (5280 ft)

Width of test section: 33 ft

Compacted density: 1.6 tons/yd^3

Test Section	ADT	Measured Aggregate Loss/ mi/4.5 months (ft)	Estimated Aggregate Loss/ mi/year (ft)	Estimated Aggregate Loss/ mi/year (ton)	Estimated Aggregate Loss/ mi/year/vehicle (ton)
Lignosulfonate	515	0.019	0.050	519.88	1.01
$CaCl_2$	421	0.023	0.061	629.33	1.49
$MgCl_2$	448	0.017	0.045	465.16	1.04
Untreated	538	0.051	0.135	1,395.47	2.59

Cost Analysis

Some of the major problems associated with unpaved roads are aggregate replacement cost and periodic maintenance cost. These items take a substantial portion of local government's budgets. In Larimer County, Colorado, for example, using 1994 budget figures, 12% of the total budget of the Road and Bridge Department was spent on aggregate replacement alone and another 17% on periodic maintenance of the nearly 700 miles of unpaved roads under the County's jurisdiction. The main economic reason for suppressing dust on unpaved roads is to prevent the loss of aggregate in the form of fines/dust as well as reduce the frequency of periodic maintenance required to keep the road surface in good condition. For this reason, in order for the relative effectiveness of the dust suppressants evaluated in this research to be ascertained, a cost accounting for each test section was done.

Table 5 represents the cost analysis. The unit prices of the three dust suppressants evaluated were the same at \$0.285 per gal. The total cost of material (suppressant), labor and equipment for placing the treatments was \$3,528 per mile for the lignosulfonate test section and \$2,768 per mile each for the $CaCl_2$ and $MgCl_2$ test sections. The lignosulfonate treatment cost \$760 more in labor and equipment than the $CaCl_2$ or $MgCl_2$ treatment. The difference was due to the different methods of applications of the lignosulfonate and the chloride compounds. A mixed-in-place application was used for the lignosulfonate treatment while a surfaced sprayed application was used for the chloride compounds treatments. The compacted density of the roadway was 1.6 tons/yd^3 and the cost to replace the estimated lost aggregate was \$11.57 per ton in place. The cost of periodic maintenance, which included the use of water trucks and compactors, was \$529 per mile. Based on the 4.5 months study period it was estimated that the untreated test section would require 8 periodic maintenances during the year while the treated test sections would require only 2 periodic maintenances.

Table 5--- Cost Analysis

Length of test section: 1.00 mi (5280 ft)
Width of test section: 33 ft
Compacted density: 1.6 ton/cu. yd.
Cost of gravel: $11.57/ton in place
ADT: Average Daily Traffic
PM: Periodic Maintenance
M+L+E: Material (suppressant), Labor and Equipment

Test Section	ADT	Measured Agg. Loss/ mi/ 4.5 months (ft)	Estimated Annual Agg. Loss/mi (ft)	Estimated Annual Agg. Loss/mi (ton)	Cost of Test Sections: Agg. Lost/ mi/yr (dollars)	(M+L+E)/mi/yr (dollars)	PM/mi (dollars)	* PM/yr	Actual Total Cost/mi/yr (dollars)	Actual Total Cost/mi/yr/Veh (dollars)
Lignosul.	515	0.019	0.05	519.88	$6,015	$3,528	$529	2	$10,601	$21
$CaCl_2$	421	0.023	0.061	629.33	$7,281	$2,768	$529	2	$11,107	$26
$MgCl_2$	448	0.017	0.045	465.16	$5,382	$2,768	$529	2	$9,208	$21
Untreated	538	0.051	0.135	1395.47	$16,145	$0	$529	8	$20,378	$38

*** The Periodic Maintenance was performed with a Water Truck and Compactor.**

If this were being performed without these tools, we anticipate that the Periodic Maintenance would have to be done weekly in the case of the untreated test section.

- Duration of study: 4.5 months

With reference to Table 5, the computed cost for the lignosulfonate treated test section per mile per year per vehicle is approximately \$21, the costs for the $CaCl_2$ and $MgCl_2$ treated test sections are \$26 and \$21 respectively. The untreated test section cost \$38/mi/yr/vehicle. This analysis indicates a 30-46% cost saving in the treated test sections over the untreated test section. The slight differences between the treated test sections costs could be just random and therefore not very significant. What is of importance, is the fact that the use of road dust suppressants reduced the overall total aggregate loss from the unpaved road surface as well as the frequency of periodic maintenance required to keep the road in good condition. This results in substantial cost savings especially when the ADT on the unpaved road is high.

Because of the high initial cost (material, labor and equipment) involved in applying dust suppressants, the question, "at what minimum ADT would the use of road dust suppressants be feasible?" was posed. The answer may be influenced by several factors, the most important of which is the cost of aggregate in place. Based on the aggregate loss measurement and cost figures for the different treatments studied in this research, Figure 4 was developed to answer this question. As mentioned previously the cost of aggregate in place was \$11.57/ton, the initial cost per mile of roadway per year in material (suppressant), labor and equipment for placing each treatment was \$3,528 for the lignosulfonate test section, \$2,768 each for the $CaCl_2$ and $MgCl_2$ test sections and \$529 for the untreated test section (Y-intercept Fig. 4). The cost of periodic maintenance for each test section was \$529.00/mile. Two periodic maintenances per year was assumed for the treated test sections and 8 per year was assumed for the untreated test section. Based on the traffic count in this research, the cost of aggregate in place and periodic maintenance cost, the slope of each curve was established.

With reference to Figure 4, it is obvious that at low ADT it is more economical to leave the unpaved road untreated. As the ADT increases, the cost of maintaining the untreated road increases. The point where a treated test section curve crosses the untreated test section curve (indicated with vertical lines on Figure 4 at approximately 100 and 130) is the minimum ADT at which a particular treatment is economically feasible.

Since the cost of aggregate in place is such an important variable influencing the economics of this exercise, the minimum ADT's at which treatment is feasible was determined at different aggregate costs and the results are shown in Table 6.

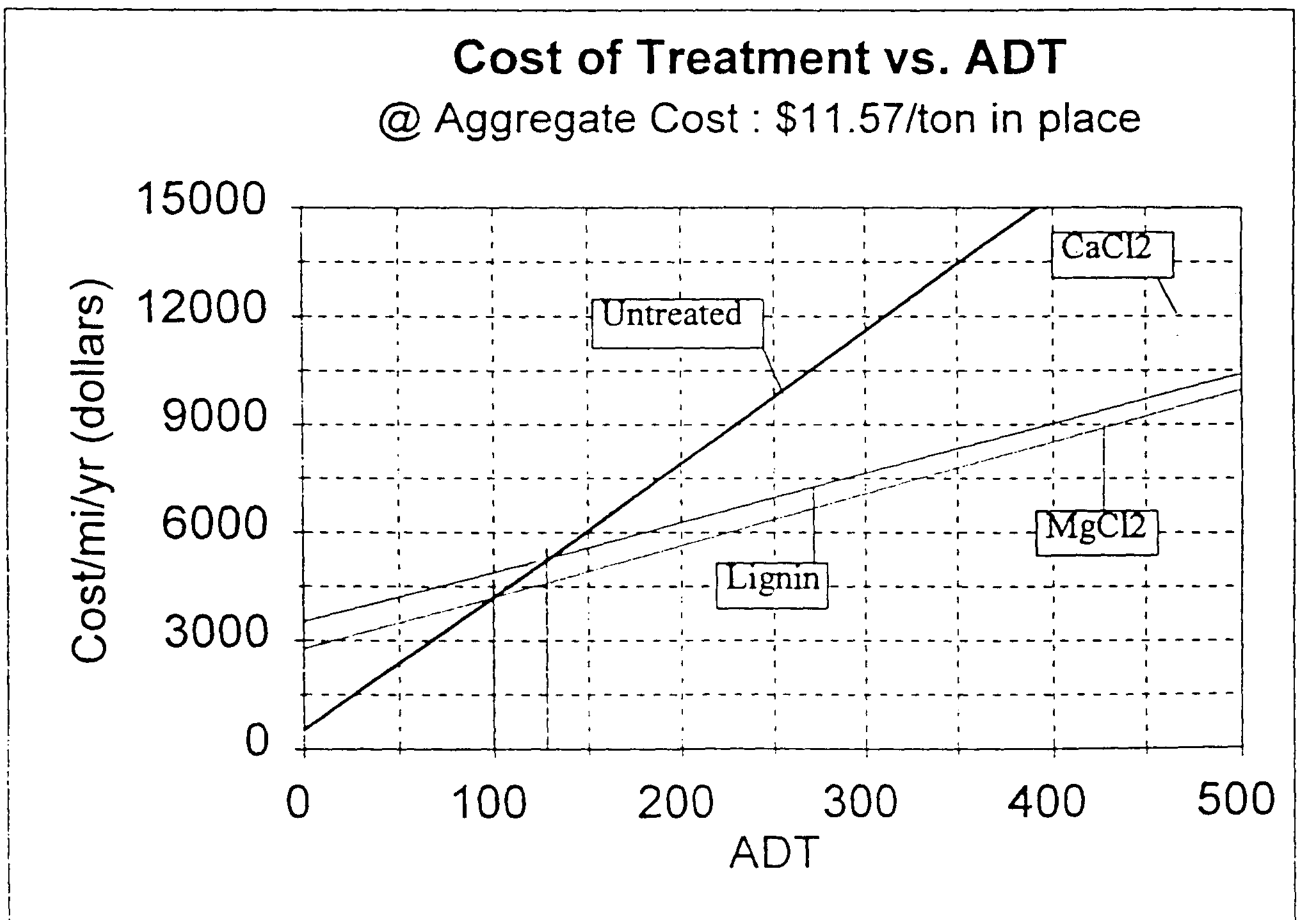

Figure 4---Cost of Treatment Versus ADT

Table 6---Minimum ADT at which use of Dust Suppressant is Economically Feasible

	Lignosulfonate	CaCl2	MgCl2
Cost of Agg./ton	ADT	ADT	ADT
$5.00	232	225	180
$7.50	180	180	140
$11.57	130	130	100
$15.00	105	105	80

The procedure followed in establishing the minimum ADT's for the different aggregate costs is the same as described above. The minimum ADT's at $5.00/ton, $7.50/ton and $15.00/ton in addition to the $11.57/ton were determined. From the results (Table 6) one can conclude that as the cost of aggregate in place increases, the minimum ADT at which the use of dust suppressants become economically feasible, decreases.

Conclusions

The following conclusions are based upon results of this field based research:

- Dust measurement data indicate that there is a substantial reduction in fugitive dust emission with application of chemical dust suppressants (50-70% reduction).
- Under high temperature and low relative humidity conditions, the lignosulfonate treated test section appears to produce less dust than the test sections treated with the chloride compounds during the test period. However, field observations after the research was completed showed that the lignosulfonate test section produced equal or more dust than the chloride compounds. The driving comfort on the lignosulfonate treated test section was also found to be considerably less than on the chloride treated test sections, mainly because of pothole formations on the

lignosulfonate test section after the test period.

- There is an estimated total aggregate loss of 1.0 ton/mile/year/vehicle from the lignosulfonate treated test section, 1.5 tons/mile/year/vehicle from the $CaCl_2$ treated test section, 1.0 ton/mile/year/vehicle from the $MgCl_2$ treated test section and 2.6 tons/mile/year/vehicle from the untreated test section. This translates into a 42-61% reduction in total aggregate loss when unpaved roads are treated.
- Cost analysis shows a 30-46% reduction in total annual maintenance cost for treated test sections over the untreated test section.
- At ADT of over 120, the use of any of the dust suppressants evaluated proved to be cost effective. This is the traffic volume at which the economic feasibility of the use of dust suppressants will decrease as the cost of in place aggregate increases.
- The minimum ADT at which the use of dust suppressants are economically feasible is variable depending on cost of aggregate in place.

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