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Assessment of Road Carpet for Control of Fugitive Emissions from Unpaved Roads

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EPA REVIEW NOTICE

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Assessment of Road Carpet for Control of Fugitive Emissions from Unpaved Roads

by

T. R. Blackwood

Monsanto Research Corporation
1515 Nicholas Road
Dayton, Ohio 45407

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EPA Project Officer: Dennis C. Drehmel

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

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ABSTRACT

Historically, emissions from unpaved roads have been controlled by watering, oiling, and chemical soil stabilization. An analysis of the forces which produce emissions shows that if fine material can be reduced, fine particle emissions (<15 μm) will also be reduced. A new concept for control has been proposed which utilizes a stable, rot-resistant, water permeable fabric to separate road ballast from subsoil. Fine material is not accumulated in the ballast due to gravitational and hydraulic forces during normal rainfall. Preliminary studies indicate that fine material will pass through the fabric without "blinding" and fines in the subsoil do not "pump into the ballast from the subsoil. Economic evaluations show that roads constructed with the fabric are cheaper for emissions control than conventional control methods. The effectiveness of control cannot be calculated; however, continuing research is anticipated. Construction and testing of a prototype road is anticipated in early 1979.

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SECTION 1

INTRODUCTION

Fugitive emissions from vehicular movement on unpaved industrial haul roads are the major source of respirable emissions from urban quarrying. Current control methods, which include water wetting, treatment with surface agents, soil stabilization, paving, and traffic control, have their own merits and limitations. Environmental problems could result from surface agents (such as oil) leaching into streams. Safety problems could result from slippery and dangerous road conditions. High initial cost and subsequent maintenance and repair costs make otherwise effective control measures (such as paving) impractical.

A new concept for emissions control has been proposed based on the use of a civil engineering fabric which is synthetic, stable, water-permeable, rot-resistant and usually employed in road stabilization. Laid below the haul road overburden, this tough fabric termed "Road Carpet" separates the fine soil particles in the roadbed from the coarse aggregate. This action prevents the fine material from reaching the road surface so that dust emissions are reduced.

This report describes the theory of operation of this concept to control of emissions from unpaved roads. Preliminary test data are included, and the economics of application are presented.

SECTION 2

SUMMARY AND RECOMMENDATION

The "road bed" concept has the potential for preventing virtually all of the emissions from unpaved roads at little or no additional cost over conventional controls. Any dust which falls to the road will be restricted, and most emissions that might occur would come from the grinding action of the vehicles over a short period of time. Any fines (less than 15 μm) in the road surface would be removed during rainfall by being washed into the road ballast. Fine dust which enters the ballast will pass through the fabric either into the subsoil or to the edge of the road. Fines in the subsoil cannot be pumped up into the ballast because of the siphoning action of the fabric. Thus essentially all of the sources of fine dust are eliminated from the road surface. Preliminary measurements have shown that emissions increase when the concept is reversed. Preliminary economics indicate that roads constructed using fabric stabilization are 40% to 50% cheaper than conventional roads on soft soil. For firm soil, the road with fabric is 10% more expensive and may require replacement during the life of a quarry or mine. However, maintenance would be insignificant for the road with fabric compared to the conventional costs of dust control. For permanent or temporary roads, this new concept is cheaper over the life of the plant for soft soil. On firm soil, the permanent road with fabric may be cheaper depending upon inflation and the life expectancy of the fabric. For temporary roads, the concept would be about 10% more expensive; however, firm subsoil is unusual for temporary roads.

It is recommended that a prototype of this concept be installed at a quarry and that experiments be conducted to evaluate the following:

- The reduction in fine dust (less than 15 μm) compared to the same unpaved road with no control, watering and oiling (if possible).
- Deterioration of the road containing fabric, including ballast replacement.
- Factors which may improve the concept for emissions control.

SECTION 3

DESCRIPTION OF CONCEPT

BACKGROUND

Health hazards and haze problems are associated with fugitive emissions from industrial processing. Emissions of particulates and other pollutants from open source industries, which emit air pollutants primarily in a nonpoint source manner, have drawn increased attention in recent years because of frequently encountered fugitive emission problems. Consequently, new concepts for controlling fugitive particles are being sought.

Sources of Emissions

From an industrial standpoint, the hauling of raw materials from mines or quarries to processing plants by large rubber-tired hauling vehicles over unpaved haul roads is responsible for a major portion of the fugitive dust generated by quarrying and mine operations.

Emissions occur due to comminution, vortex entrainment, and saltation. Comminution is the grinding of the aggregate between the truck tires and the road surface. Vortex entrainment suspends the smaller particles as the truck creates a wind over the road. As large aggregate falls on a dusty road surface (kicked up from the tires), the smaller particles are suspended from the impact; this is called saltation.

In the crushed limestone industry, for example, total particulate emissions from vehicular movement on unpaved roads (between quarry and plant) contribute approximately 66% of the overall emissions and 35% of the respirable emissions, i.e., particles smaller than 7 μm (1). Similarly, for an average surface coal mine, the transport and unloading operations contribute 40.8% of the overall respirable particulate emissions (2), as shown in Table 1.

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(1) Chalekode, P. K., T. R. Blackwood, and S. R. Archer. Source Assessment: Crushed Limestone State of the Art. EPA 600/2-78-004e, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1978. 61 pp.

(2) Rusek, S. J., S. R. Archer, R. A. Wachter, and T. R. Blackwood. Source Assessment: Open Mining of Coal State of the Art. EPA 600/2-78-004x, U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1978. 87 pp.

TABLE 1. AVERAGE SURFACE COAL MINE RESPIRABLE PARTICULATE EMISSIONS (2)

Operation	Percent of respirable emissions
Drilling	11.9
Coal loading	14.8
Transport and unloading	40.3
Blasting	31.9
Augering	0.6
Total	∿100

These emission sources are important because most quarrying occurs in urban areas and mining is an important part of the national economy. Since the price of raw materials, especially aggregate and construction materials, is a function of the haul distance from the plant to the consumer, most quarries are located near the mass of population which consumes its product. Quite often several quarries surround the urban area which can make these emission sources a constant problem in attaining acceptable urban air quality.

Conventional Methods of Emission Control

Emissions from hauling operations are proportional to the condition of the road surface and the volume and speed of vehicular traffic (3). Control measures include methods to improve road surfaces, suppress dust, or minimize the effect of vehicular traffic by means of operations changes. Currently available control measures, which include water wetting, treatment with surface agents, soil stabilization, paving, and traffic control, each has its own merits and limitations (3). Watering, for example, may be totally ineffective on warm and windy days because of rapid evaporation. Excessive watering may result in muddy, slippery road surfaces which create hazardous conditions for haulage vehicles.

The most commonly applied form of surface treatment is oiling. Although the frequency of application is significantly reduced, a potentially adverse environmental impact may result due to oil leaching into streams. Oiling is usually supplemented by

(3) Ochsner, J. C., P. K. Chalekode, and T. R. Blackwood. Source Assessment: Transport of Sand and Gravel. EPA600/2-78-004y, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1978. 62 pp.

watering and, again, improper application can cause slippery, dangerous road conditions. Other surface treatments include the application of hygroscopic chemicals (which absorb moisture from the air). These chemicals dissolve in the moisture which they absorb and form a clear liquid that resists evaporation. However, since they are water soluble, their use in areas of frequent rainfall may require repeated application. Additionally, these agents may contribute to increased corrosion of expensive haulage vehicles.

Soil stabilizers usually consist of a water-dilutable emulsion of either synthetic or petroleum resins which acts as an adhesive or binder. Substantial success has been reported by quarry operators using one such soil stabilizer. In addition to the environmental benefits, operators report considerable savings and operating benefits over traditional watering methods including reduced labor costs, lower maintenance costs on haulage vehicles, and safer road conditions. Daily applications of these chemicals, however, are required to effectively control dust emissions.

Paving is probably the most effective means of reducing some of the particulate emissions, but it may be impractical due to high initial cost and subsequent maintenance and repair costs. Operational methods that would result in reduced emissions include the reduction of traffic volume, control of traffic speed, and replacement of smaller haulage vehicles with larger capacity units.

THE "ROAD CARPET" CONCEPT FOR EMISSIONS CONTROL

A new, effective, and economical technique is desired for the control of fugitive particle emissions. This project involves the application of nonchemical road stabilization as a control option. The concept uses a stable, water-permeable, rot-resistant polyester fabric ("road carpet") laid below haul road overburden to separate the roadbed from the coarse aggregate as shown in Figure 1.

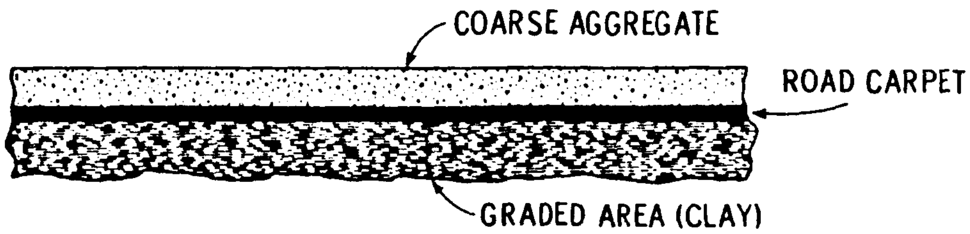

Figure 1. This concept employs a road carpet which spreads the vehicular load, prevents moisture from eroding the graded area, and keeps the dirt from reaching the tires where it can be picked up and dispersed.

The fundamental concept behind the use of a fabric roadbed stabilizer, or road carpet, for the control of fine particle emissions from haul roads is the prevention of vortex entrainment and saltation effects by the separation of fine roadbed materials from the coarse aggregate. Large aggregate is held from settling, while fines (less than 70 μm) are filtered by gravitation and hydraulic action. Road carpet can be made from spun-bonded, thin-film polypropylene on nylon sheet (Celanese), continuous filament polyester fibers needled to form a highly permeable fabric (Monsanto Company), or other synthetic materials spun or needle punched. The mechanical interlocking of fibers makes a formed fabric with the durability and toughness required for the proposed use. Designed for road construction use, this fabric is laid over poor load-bearing soils to help support and contain the overburden aggregate. It spreads the concentrated stress from heavy-wheeled traffic over a wider area, siphons away ground water, and contains fine soil particles in the roadbed that can otherwise contaminate road ballast.

Use of road carpet results in no health or safety hazards or in any other unfavorable environmental impact. In the development of these fabrics, various synthetic polymers, including nylon, propylene, and polyester were screened and evaluated. Fabrics made from any of these products generally are resistant to mildew, mild acids, and alkali, and are rot and vermin proof. Polyester was chosen by Monsanto Company because of the following distinct advantages (4):

- resistance to chemicals, including those found in soils
- constant properties over a wide range of temperature
- high melting point
- little change in properties wet or dry
- low moisture absorption
- high abrasion resistance
- high modulus of elasticity and excellent resilience
- excellent creep resistance.

Thus, use of road carpet precludes any environmental damage due to leaching of hazardous chemicals or heavy metals.

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(4) BIDIM® Engineering Fabric for Soil Stabilization and Drainage. Product Brochure published by Monsanto Company, St. Louis, Missouri. 24 pp.

SECTION 4

THEORY OF EMISSIONS FROM UNPAVED ROADS

FACTORS AFFECTING EMISSIONS

Once fugitive particles are airborne, they must be collected in order to be suppressed. The most effective approach to solving the emissions problem is thus to prevent the particles from becoming airborne. For unpaved roads within industrial processing areas, roads are usually constructed to serve haul trucks for a limited period of time (e.g., 4 to 6 months). These roads are usually created by bulldozing and grading a path from the working site (mine or quarry) to the processing plant (crusher or tipple). To create traction and to prevent subsidence of the road, a coarse aggregate is usually placed on the graded surface. The emissions are generated by comminution, vortex entrainment, and saltation of the large aggregate. These mechanisms are related to air turbulence and the mechanical forces of tires on the road surface. Emissions, E_u (g/vehicle), are affected by several factors which can be used to relate dependent and independent variables in equation form:

- vehicle speed (V), km/hr
- number of wheels/vehicle (N)
- particle size distribution (P), %
- surface moisture (M), or P.E. index
- vehicle weight (T), metric tons
- vehicle cross section (A), m^2
- tire width (W), m
- length of unpaved road (L), m

A literature search yielded only scattered quantitative information on emissions from unpaved roads. Most of the reported studies were directed toward quantifying the influence of vehicle speed on unpaved road emissions.

Vehicle Speed

Table 2 lists results of various tests conducted on emissions from unpaved roads.

TABLE 2. TESTS OF UNPAVED ROAD EMISSIONS

Investigator	Sampling site	Type of road	Vehicle speed, km/hr	Emission factor, g/veh-m	Particle size distribution, μm
Anderson, C. (5)	Bernalillo County, NM	Dirt	48	0.14 to 0.20	–[a]
School of Engineering, University of New Mexico (5)	University of NM	Dirt	40	0.26	<6
				0.01	<3
Pedco-Environmental Specialists, Inc. (6)	Sante Fe, NM	Dirt	24	0.19	–[a]
			40	0.28	–[a]
			56	0.56	–[a]
			64	0.99	–[a]
Engineering Research Institute, Iowa State University	Powshiek County, IA	Dirt	–[a]	1.55	–[a]
Puget Sound Air Pollution Control Agency (7)	Duwamich Valley, WA	Gravel	16	0.62	–[a]
				0.12	<10
				0.03	<2
			32	2.40	–[a]
				2.48	–[a]
				0.65	<10
				0.68	<10
				0.08	<2
			48	3.92	–[a]
				1.47	<10
				0.12	<2
Midwest Research Institute (8)	Franklin County, KS	Gravel	48	1.135	>30
				0.950	2 to 30
				0.770	<2
		Gravel	48	1.0	>30
				1.05	2 to 30
				0.882	<2
		Gravel	64	1.705	>30
				1.22	2 to 30
				1.025	<2
	Morton County, KS	Dirt	48	2.33	>30
				1.25	2 to 30
				1.05	<2
		Dirt	64	0.597	>30
				0.597	2 to 30
				0.512	<2
	Wallace County, KS	Dirt	48	6.82	>30
				5.35	2 to 30
				3.72	<2

[a]No designated size distribution.

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(5) Anderson, C. Air Pollution from Dusty Roads. In: Proceedings of the 1971 Highway Engineering Conference, (Bulletin No. 44-NMSU-EES-44-71, Las Cruces, New Mexico, 1971. 12 pp.

(6) Investigation of Fugitive Dust Sources, Emissions, and Control. Contract 68-02-0044, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1973. 152 pp.

(7) Roberts, J. W., A. T. Rossano, P. T. Bosserman, G. C. Hofer, and H. A. Watters. The Measurement, Cost and Control of Traffic, Dust and Gravel Roads in Seattle's Duwamish Valley. In: Proceedings of the Annual Meeting of the Pacific Northwest International Section of the Air Pollution Control Association, Paper No. AP-72-5, Eugene, Oregon, 1972. 10 pp.

(8) Cowherd, J., Jr., K. Axetell, Jr., C. Guenther, F. Bennett, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

The study conducted by the Puget Sound Air Pollution Control Agency can be used to predict a mathematical relationship for the emission of respirable particles from unpaved roads. Their results show that emissions of particles less than 2 μm in diameter are proportional to the vehicle speed (V), and those less than 10 μm in diameter are proportional to the square of the vehicle speed (V^2). Based on this study, one could expect emissions of respirable particles (less than 10 μm) to be proportional to ($aV^2 + bV$) where a and b are constants. Then

$$E_u = (aV^2 + bV) \tag{1}$$

where E_u = emissions, g/vehicle
V = vehicle speed
a, b = constants

Number of Wheels

A vehicle moving on an unpaved road generates dust in proportion to the number of its wheels. Thus,

$$E_u \propto N \tag{2}$$

where N = number of wheels per vehicle

Particle Size Distribution of the Road Surface Material

Particles greater than 100 μm are moved by saltation and surface creep[a] and are deposited in or near the affected area. Particles less than 10 μm are moved by the wind, mostly by suspension, and are carried over long distances from their sources. Thus, smaller particles from unpaved road emissions have a significant impact on ambient air particulate levels. Wind-tunnel studies and open-field measurements show that the proportion of movement by suspension is approximately equal to the proportion of particles less than 100 μm found in the soil (9). Hence,

$$E_u \propto P \tag{3}$$

where P = percent of particles (less than 100 μm) in the road surface material (0 cm to 10 cm depth)

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[a] Saltation refers to movement of particles (100 μm to 500 μm) in a series of short bounces, and surface creep refers to the rolling and sliding of particles (greater than 500 μm) along the surface of the ground. Soil movement in saltation occurs below a height of 0.6 m to 1.0 m above ground level; over 90% of the soil transported by saltation is below a height of 0.3 m from ground level (9).

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(9) Chepil, W. S. Dynamics of Wind Erosion: I. Nature of the Movement of Soil by Wind. Soil Science, 60(4):305-320, 1945.

Surface Moisture

As particle moisture increases, the cohesive force between particles increases, and therefore, the rate of soil entrainment decreases. The rate of soil movement varies inversely as the square of its moisture content (10). However, soil surface moisture is assumed to be proportional to the Thornthwaite Precipitation-Evaporation (PE) Index. The PE Index is determined from the total annual rainfall and mean annual temperature (11).

$$E_u \propto \frac{1}{(PE)^2} \qquad (4)$$

Vehicle Weight, Vehicle Cross Section, and Tire Width

No quantitative data are available in the literature describing how these factors influence unpaved road emissions.

Distance of Unpaved Road

A vehicle generates dust in proportion to the length of unpaved road. Thus,

$$E_u \propto L \qquad (5)$$

where L = the length of unpaved road.

ESTIMATION OF EMISSIONS FROM UNPAVED ROADS

General Expression for Emissions

Based on available data in the literature, emissions from unpaved roads can be expressed as follows:

$$E_u = \frac{K_u(aV^2 + bV)(P)(N)}{(PE)^2} f(T,A,W)L \qquad (6)$$

where E_u = emissions, g/vehicle

K_u = constant of proportionality

Equation 6 is too general to be evaluated with the limited data available.

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(10) Chepil, W. S., W. H. Siddoway, and D. V. Armburst. Climatic Factor for Estimating Wind Erodability of Farm Fields. Journal of Soil and Water Conservation, 17:162-165, 1962.

(11) Thornthwaite, T. W. Climates of North American According to a New Classification. Geographical Review, 21:633-635, 1931.

The overall emissions (Q) due to vehicle traffic are the sum of the emissions from four basic sources (i.e., vortex entrainment, comminution, saltation, and creep). Both saltation and creep are related to the slippage of material between the time of the vehicle and the roadway, as is comminutive action. In essence, the general entrainment model is as follows (where Q is expressed in g/s):

$$Q = Q_A + Q_B + Q_C + Q_D \qquad (7)$$

where Q_A = emissions due to vortex forces (air compression and expansion)
Q_B = emissions due to comminution (grinding of the road by tires)
Q_C = emissions due to saltation
Q_D = emissions due to creep

Q_C and Q_D are functions of the same parameters as Q_B; consequently, the general model reduces to the following (with different internal constants for Q_B):

$$Q = Q_A + Q_B \qquad (8)$$

Emissions Due to Vortex Entrainment

As a vehicle passes, air compression and expansion result in a draft that "pumps" dust into the air. An expression has been developed for wind erosion from flat storage piles. The following expression for coal was derived based upon the results of wind tunnel experiments conducted at the Pittsburgh Mining and Safety Center (12)

$$E_c = \frac{0.336V^3P^2s^{0.35}}{(PE)^2} \qquad (9)$$

where E_c = emissions due to wind erosion of a coal storage pile, g/s
V = wind speed, m/s
P = bulk density, g/cm^3
s = surface area, m^2
PE = Precipitation-Evaporation Index

(12) Singer, J. M., F. B. Cook, and J. Gurma. Dispersal of Coke and Rock Dust Deposits. Bureau of Mines RI-7642, U.S. Department of the Interior, Pittsburgh, Pennsylvania, 1972. 32 pp.

For a typical haul road vehicle of 21 metric tons, the 2.4-meter wide truck displaces a 3-meter width of air over the average length of travel (2.2 km) (3). If this displaced air can be raised to two-thirds of the average vehicle speed, 32 km/hr (3), with a soil bulk density of 2 g/cm³ in a PE index region of 100, then the emission due to vortex entrainment is 0.58 g/s. For the 2.2-km road, the vehicle will travel 248 seconds; hence, the emission factor is 0.07 grams per vehicle-meter.

Emissions Due to Comminution

Slippage between truck tires and the road surface will suspend the material in the slippage zone. The larger (greater than 100 μm) material will fall back to the surface rapidly while the fines (less than 15 μm) will remain suspended for great distances. Material between 15 μm and 100 μm will carry for limited distances, generally less than 20 meters. MRI has determined that emissions from unpaved roads can be related to vehicle speed and soil siltiness as shown in Equation 10 (13).

$$E = 0.23(S)(V/13)(365 - R/365) \qquad (10)$$

where E = emissions, gram per vehicle-meter
R = days of rainfall over 0.03 cm, per year
V = vehicle speed, m/s
S = soil siltiness, %

Soil siltiness is a function of particle size distribution in the soil and affects the depth of soil disruption in the slippage zone. Vehicle speed also contributes to the depth of soil displacement. A general model for comminution may take the form of Equation 11:

$$Q_B = (k_1)\frac{LWZ\rho}{T} = k_1VWZ\rho \qquad (11)$$

where k_1 = emissions constant
L = length of vehicle travel
W = width of tires
Z = thickness of soil disturbed
ρ = soil density
T = time of travel
V = vehicle speed, L/T

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(13) Cowherd, C. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

Because the large particles (greater than 100 μm) suspended by this process result in saltation and creep, the emissions constant will include this contribution. The thickness of soil disturbed will be proportional to the vehicle speed and soil siltiness (5). Thus, the emission rate becomes:

$$Q_B = k_2 V^2 S W \rho = k_3 V^2 S \qquad (12)$$

where k_2, k_3 = constants

Equation 12 is similar to that developed by MRI since the factor (365 - R/365) is an adjustment for the frequency of dry days when emissions would occur. Use of Equation 10 at the average conditions of 12% silt and 120 "wet" days (13) yields 1.27 grams per vehicle-meter. Thus, the effects of vortex entrainment (0.07 grams per vehicle-meter) are small.

Comminution, or slippage between the road and tire, is the major part of the problem of unpaved road emissions. While it is not feasible to eliminate the slippage, the emissions could be reduced if the fine material (less than 15 μm) was eliminated from the slippage zone. The fine material in the road ballast comes from three sources as follows:

1) Dirt from the vehicle tires, body, or payload may fall off and be deposited on the roadway.

2) Soil particles can be pumped up through the road ballast during rainfall. When the surface drys out, the soil will be dispersed by the traffic.

3) The ballast may be ground up by the action of the vehicle tires on the road surface. This material can eventually become small enough to be suspended.

SECTION 5

GENERAL THEORY OF ROAD CARPET OPERATION

An important characteristic of road carpet is its ability to transport water along the plane of the fabric. This siphoning action aids in subsurface consolidation. Figure 2 shows a laboratory model in which the polyester fabric made by Monsanto Company is placed in direct contract with silty soil. Water contacting the fabric flows to the edges of the road, even if there is an ascending gradient. The flow is not materially affected by the existence of a load. The random entanglement of the polyester filaments and the low fabric density still enable groundwater and rain to pass freely through the fabric.

Since the fabric filters selectively, particles larger than 70 μm are held back, while smaller waterborne fines pass through without clogging or binding. Fine particles which may settle on the roadway pass through the fabric and re-entrainment is prevented. This feature shows that the concept has the potential capability of reducing emissions of fine particles (less than 1 μm) by at least 90%.

Road carpet will prevent pumping of soil particles to the surface by carrying water out of the ballast. As this water flows through the ballast, it will pick up the fines due to material spillage and grinding of the ballast.

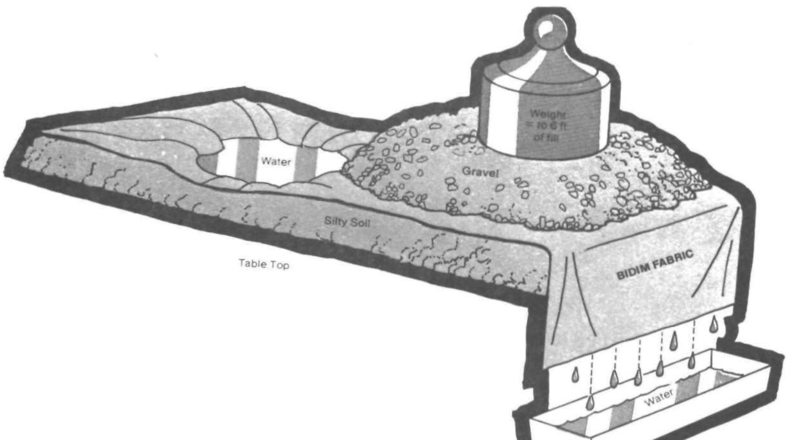

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Figure 2. The siphoning action of road carpet aids in sub-surface soil consolidation even in the presence of an ascending gradient (4).

PUMPING OF SOLIDS

The road carpet prevents the fine material in the soil from reaching the road ballast. As shown in Figure 3, the ballast of a railroad is uncontaminated when the fabric is installed. Rain is removed rapidly from the ballast to the edge of the roadway, and the soil remains stable. At a site in Georgia, an unpaved road was observed to drain free of water after a severe storm in just over four hours, while an adjacent road without the fabric remained wet.

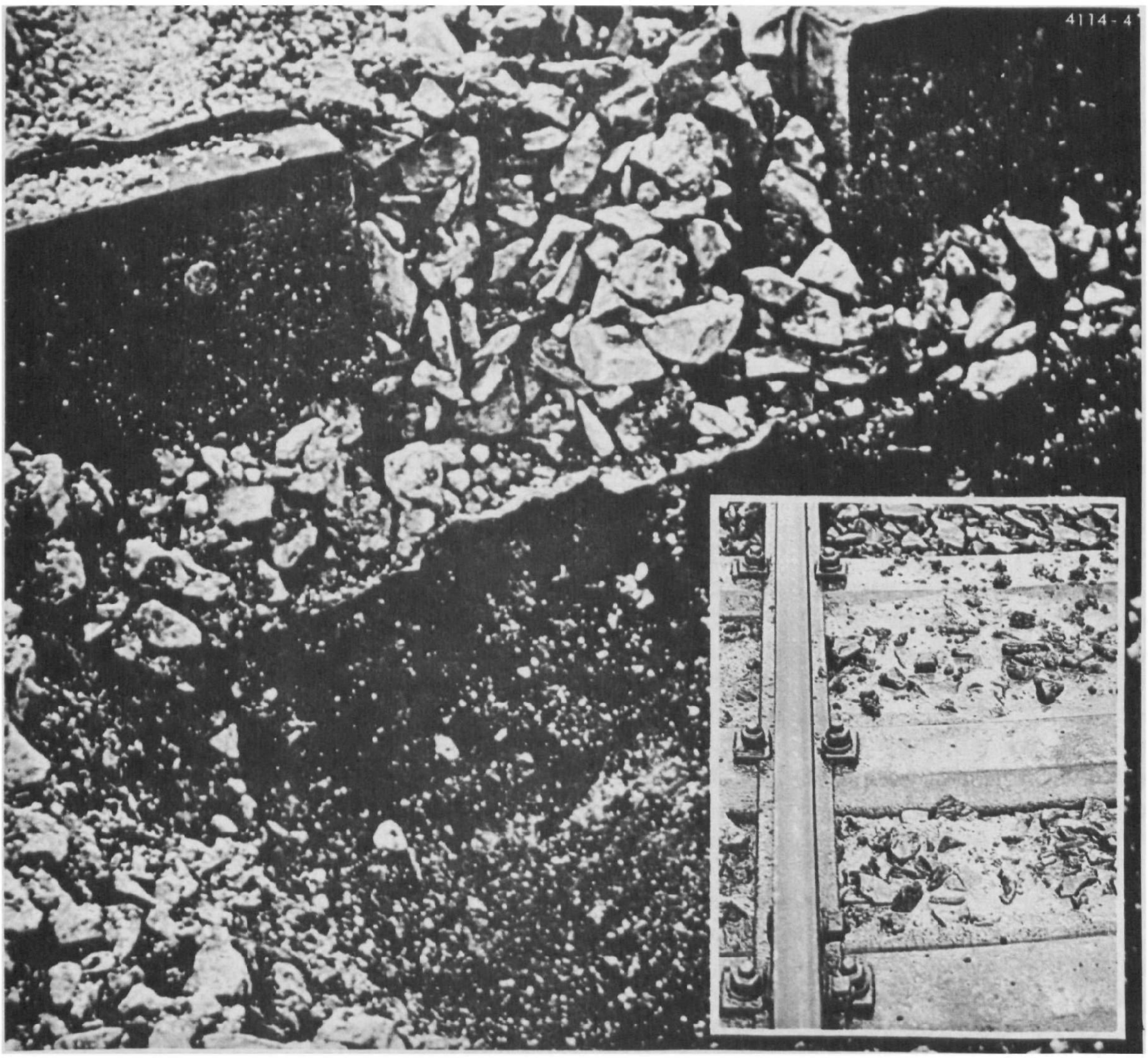

Figure 3. This picture, taken one year after installation of BIDIM® fabric, shows the ballast remains clean with minimum contamination (4). The lower insert shows the result of fine soil particles being pumped up into the ballast.

REMOVAL OF FINES CONTAMINATING THE BALLAST

When fine material enters the ballast, from either the aggregate or traffic, rainfall should carry it down to the fabric. If the fines do not pass through the fabric, they will build up and eventually contaminate the ballast. However, preliminary studies indicate that some fines do pass through some of the fabrics. In tests of clay blockage rates with vertical water flow, BIDIM and Cerex fabrics reached a limited blockage of 4 to 18% of the fabric area. Other fabrics, as shown in Figures 4 and 5, became essentially plugged up with the clay and bentonite solutions (private communication, C. J. Setzer, Monsanto Triangle Development Center, Research Triangle Park, NC). These results indicate that the fabric will pass the particles vertically and could be consolidated into the sub-surface or carried out through the fabric in a horizontal direction.

To further evaluate the particle transport characteristics of the fabric, tests were conducted on the horizontal flow through the fabric. The fabric to be tested was placed in the apparatus shown in Figure 6, which resembles a bell jar. A constant head of water was maintained and the horizontal flow measured. In-plane (horizontal flow) transmissability for several fabrics was deduced from these tests and is given in Table 3 (personal communication C. J. Setzer, Monsanto Triangle Research Center, RTP). In-plane transmissability of water is four to nine times higher for BIDIM than other fabrics. Additional flow studies were conducted with typical road dirt suspended in the water solutions. During the assessment of the transport of sand and gravel (3), samples of road dirt were collected throughout the United States to evaluate the composition and dustiness of unpaved roads near quarries. Since the quarries were in urban areas, a composite of these samples could be representative of "typical" unpaved road dust. This composite was suspended in water and, after settling of the large aggregate (greater than 70 μm), the slurry was sent to the bell jar to measure the in-plan flow of the slurry. A load equivalent to 0.2 m to 0.25 m of aggregate was placed on the fabric. Further details are provided in Appendix A.

Table 4 compares the vertical and horizontal flow rates for the BIDIM fabric with and without the presence of solids (i.e., clean water vs slurry). The horizontal flow is reduced to about 40% of the initial clean water flowrate, but the fabric is not completely occluded. It is anticipated that, in the real world, pulsations of flow and channeling may increase the effective flow rate. This was verified in experimental work by momentarily raising the pressure on the fabric. Pulsations would result from the compression and expansion of the fabric under the load of vehicles. A 17% increase in flow was observed due to these pulsations. Channeling is a common phenomenon due to the nonhomogenicity of the aggregate and soil adjacent to the fabric.

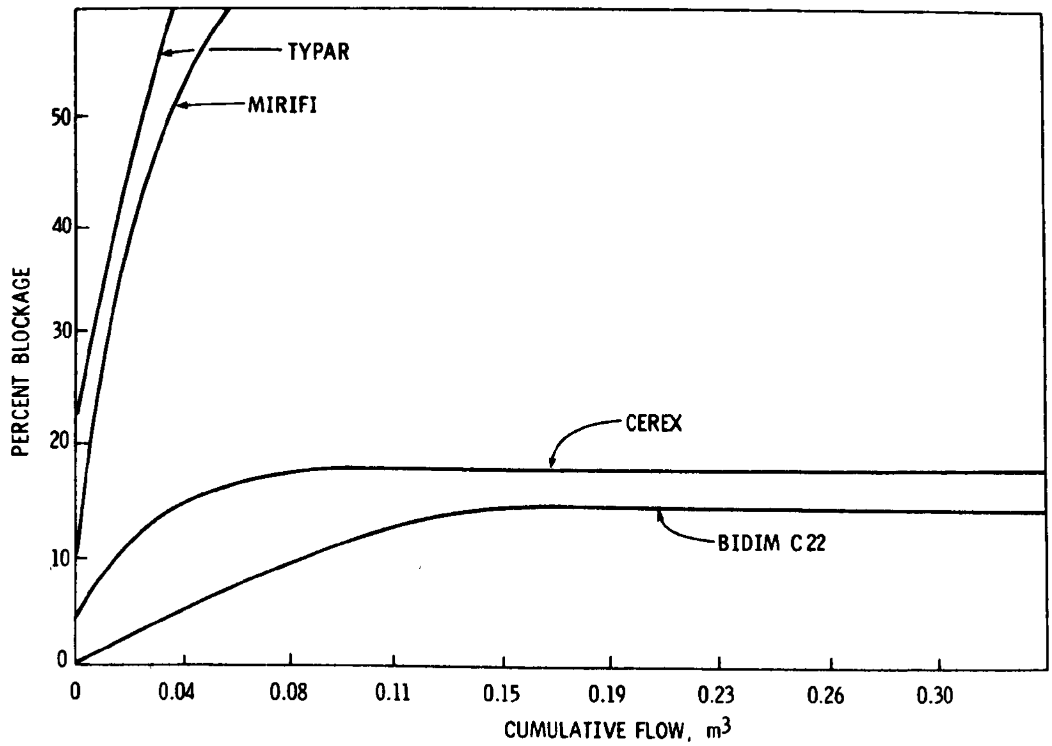

Figure 4. Blockage of fabric due to bentonite clay in water.

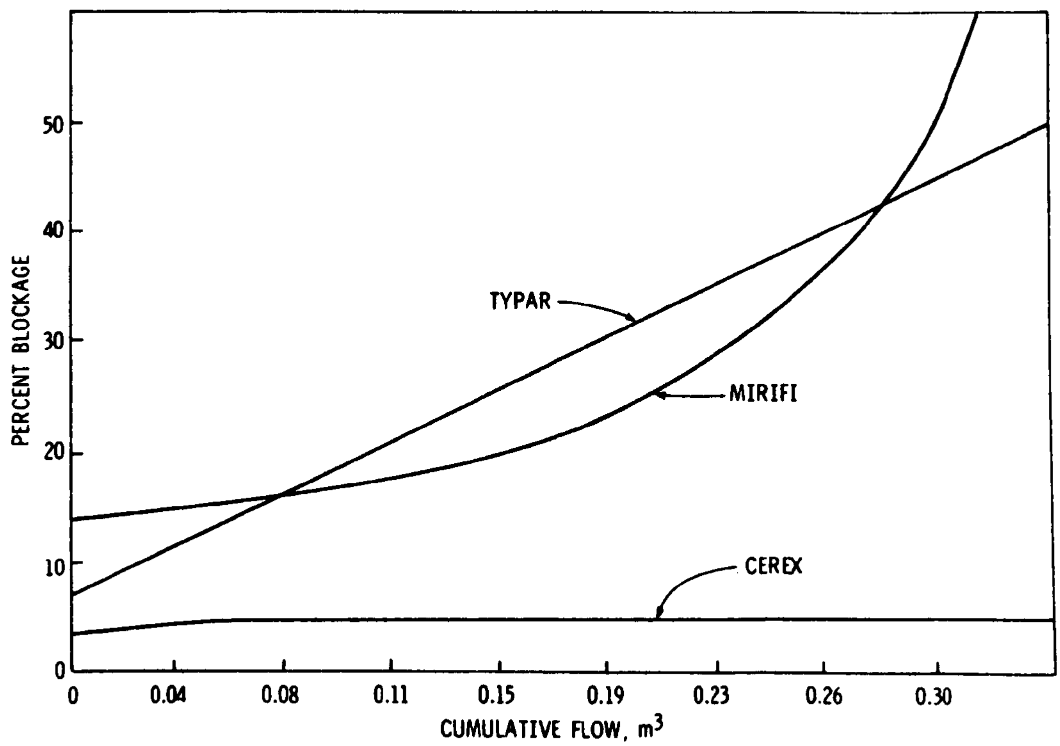

Figure 5. Blockage of fabric due to Hoytville clay in water.

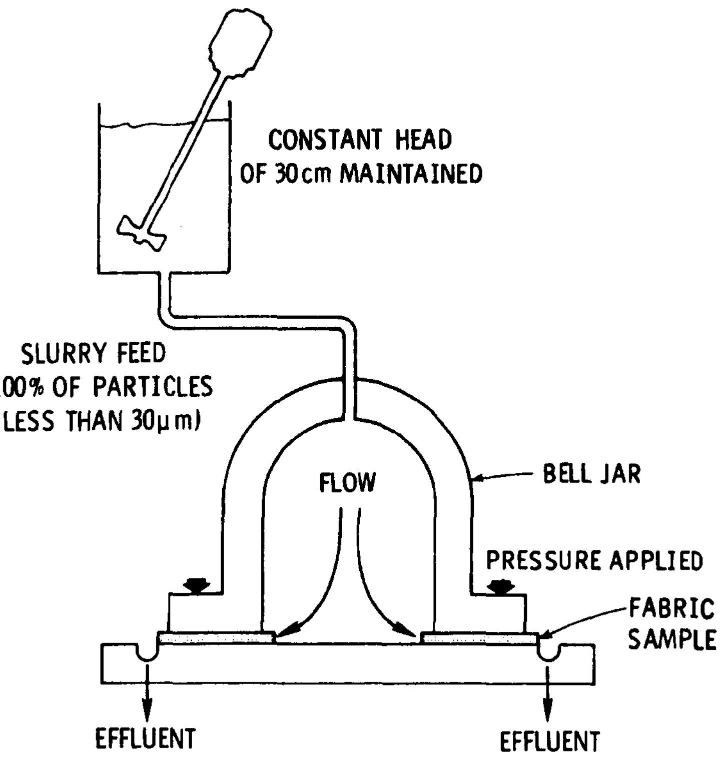

Figure 6. Laboratory instrument used to evaluate in-plane flow of slurries through fabrics.

TABLE 3. IN-PLANE WATER TRANSPORT OF FABRICS

Fabric	Transmissability, 10^{-3} cm^2/s
BIDIM C22	16
BIDIM C34	26
BIDIM C38	36
MIRAFI 140	4
TYPAR	1

TABLE 4. COMPARISON OF FLOWRATES THROUGH BIDIM FABRIC

Direction	Flowrate, m/min	
	Fabric C-22	Fabric C-34
Vertical:		
Clean water	22	15
Slurry[a]	19	13
Horizontal:		
Clean water	1.7	1.9
Slurry[b]	0.69	0.88

[a]Slurry contains bentonite clay; flow rate is the limit at steady state.

[b]Slurry contains typical road dirt; flow rate is the limit at steady state.

Particle Separation by Size

The holes in the fabric are approximately 70 μm in diameter and will pass particles up to that size depending upon particle shape. Because the fabric does not "blind," the effective size of the holes is not reduced significantly, and all particles smaller than 15 μm (the size of interest) should pass through the fabric vertically. If the soil is soft (cone penetrometer less than 1,000 kpa), these particles would be consolidated with the existing soil. When firm soil (soil penetrometer greater than 1,200 kpa) is present, consolidation would be difficult. Because the presence of the fine soil particles does not plug the fabric during horizontal water flow, some if not all of the fines could be purged along with normal water flow. The median particle size which passed through the fabric during the horizontal flow tests was about 3 μm. Particles as large as 20 μm also came through the fabric. This means that only the very small particles would pass horizontally over firm soil; however, some channeling would exist and carry off the intermediate size particles (3 to 15 μm).

SECTION 6

ECONOMICS OF THE ROAD CARPET CONCEPT

Capital and operating costs of various control options differ with each alternative. Cost comparisons have been made between the cost of new roads constructed with a fabric base and conventional subsurface preparation.

For very soft soil (cone penetrometer index less than 600 kpa), the thicker the fabric the cheaper the road, since the fabric spreads the stress and can replace 0.5 to 0.75 meters of rock. For soft soil (cone penetrometer index less than 1,000 kpa), the road with fabric is only 40% to 50% cheaper. On firm or existing aggregate-covered roads, the road would cost about 10% more. The maintenance cost of a conventional road would be higher than that for one containing road carpet; this will offset the difference in capital costs.

Tables 5 and 6 provide estimates of road construction capital costs. Table 7 shows the cost of two common control options, watering and oiling. The amortized costs for conventional control measures and for the new concept are summarized in Table 8. The life expectancy of the fabric in the road is unknown; experience indicates that 12 years would not be an unreasonable estimate. A haul road may last for the life of the plant (25 yr) with proper maintenance.

The road constructed with fabric is cheaper than either watering or oiling. Better data would be required on ballast replacement and watering costs due to the high inflation trends which are presently occurring. With conventional roads, a higher percentage of the yearly cost is required for perpetual care. This would make an even higher capital cost more attractive, if the life expectancy were better than anticipated.

The following is an explanation of Table 8. The annual cost of a conventional road (25-yr life) is $7,600 per kilometer. Watering and ballast replacement would add $6,750 to give $14,400 for an ordinary road. Adding $7,600 to the oiling and ballast replacement would give $13,800. This indicates that of the two options, watering or oiling, oiling is cheaper. By comparison, a fabric unpaved road would amortize over 12 years to $9,600 and with only ballast replacement, the annual cost would be $11,200. This indicates that the fabric unpaved road is cheaper than oiling or watering; however, rebuilding the road at the end of 12 years would amortize at $30,300 per km per year. In the 13th year, watering would be cheaper than the fabric road ($28,800 vs $35,300) but the cost of watering will continue to increase as it did for the previous 12 years.

TABLE 5. CAPITAL COSTS OF UNPAVED ROAD CONSTRUCTION

Assumption:

Road width = 10 m; road length = 1.6 km
Soft Soil requires a minimum of 0.36 m of aggregate for 18 metric ton axle loads on 10:00-20 tires (as shown in Figure 7). A grader and pan would be required.

Item	Cost, $
0.15 m of excavation (3 km haulage) requires 4 days at 8 hr/day and $110/hr	3,500
No. 57 aggregate fill requires 12,443 metric tons at $4.14/metric ton (FOB)	51,500
330 man-hours of haulage of aggregate (500 trips at 48 km/hr and 16 km of haulage)	8,300
Grading of surface (5 days with 10 trucks)	2,200
Taxes and permits	5,075
Total	$70,600

Firm Soil requires a minimum of 0.20 m of aggregate, which is equivalent to 7,100 metric tons of aggregate and 190 hr of haulage. This decreases the cost of a 1.6 km road to $43,900.

TABLE 6. CAPITAL COST OF CONSTRUCTION OF UNPAVED ROAD USING FABRIC

Assumption:

Road width = 10 m; road length = 1.6 km

Minimum thickness of aggregate is 0.15 m for 18 metric ton axle loads on 10:00-20 tires (as shown in Figure 7). Fabric can be laid with no surface preparation on firm or soft soil.

Item	Cost, $
17,000 m^2 of fabric at $0.86/$m^2$ (FOB)	14,700
Installation (3 men for 1 hr at $20/hr), transportation to site (48 km), and freight (57 rolls at $50/roll; 2 truck loads)	2,800
0.15 m of No. 57 aggregate fill; 5,330 metric tons at $4.14/metric ton (FOB)	22,100
140 hours of aggregate haulage (200 trips at 48 km/hr and 16 km of haulage)	3,600
Surface grading (3 days with 10 trucks)	1,300
Taxes and permits	3,600
Total	$48,100

TABLE 7. OPERATING COSTS OF WATERING AND OILING CONTROL OPTIONS

WATERING

Assumptions: Truck nets 1.6 km/hr including water loading time. Water applied each day when rainfall is less than 0.1 cm or two out of three days (U.S. average). Plant operates 130 days/year.

Item	Cost, $
Amortized cost of watering trucks ($12,000 over 10 yr at 17% interest)	2,600/yr
Maintenance and repair of watering truck	1,000/yr
Manpower for watering 2.2 km of road, two times daily at $25/hr	5,960/yr
Water (1 cm or 156,000 liter)	680/yr
Total for 2.2 km road	10,200/yr or 4,640/km-yr
Road repair (24 hr of grading and 3-5% of ballast replaced per year)	2,100/km
Total per km of road	6,750/yr

OILING

Assumptions: Typical application for haul road trucks is 0.19 cm of oil per month. For 6 months of operation on a 9-m wide road (1 km long), 104,000 liters of oil would have to be applied at $0.055 per liter.

Item	Cost, $
Oiling service (1 km)	5,800/yr

For dusty road surfaces (0.3 cm of dust), 0.27 cm of oil would be applied with an asphaltic sealer. This material would require application twice during 6 months of operation but would cost about $0.092 per liter.

Item	Cost, $
Cost of asphaltic oiling service (1 km)	4,600/yr
Ballast replacement (3-5%/yr)	1,600/yr
Lowest expected cost for oiling (1 km)	6,200/yr

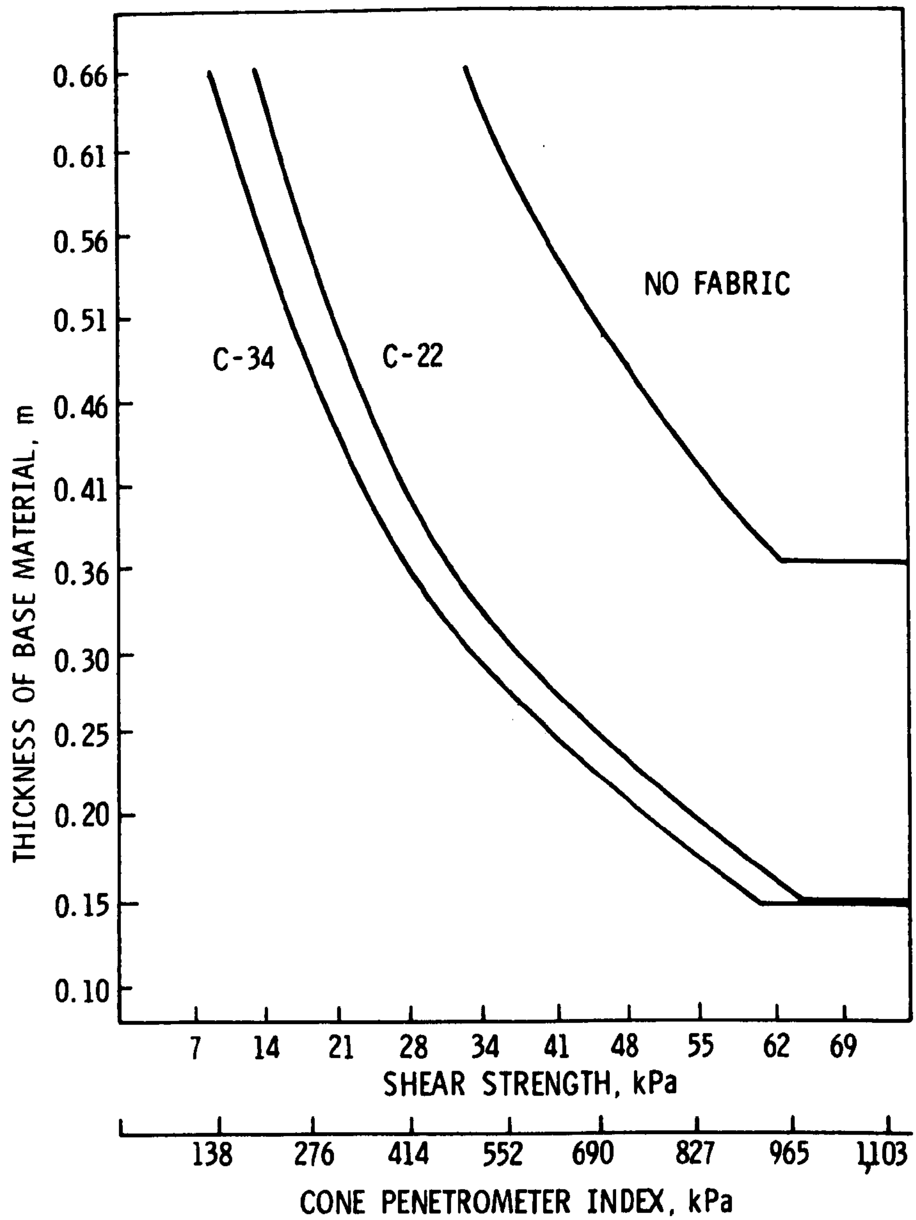

Figure 7. Design curves for 18 metric ton axle load on 10:00-20 tires for BIDIM fabric.

TABLE 8. AMORTIZED COSTS OF DUST CONTROL ON UNPAVED ROADS

Type of road and/or dust control	Cost, $/km
Unpaved road on firm soil (no control); $27,400 over 25 years (17% interest)	4,750
Watering and ballast replacement	6,750
Oiling and ballast replacement	6,200
Ordinary road with watering and ballast replacement	11,500
Ordinary road with oiling and ballast replacement	10,950
Fabric *unpaved road; $30,000 over 12 years* (17% interest)	6,000
Ballast replacement	1,600
Fabric road with ballast replacement	7,600
Fabric replacement (amortized cost in 12 years at 17% interst and 10% inflation)	18,900
Cost of fabric road in 13th year with ballast replacement	24,400
Cost of conventional road with watering and ballast replacement in 13th year	28,000
Cost of conventional road with watering and ballast replacement in 12th year	25,900
Cost of fabric road in 12th year with ballast replacement	11,500

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APPENDIX A

RAW DATA FOR DETERMINATION OF FLOW CHARACTERISTICS OF SUSPENDED SOLIDS THROUGH BIDIM FABRIC

This test work was initiated at the request of Tom Blackwood at the Dayton Laboratory who is looking at a new application for Bidim. For this application Bidim would underlay an 8-10 in. gravel road bed used by large trucks in mining operations. The fabric will help control a dust pollution problem by carrying fine silt particles generated by abrasion away from the road bed. The installation could need a supply of water which could wash the fines down through the gravel to the fabric.

To evaluate the fabric, a modified lateral flow permeameter and a dilute slurry of fine soil particles were used to test the fabric. Soil particle sizes, before and after passage through the fabric, and flow rates were measured.

SLURRY PREPARATION

The soil was supplied by Tom Blackwood in eight plastic containers. These were blended.

Two kinds of slurries were used. The first slurry was composed of about 12-15 lb of the soil-rock blend in 14 gallons of water. This slurry was agitated vigorously during the experiment and relatively large soil particles were kept in suspension. This slurry caused rapid blinding of the fabric because the mean particle size was too large to pass through the fabric pores (approximately 70 μ).

The second slurry was an attempt to reduce the mean particle size to <70 μ and to have the concentration of fines between 5-20 g/ℓ. To accomplish this the blended soil was sieved through the No. 20 seive. These fines (>841 μm) were stirred into 14 gal of water. This slurry was allowed to settle for about 10 min before using. The concentration of suspended particle was about 18 g/ℓ. Further stirring of the 14 gal slurry tank was minimized.

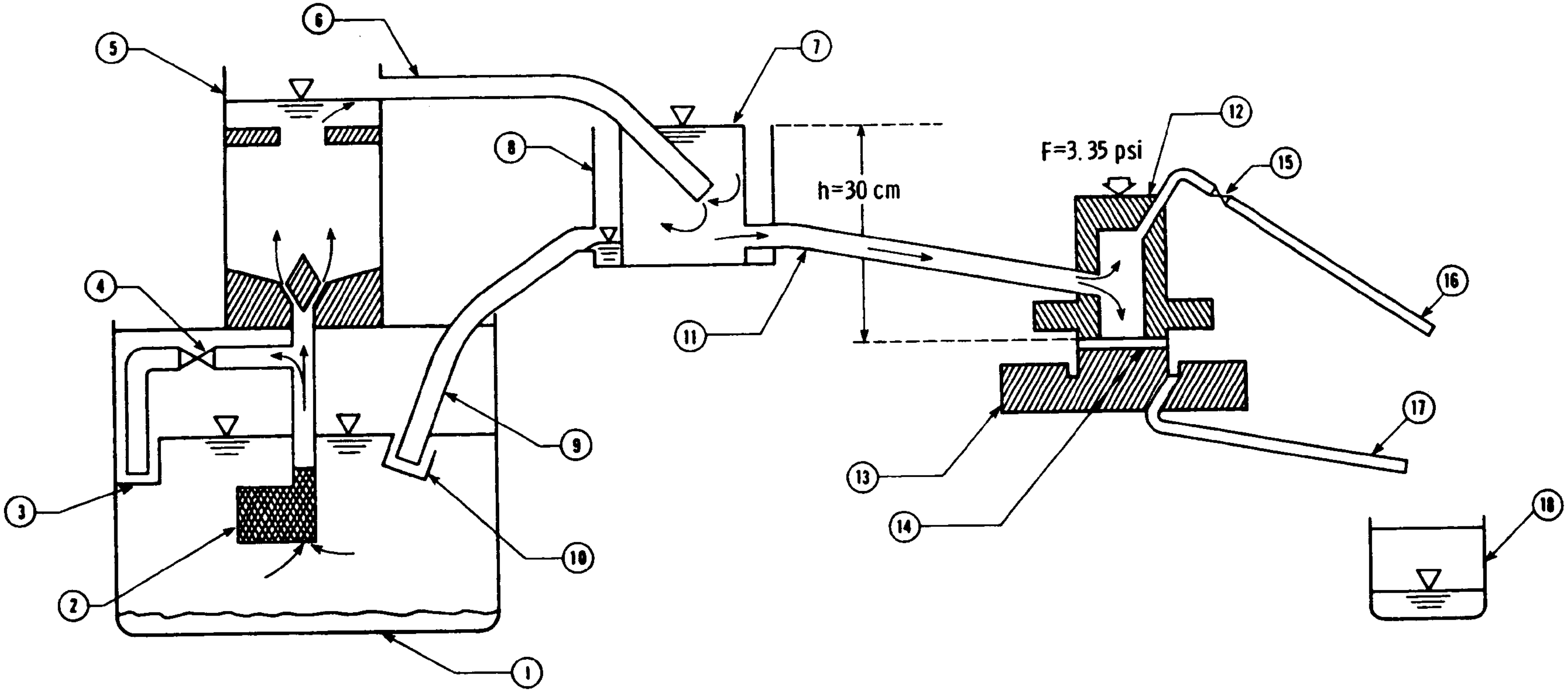
APPARATUS

Modifications to the Advanced Drainage System (ADS) equipment and to the Planar Permeameter (PP) were necessary to perform this test. The constant head tank (CHT) was also modified. The general arrangement of equipment used for these experiments is given in Figure A-1.

PROCEDURE

1 - Stir slurry in tub vigorously. Wait 10-15 min before starting pump. Allow CHT to overflow 30 min.

2 - Install pre-wet fabric. Rubber gaskets were not used to seal interface between plate and fabric. Apply combined force of 3.35 psi on fabric. Open bleed valve on PP.



1 SLURRY TUB 18 in. x 22 in. x 15 in. DEEP
2 MIGHTY MITE PUMP (2D-N)
3 BIPASS BAFFLE
4 BIPASS VALVE
5 ADS CHAMBER D = 8 in. L = 16 in. w/4 in. I.D. RESTRICTION PLATE
6 GRAVITY SUPPLY TUBE TO CHT
7 CHT D = 6 in. L = 9 in. (STRIPPER NOT SHOWN)
8 CHT OVERFLOW D = 9-1/2 in L = 9 in.
9 CHT OVERFLOW TUBE
10 CHT OVERFLOW BAFFLE
11 SUPPLY TUBE TO PP
12 PP PRESSURE CAP
13 PP BASE PLATE W/OVERFLOW TROUGH
14 FABRIC SPECIMEN D - 4-1/4 in.
15 BLEED VALVE
16 BLEED TUBE 1/4 in. O.D.
17 FABRIC DRAIN TUBE
18 SLURRY RECYCLING CONTAINER

Figure A-1. Apparatus used for testing slurry flow.

3 - Initiate flow in PP supply tube by removing plug on inside of CHT. Start run timer with initial flow of slurry out of bleed tube.

4 - Measure flow rate from fabric drain tube. After 2, 20, and 60 min lapse times, slurry samples are to be collected from the fabric drain tube and the bleed tube.

5 - Recycle slurry out of PP by pouring into CHT overflow every 2-3 min.

RESULTS

Run Data: C-34 Bidim Fabric

Preliminary runs were made to develop techniques prior to this single run.

Area of fabric under compression, 10.21 in.^{2}
Compressive force, 3.35 psi
Hydraulic head, 30 cm of water
Flow through the PP bleed tube, 390 mℓ/min
Temperature in the CHT, 23.7°C, RT = 0.916

Elapsed time, min	Flow, cc/min	Elapsed time, min	Flow, cc/min
1	950	45	575
5	875	50	560
10	810	55	540
15	750	60	520
20	710	65	510
25	675	75	485
30	645	90	450
35	620	100	435
40	600		

Run Data: C-22 Bidim Fabric

Temperature in the CHT, 22.6°C, RT = 0.940
Experimental constants same as for C-34

Elapsed time, min	Flow, cc/min	Elapsed time, min	Flow, cc/min
2	590	50	350
10	520	55	335
15	480	60	325
20	450	70	305
25	430	80	290
30	410	90	275
35	390	100	260
40	375	110	245
45	360	120	235

After 120 min, the pressure was momentarily increased to 48.1 psi then returned to 3.35 psi where the flow was checked.

125 min	275 cc
135 min	233 cc

This suggests that pumping action may stimulate and improve the fabric's performance.

COMPARATIVE DATA

The PP was used to generate transmissability and permeability values for a variety of fabrics using pure water. These tests used a constant hydraulic head of 30 cm. The RT was 0.990 and 1.017 for C-22 and C-34 Bidim fabrics. However, the load on the fabric was varied every 5 min so the flows did not reflect any creep that would probably occur in 120 min.

C-22 flow after 5 min lapse time:

max 650 cc/min, min 502 cc/min, mean 566 cc/min

C-34 flow after 5 min lapse time:

max 982 cc/min, min 840 cc/min, mean 903 cc/min

QUANTIMET ANALYSIS OF SLURRY USED IN PLANAR PERMEAMETER

Slurry samples (100-200 mℓ) were collected at the bleed tube (#16, Figure A-1) and at the fabric drain tube (#17, Figure A-1) at various time intervals during the testing of C-22 and C-34 fabrics. The samples were labeled by fabric weight, lapse time, and "BP" if sample was taken at the bleed tube.

The Quantimet was programmed to view 30 different fields each having an area of 110,178 μm^2 and count the number of "features," soil particles between 1 and 100 μm in equivalent circular diameter, a standard way of sizing irregular shaped particles. The computer also calculated the total particle volume. Using this information the relative concentrations of solid particles in each slurry could be determined.

The obvious problem was being sure a typical drop from 100-200 mℓ of sample was being taken. The microscopist did check successfully for reproducibility on several of the odd samples.

The original water suspension was allowed to air dry on the slide and was replaced by a silicone and then stirred for uniform dispersion. The results are given in Table A-1.

TABLE A-1. PARTICLE SIZE DISTRIBUTION THROUGH FABRIC

Sample I.D.	Equivalent circular diameter, μ				Particle volume, μ^3	Solid concentration, g/ℓ
	Max	Min	Mean	Median		
34-1	15.48	1.617	3.367	3.866	73,255.4	0.060
34-1 BP	21.90	1.617	3.660	3.977	116,471	0.069
34-20	12.74	1.617	3.219	3.842	38,550.8	0.004
34-20 BP	21.77	1.617	3.214	3.846	72,283.6	0.043
34-60	17.88	1.617	3.516	3.915	99,534.9	0.072
34-60 BP	16.95	1.617	3.404	3.896	103,304	0.079
22-2	22.02	1.617	3.891	4.042	204,057	0.12
22-2 BP	20.69	1.617	3.604	3.945	171,430	0.11
22-20	17.07	1.617	3.309	3.851	64,500.8	0.065
22-20 BP	13.14	1.617	2.697	3.782	27,404.5	0.027
22-60	11.55	1.617	3.251	3.822	46,121.2	0.050
22-60 BP	14.10	1.617	3.181	3.815	40,863.5	0.038

Note: C-22 fabric was tested first then the slurry reused for fabric C-34. Quantimet analysis performed on 2-9-79, and 2-13-79.

Calculation for sample 22-2:

$$\text{Concentration} = (g/\ell) = \frac{\rho\, V_S}{V_L}$$

V_S = volume solid

V_L = volume liquid

ρ = 4.2 x 10^{-2} g/cm³ or 2.65 lb/ft³

L = max equivalent circular diameter

$$[C] = \frac{(4.2 \times 10^{-2}\ g/cm^3) \times (V\mu^3) \times (1 \times 10^{-12}\ cm^3/\mu^3)}{30 \times (1.1 \times 10^{-3}\ cm^2) \times (Lcm) \times (1 \times 10^{-3}\ \ell/cm^3)}$$

$$= \frac{4.2 \times 10^{-14}}{3.3 \times 10^{-5}} \times \frac{204{,}057}{2.2 \times 10^{-3}}$$

$$= 1.3 \times 10^{-9} \times \frac{204{,}057}{2.2 \times 10^{-3}}$$

$$= 0.12\ g/\ell$$

Wilsford E. Artz
Monsanto Triangle Park
Research Center

TECHNICAL REPORT DATA
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16. ABSTRACT The report gives results of an assessment of the use of carpeting to control fugitive emissions from unpaved roads. Historically, emissions from unpaved roads have been controlled by watering, oiling, or chemical soil stabilization. An analysis of the forces which produce emissions shows that, if fine material can be reduced, fine particle emissions (<15 micrometers) will also be reduced. A new concept for control has been proposed: it utilizes a stable, rot-resistant, water-permeable fabric to separate road ballast from subsoil. Fine material is not accumulated in the ballast due to gravitational and hydraulic forces during normal rainfall. Preliminary studies indicate that fine material will pass through the fabric without blinding, and that fines in the subsoil do not pump into the ballast from the subsoil. Economic evaluations show that roads constructed with the fabric are cheaper for emissions control than with conventional control methods. The effectiveness of control cannot be directly calculated; however, research is continuing. Construction and testing of a prototype road in anticipated in 1979.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Roads	Stationary Sources	
Dust	Unpaved Roads	11G
Carpets	Particulate	11E
Fabrics	Road Carpets	

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