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DUST CONTROL FOR HAUL ROADS

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16. Abstract (Limit: 200 words)

The purpose of this study was to evaluate the various techniques for mine roadway dust control. The evaluation included (1) the types of dust suppressants available, (2) the interaction of the dust suppressants with the properties of the roadway surface, and (3) the costs and performance measures of the predominantly used dust suppressants. Over 30 products were identified with a wide range of effectiveness depending largely on the properties of the road base, subsurface, and wearing surface. The effectiveness of a dust suppressant was also found to depend on the application and maintenance procedures employed. As a result of this investigation, five dust suppressants were identified as being predominant in the surface mining industry: petroleum resins wetting agents, lignin sulfonate, water, and calcium chloride. An approximate cost-effective analysis, limited by lack of quantitative field performance data, showed that the five suppressants ranked in the order given, with water being one of the least cost effective. This report also presents an analysis of applicable Federal and State regulations.

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FOREWORD

This report was prepared by the Midwest Research Institute's Air Quality Assessment Section located in Kansas City, Missouri, under USBM Contract No. J0285015. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Twin Cities Research Center with Mr. H. William Zeller acting as technical project officer. Mr. R. J. Simonich was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period September 1978 to February 1981. This report was submitted by the authors on February 27, 1981.

Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

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1.0 EXECUTIVE SUMMARY

The purpose of this study was to evaluate the various techniques used for mine roadway dust control. This evaluation included the assessment of the types of dust suppressants available, their respective performance and costs, and their interaction with properties of the roadway structure.

Vehicular traffic on unpaved roads is the largest source of particulate emissions within the surface mining industry. Emission inventories of mining operations show that mine roadway dust emissions typically constitute 50 to 90% of the particulate emissions. Due to the magnitude of the emissions, many state and federal regulatory agencies have promulgated regulations for the control of road dust emissions. The purpose of these regulations includes the improvement of ambient air quality and the improvement of operator safety. The most specific regulations are those from the Office of Surface Mining. As a result of this agency's regulations, by March 1980, operators of western surface mines were required to submit fugitive dust control plans.

The research in this study was divided into two major categories: (a) the researching of information concerning various dust control products and (b) the assessment of the roadway structure to be controlled. Information concerning these topics was obtained from a literature search, visits to mine sites, contacts with trade associations active in the field, and contacts with other researchers in the field of fugitive dust control.

From these contacts, over 30 products were identified as having been used in one form or another for road dust control. These products work by binding the loose surface materials together, reducing the amount of fines available for vehicular entrainment. The effectiveness of these products may last from 30 min to 1 year depending on product type, application procedures, the type of vehicles traveling over the surface, and the frequency with which they travel.

Through the analysis of the roadway structure, it became evident that the various properties of the road base, subsurface, and wearing surface greatly affect the performance of a dust control program. Weak road structures invariably result in poor surfaces for vehicular travel and increase the difficulty of maintaining the roadway for dust control purposes. A successful roadway dust control program is usually associated with the proper construction and maintenance of the road structure.

In addition to having a well-constructed roadway on which to work, a dust suppressant must be applied and maintained properly. Important application techniques for many dust suppressants include surface scarification, adequate grading and smoothing of the surface, application of the dust suppressant in quantities suitable for effective control, and proper finishing procedures, which include the forming of the surface crown and the optimum compaction of the roadway surface.

As a result of this investigation, five dust suppressants were identified as being predominant in the surface mining industry. An assessment of these five dust suppressants was performed which included application procedures, associated costs, performance, and cost effectiveness. These five materials are presented in Table 1 by their respective annual expenditures for a dust control program at a mine having 2 miles of haul roads and 3 miles of access roads.

TABLE 1. ANNUAL OPERATING COST

Materials	Operating Cost
Calcium chloride	$188,000
Lignin sulfonate	141,000
Petroleum resins	97,000
Water	150,000
Wetting agents	124,000

These results are only approximate due to the lack of actual mine environment performance data. They are based on information derived from mine personnel, product vendors, and specific assumptions by the authors. The purpose of the table is to provide a general guide of the control costs and for other assumed operating conditions the costs would be different.

The above analysis can be strengthened only by obtaining quantitative field performance data on these dust suppressants. This would involve measuring the decay of the dust suppressants' control effeciency versus time and application procedure. From this field testing, observations could be made of the advantages and disadvantages of the control measures. In addition, actual manpower, product, and equipment costs could be obtained. As a result, a more thorough cost-effectiveness analysis of these products would be realized.

2.0 INTRODUCTION

This chapter introduces the program objective and the various tasks undertaken to meet this objective. Also, the magnitude of dust produced by mine haul road traffic on unpaved roads is presented to demonstrate the need to meet the program objective.

2.1 Program Objective

The overall objective of this project is to provide technical guidelines to the mining industry for selecting and implementing cost-effective dust control for haul roads. The ultimate objectives of haul road dust mitigation are: (a) the improvement of air quality, (b) the reduction of vehicle maintenance costs, and (c) the improvement of employee morale and safety.

2.2 Magnitude of Haul Road Dust Emissions

2.2.1 Introduction

Since the objective of this study is to develop guidelines for selecting and implementing cost-effective dust control for haul roads, it is appropriate to demonstrate the magnitude of haul road dust emissions compared to other sources at a surface mine. The following sections show that haul road traffic on unpaved roads is by far the major source of dust produced at mines. A review of emission inventories of various mining operations across the country clarifies and substantiates this statement.

Virtually all of the particulate matter produced at surface mines is generated in the form of fugitive dust, a broad term used to characterize particles that become airborne through forces of wind, man's activity, or both. Major particulate-emitting activities at mines include the following:[1]

- Conveying
- Transfer points
- Screening
- Truck and train loadout
- Open storage piles
- Haul roads
- Exposed areas
  - Refuse piles
  - Railroad facilities
  - Mine facilities

- Overburden removal
  - Dragline operations
  - Truck/shovel operations
  - Scraper operations
- Drilling
  - Coal
  - Overburden
- Blasting
  - Coal
  - Overburden
- Topsoil removal
  - Scraping
  - Dumping
- Crushers

Iron ore, coal, and copper mining emission inventories are discussed below, and the importance of haul road emissions to the overall emissions is reviewed.

2.2.2 Iron Ore Mining Emissions

A study of emissions emanating from the iron range mines in Minnesota was undertaken by Midwest Research Institute (MRI) in 1978.[2,3] Emissions for source categories at the iron range mines were calculated using 1976 as the base year. Table 2 shows the emissions for several mines. Overall, emissions from loaded and unloaded haul vehicles on unpaved roads ranked first in emission production. At the first eight mines shown in the table, haul traffic on unpaved roads produced from 47 to 77% of all fugitive emissions inventoried.

2.2.3 Coal Mining Emissions

Table 3 ranks emission sources at surface coal mines in the four prevalent combinations of mining operations.[1] Emissions for vehicular traffic on haul roads constituted the major source of fugitive dust at the inventoried coal mines. Hauling of coal and overburden ranked either first or second in fugitive dust production. Heavy duty vehicles traveling on unpaved roads contributed from 64 to 87% of the total fugitive emissions at the mines.

2.2.4 Copper Mining Emissions

MRI compiled a very detailed emission inventory of particulate sources for various locations in Montana.[4] This study included an emission inventory of sources at the Berkley Pit, a large copper mine located in Butte.

TABLE 2. MINING COMPANY EMISSION INVENTORIES

Source category	Mining company total emissions (g/sec)															
	Butler Taconite	Erie Mining	Eveleth Taconite	Hibbing Taconite	Inland Steel	U.S. Steel	National Steel	Reserve Mining	Sherman Group[a]	Rana[a]	Sharon-Culver[a]	Rouchleau[a]	Stephens Group[a]	Lind Greenway[a]	McKinley[a]	Hill-Annex[a]
1. Unpaved roads																
. Loaded heavy duty	62.7	33.4	21.8	16.0	3.17	195.4	71.7	112.6	18.4	0.5	2.0	4.9	1.0	8.8	3.7	14.6
. Unloaded heavy duty	39.7	26.7	18.1	7.86	1.58	105.5	45.4	81.6	12.1	0.4	1.5	3.0	0.7	4.4	8.0	7.6
. Medium duty	9.42	4.40	1.62	1.60	0.10	19.9	10.7	34.3								
. Light duty	1.77	17.7	5.02	3.56	2.15	1.11	2.12	15.5								
2. Paved roads																
. Medium duty	0.063	0.14	0.04	0.04	b	0.17	0.06	0.11								
. Light duty	0.087	3.02	0.23	0.24	b	8.14	0.10	0.09								
3. Wind erosion of surface dumps	0.41	1.16	0.32	0.55	0.12	5.74	1.43	1.10								
4. Wind erosion of waste and lean ore stockpiles	0.25	1.94	0.06	0.03	b	0.73	0.82	1.27								
5. Wind erosion of pellet stockpiles	0.18	21.2	b	b	b	0.64	0.19	c								
6. Wind erosion of tailings beaches	13.3	4.69	2.48	b	b	47.5	11.1	c								
7. Wind erosion of tailings slopes	4.95	0.47	0.04	b	b	0.38	4.11	c								
8. Wind erosion of concentrate piles	1.77	b	7.12	b	b	2.23	3.16	c								
9. Load-in of pellets into railcar from loading pocket, bins, or silos	0.22	0.11	0.21	0.03	b	1.15	0.22	c								
10. Pellet stacking (onto pile)	0.22	0.37	b	b	b	1.15	0.22	c								
11. Load-in of pellets into railcar with power shovel or loader	b	2.03	b	b	b	b	b	c								
12. Load-in of crushed ore (minus 4 in.) into piles	<0.01	b	0.07	0.12	b	b	<0.01	0.02								
13. Blasting (waste rock and ore)	1.05	4.82	1.03	0.45	b	4.91	1.70	4.05								
14. Wind erosion of crushed ore stockpile	0.02	b	0.05	0.23	b	b	0.03	0.69								

[a]Natural ore mine. *Data compiled* only for loaded and unloaded heavy duty traffic on unpaved roads.

[b]Source did not exist.

[c]Processing plant not on Mesabi Iron Range.

TABLE 3. RANKING OF SURFACE COAL MINING SOURCES FOR FOUR TYPICAL OPERATIONS

Source	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	Emission rate (lb/yr)	Individual source rank	Generic category rank	Emission rate (lb/yr)	Individual source rank	Generic category rank	Emission rate (lb/yr)	Individual source rank	Generic category rank	Emission rate (lb/yr)	Individual source rank	Generic category rank
I. Batch drop operations			9			9			9			9
A. Front-end loader to truck	-			-			-			-		
B. Shovel to truck												
1. Coal	100 (0)	17		100 (0)	19		100 (0)	20		100 (0)	22	
2. Overburden	-			1,670 (0.026)	13		-			1,670 (0.026)	15	
C. Dragline	1,670 (0.075)	12		-			1,670 (0.074)	14		-		
D. Truck dump												
1. Coal	50 (0)	18		50 (0)	20		50 (0)	21		50 (0)	23	
2. Overburden	-			836 (0.013)	16		-			836 (0.013)	18	
II. Continuous drop operations			10			10			10			10
A. Coal stacking onto pile	-			-			130 (0)	19		130 (0)	21	
B. Conveyor transfer station	13 (0)	19		13 (0)	21		13 (0)	22		13 (0)	24	
C. Silo loading	13 (0)	19		13 (0)	21		-			-		
D. Train loading	1,300 (0.059)	13		1,300 (0.02)	14		1,300 (0.058)	15		1,300 (0.02)	16	
III. Wind erosion			7			7			6			6
A. Flat areas	31,300 (1.4)	9		31,300 (0.49)	10		31,300 (1.4)	9		31,300 (0.48)	10	
B. Coal piles	-			-			8,100 (0.36)	12		8,100 (0.13)	13	
IV. Vehicular traffic on unpaved roads			1			1			1			1
A. Light and medium duty vehicles	165,000 (7.4)	3		165,000 (1.6)	4		165,000 (7.3)	3		165,000 (2.6)	4	
B. Heavy duty vehicles												
1. Coal	1,300,000 (58)	1		1,300,000 (20)	2		1,300,000 (57.6)	1		1,300,000 (20)	2	
2. Overburden	-			4,195,000 (65)	1		-			4,195,000 (65)	1	
3. Topsoil	148,000 (6.6)	4		148,000 (2.3)	5		148,000 (6.6)	4		148,000 (2.3)	5	

(continued)

TABLE 3. (continued)

Source	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	Emission rate (lb/yr)	Individual source rank	Generic category rank	Emission rate (lb/yr)	Individual source rank	Generic category rank	Emission rate (lb/yr)	Individual source rank	Generic category rank	Emission rate (lb/yr)	Individual source rank	Generic category rank
V. Vehicular traffic on paved roads	6,370 (0.28)	11	8	6,370 (0.099)	12	8	6,370 (0.28)	13	8	6,370 (0.1)	14	8
VI. Blasting	106,000 (4.7)	5	4	106,000 (1.6)	6	4	106,000 (4.7)	5	4	106,000 (1.6)	6	4
VII. Rotary drilling			3			3			3			3
A. Coal	14,600 (0.65)	10		14,600 (0.23)	11		14,600 (0.65)	11		14,600 (0.23)	12	
B. Overburden	99,800 (4.5)	6		99,800 (1.55)	7		99,800 (4.4)	6		99,800 (1.5)	7	
VIII. Crushing			12			12			12			12
A. Primary	500 (0.022)	15		500 (0)	17		500 (0.022)	17		500 (0)	19	
B. Secondary	375 (0.017)	16		375 (0)	18		375 (0.017)	18		375 (0)	20	
IX. Screening	1,000 (0.045)	14	11	1,000 (0.016)	15	11	1,000 (0.044)	16	11	1,000 (0.015)	17	11
X. Grader operations	81,000 (3.6)	7	5	81,000 (1.3)	8	5	81,000 (3.6)	7	5	81,000 (1.3)	8	5
XI. Dozer operations			2			2			2			2
A. Road construction and land reclamation	240,000 (11)	2		240,000 (3.7)	3		240,000 (10.6)	2		240,000 (3.7)	3	
B. Coal pile maintenance	-			-			17,000 (0.75)	10		17,000 (0.26)	11	
XII. Scraper pickup and dump	36,100 (1.6)	8	6	36,100 (0.56)	9	6	36,100 (1.6)	8	7	36,100 (0.56)	9	7
Total emissions	2,230,000			6,430,000			2,260,000			6,450,000		

Table 4 shows various source categories, their annual emissions, their contribution in percentage of total emissions, and their rank in emission production. Traffic on unpaved roads accounted for 78% of the total emissions at the mine. Haul trucks traveling on unpaved roads ranked first compared to other fugitive emission sources.

2.2.5 Summary

The importance of fugitive dust emissions generated by trucks traveling on unpaved roads was reviewed for taconite ore, iron ore, coal, and copper mining operations. Table 5 summarizes the impact of haul road traffic on the total fugitive emissions inventory of these mine operations.

Including all the mining operations surveyed, fugitive dust generated by haul truck travel on unpaved haul roads accounted for 47 to 87% of the total annual emissions and was first in fugitive emission production. It can be concluded that fugitive dust emissions for haul roads constitute the major particulate emission source of all mining activities.

2.3 Identification of Major Tasks

In order to meet the program objectives discussed in Section 2.1, this program was divided into five major tasks. These tasks are outlined in Table 6.

TABLE 4. BERKLEY PIT EMISSIONS

Source category	Emissions (tons/year)	Percentage of Total emissions	Rank
Unpaved roads			
. 100-ton haul truck--overburden	2,900	19.0	1
. 100-ton haul truck--wood	1	Neg.	
. 85-ton water truck	730	4.9	7
. 150-ton haul truck--overburden	360	2.4	9
. 170-ton haul truck--overburden	1,800	12.0	4
. 85-ton wrecker	230	1.6	
. Pickups	780	5.3	6
. Buses	15	0.1	
. Truck bulldozer	10	0.1	
. Rubber-tired partrols	80	0.5	
. Rubber-tired loaders	23	0.2	
. Fork lift	Neg.	Neg.	
. Lube, powder and lime truck	260	1.7	
. Utility truck, 10 ton	240	1.6	
. Utility truck, 5 ton	52	0.4	
. Utility truck, 3 ton	530	3.6	8
. Emergency vehicles	Neg.	Neg.	
. Hydroseeder	Neg.	Neg.	
. 100-ton haul truck--ore	1,300	8.7	5
. 150-ton haul truck--ore	160	1.1	
. 170-ton haul truck--ore	2,300	15.0	3
Paved roads			
. Pickups	64	0.4	
. Buses	Neg.	Neg.	
. Lube, powder and lime truck	18	0.1	
. Utility truck, 10 ton	27	0.2	
. Utility truck, 5 ton	Neg.	Neg.	
. Utility truck, 3 ton	43	0.3	
. Emergency vehicles	Neg.	Neg.	
Exhaust			
. Drills	2,600	18	2
. All vehicles	67	0.4	
Ore/overburden handling			
. Shovel loading	Neg.	Neg.	
. Truck dumping	Neg.	Neg.	
Wind erosion			
. Leach bed areas	7	Neg.	
. Waste dump	Neg.	Neg.	
Blasting	14	0.1	
Point sources	280	1.9	10
Total	15,000	100.0	

TABLE 5. FUGITIVE HAUL ROAD EMISSION IMPACT AT VARIOUS MINING OPERATIONS

Mining Operation	Haul Road Percentage of Total Emissions	Rank
Iron ore	47 - 77	1
Coal	64 - 87	1
Copper	78	1

TABLE 6. IDENTIFICATION OF MAJOR TASKS

Task 1 - Assess government regulations
Purpose: Summarize current and pending governmental regulations pertaining to fugitive dust control in the surface mining industry.

Task 2 - Conduct information search
Purpose: Gather all known information pertaining to dust control measures for unpaved roads.

Task 3 - Characterize mine roadways
Purpose: Identify road categories for which specific dust control techniques can be recommended.

Task 4 - Determine control effectiveness criteria
Purpose: Evaluate the cost effectiveness of road dust control techniques.

Task 5 - Reporting
Purpose: Prepare written summary of the state of the art of unpaved roadway controls.

3.0 GOVERNMENTAL REGULATIONS PERTAINING TO FUGITIVE DUST

Fugitive dust is a broad term used to characterize particles that become airborne through forces of wind, man's activity, or both. Such fugitive emissions contribute significantly to violations of federal and state ambient air quality standards for total suspended particulates (TSP). As mentioned in Section 2.2, mining activities produce a variety of fugitive dust emission sources, and the most significant source is vehicular travel on haul roads.

Because fugitive dust contributes to the violation of air quality standards, various federal and state agencies have promulgated regulations for its control. As part of this study, a few of these agencies were contacted and their fugitive dust regulations were requested. This section discusses the fugitive dust regulations issued by selected state pollution control agencies, the U.S. Environmental Protection Agency (EPA), the Office of Surface Mining (OSM), and the Mining Safety and Health Administration (MSHA). The relevance of these regulations to fugitive dust produced by haul roads is detailed. Also, requirements by EPA, OSM, and various states for construction permits pertinent to air quality are reviewed.

3.1 State Regulations

The state air quality agencies of Alabama, Arizona, California, Colorado, Florida, Georgia, Indiana, Kansas, Kentucky, Maryland, Minnesota, Missouri, Montana, New Mexico, North Carolina, North Dakota, Pennsylvania, West Virginia, and Wyoming were contacted and asked to send pertinent current fugitive dust regulations and State Implementation Plan (SIP) revisions relevant to fugitive dust control. Permit information for new source construction was also requested.

The states listed above were chosen so as to represent areas of the country which have major mineral/ore producers. Some of the pertinent selection criteria for choosing these states follow:

- Distribution over a wide geographic expanse of the United States.
- Inclusion of major coal mining states east and west of the Mississippi River.
- Inclusion of a wide spectrum of mining activities, both metallic and nonmetallic mines, a variety of mine sizes, and underground as well as surface mining activites.

A listing of air quality agency personnel who were contacted about their state's fugitive dust regulations is given in Appendix A.

It should be cautioned that state regulations are in a state of flux at present. Regulations that are presented in this report represent information requested as of late August 1979. After this date, many states promulgated new SIP revisions, but this information is not contained herein.

Other states have had SIP revisions approved which call for further analysis and demonstration projects for their TSP problem. Their regulations for fugitive dust will be formulated after the results of these analyses are known.

Federal fugitive dust control recommendations were adopted as a model for some state regulations. This model is shown in Table 7.[5]

TABLE 7. FEDERAL MODEL FOR FUGITIVE DUST ABATEMENT

The owner or operator of a fugitive dust source shall . . .

a. use, where possible, water or chemicals for control of dust in the demolition of existing buildings or structures, construction operations, the grading of roads, or clearing of land.

b. apply asphalt, oil, water, or suitable chemicals for control of dust on dirt roads, materials stockpiles, and other surfaces which create airborne dust problems.

c. install and use hoods, fans, and/or fabric filters to enclose and vent the handling of dusty materials; employ adequate containment methods during sandblasting or other similar operations.

d. cover at all times when in motion open-bodied vehicles transporting materials likely to become airborne.

e. conduct agricultural practices such as tilling of land and application of fertilizers so as to prevent dust from becoming airborne.

f. pave roadways and maintain the roads to minimize high surface dust loadings.

g. promptly remove earth or material from paved streets onto which earth or other material has been deposited by trucks or earthmoving equipment or erosion by water or other means.

Several states have extracted some or all of this model for their own fugitive dust control regulations. This model is referred to by some of the states whose regulations are summarized in Appendix B. Appendix B reveals that fugitive dust regulations exhibit a wide range of comprehensiveness. Some states do not regulate any fugitive emission while others have stringent regulations. Few specific regulations have been promulgated to control fugitive dust from haul roads.

Colorado, Minnesota, New Mexico, North Carolina, North Dakota, and West Virginia have specific regulations pertaining to haul roads. They generally require the control of dust by water, chemicals, or other dust palliatives, imposing speed restrictions, or detouring traffic where necessary. Fugitive control measures applicable to mining operations that were adopted by Colorado and North Dakota are similar to the Final Regulatory Program of OSM, which is discussed below.

3.2 Federal Regulations

This section reviews federal regulations that were promulgated to protect air quality from fugitive dust emissions. The OSM and EPA have both adopted regulations that pertain to fugitive dust emissions sources in the mining industry.

3.2.1 Office of Surface Mining

The Surface Mining Control and Reclamation Act of 1977 was passed to protect the environment and the public from the potential damage of mining activities. Specifically, Section 515(b)(4) of the Act, Environmental Protection Performance Standards, calls for the stabilization and protection of all surface areas to effectively control erosion and attendant air and water pollution.[6]

The final regulatory program, published in the March 13, 1979, Federal Register,[7] is much more specific about air pollution control. This program became effective in March 1980, if the state had failed to submit a comparable plan by that time.

Section 780.15, Air Pollution Control Plan, sets forth the following regulations:

a. For all surface mining activities with projected production rates exceeding 1 million tons of coal per year and located west of 100th meridian west longitude, the permit shall contain an air pollution control plan which includes the following:

1. An air quality monitoring program to provide sufficient data to evaluate the effectiveness of the fugitive dust control practices proposed under Paragraph (a)(2) of this Section to comply with federal and state Air Quality Standards.

2. A plan for fugitive dust control as required in Section 816.95 (discussed below).

b. For all other surface mining activities, the application shall contain an air pollution control plan which includes the following:

1. An air quality monitoring program, if required by the regulatory authority, to provide sufficient data to evaluate the effectiveness of the fugitive dust control practices under Paragraph (b)(2) of this section to comply with applicable federal and state Air Quality Standards.

2. A plan for fugitive dust control as required in Section 816.95.

Section 816.95(a) Fugitive dust - each person who surface mines shall employ fugitive dust control measures as a part of site preparation, coal mining and reclamation operations. The regulatory authority shall approve the control measures according to federal and state air quality in the area affected by mining and the available control technology.

c. Control measures shall include the above criteria, and not be limited to:

1. Periodic water on unpaved roads - minimum frequency must be approved by regulatory authority.

2. Chemical stabilization of unpaved road with nontoxic soil cement or dust palliatives.

3. Paving of roads.

4. Prompt removal of coal, rock, soil, and dust-forming debris from roads, and scraping and compaction of unpaved roads to stabilize road surface.

5. Restriction of vehicular speed to reduce fugitive dust.

6. Revegetation, mulching or stabilization of surface of all areas adjoining roads.

7. Restriction of travel by unauthorized vehicles.

8. Enclosure, covering, watering, or treating haul trucks and railroad cars to reduce loss of material.

9. Conveyor systems in substitution for haul trucks and covering of such systems when subject to wind erosion.

10. Minimizing the area of disturbed land.

11. Prompt revegetation of regraded lands.

12. Use of alternatives for coal handling restriction on dumping, wetting of disturbed materials during handling and compaction of disturbed areas.

13. Windbreaks at critical points in the permit area.

14. Control of dust from drilling using water sprays, hoods, dust collector, or other means.

15. Restriction of area to be blasted at any one time.

16. Restriction of activities causing fugitive dust during periods of air stagnation.

17. Extinguishing burning areas or smoldering coal and periodic inspection for burning areas.

18. Reduction of time period between soil distribution and revegetation or other surface stabilization.

19. Restriction of fugitive dust at spoil and coal transfer and loading points with water sprays, negative pressure systems or baghouse filters, chemicals, or other practices.

d. Additional measures - if measures in paragraph (b) of this Section are inadequate, the regulatory authority may require additional measures and practices as necessary.

e. Monitoring as required by Section 780.15.

The Final Regulatory Program has a mandatory fugitive dust control plan that every mining operator is required to submit. The regulatory authority may approve it, or, if not, recommend additional measures to control fugitive dust. Fugitive dust control techniques included in the plan that mine operators may choose for haul roads are:

- Periodic watering, whereby minimum frequency must be approved by the regulatory authority.
- Chemical stabilization with nontoxic soil cements or dust palliatives.
- Paving of roads.
- Prompt removal of coal, rock, soil, and dust-forming debris from roads and the scraping and compaction of unpaved roads to stabilize road surface.
- Restriction of vehicular speed to reduce fugitive dust.

3.2.2 Environmental Protection Agency

The Clean Air Act (1970) and the Clean Air Act Amendments (1977) were passed by Congress to protect the environment from the harmful effects of pollutants. The Clean Air Act Amendments of 1977, Section 169 require that sources with "potential" to emit 250 tons per year be subject to a Prevention of Significant Deterioration (PSD) review. In addition, 28 specific industries are regulated in a similar manner if they have potential emissions of at least 100 tons per year.

PSD requirements as they apply to mining activities are at present limited to the imposition of Best Available Control Technology (BACT). EPA Region VIII proposed BACT practices for mining (given in Table 8),[8] the only agency to do so.

TABLE 8. BEST AVAILABLE CONTROL TECHNOLOGY (BACT) PRACTICES FOR MINING

Process operation	BACT practice	BACT control efficiency (%)
Topsoil removal	-	-
Topsoil stockpile	Stabilize via:	
	a. Rapid revegetation, or	75
	b. Mulch, or	85
	c. Chemical dust suppressant. or	85
	d. Establishment of wind breaks	50
Product loading	a. Baghouse on silo	95
	b. Retractable chute on loadout	
	c. Minimizing number of openings	
	d. Spraying of material in rail cars	
Haul roads	a. Speed control, and	-
	b. Chemical stabilization worked into road	85
	c. Restriction of off-road use	100
Access roads	a. Paving or equivalent stabilization	85-100
	b. Speed control, and	-
	c. Restriction of off-road use	100
Road maintenance	a. Removal of loose debris, and	-
	b. Chemical stabilization of roadbed after grading	-
Disturbed areas	Stabilize via either:	
	a. Chemical dust suppressant, or	85
	b. Mulch	85
	c. Revegetation one growing season	75
	d. Minimizing of area disturbed	-
Conveyor	Cover	100
Drilling	Bag-type collector	90
Blasting	a. Minimizing area to be blasted	-
	b. Prevention of overshooting	-

TABLE 8. (continued)

Process operation	BACT practice	BACT control efficiency (%)
Overburden removal	Minimizing fall distance of material	-
Overburden stockpile	Stabilization via either:	
	a. Temporary vegetation, or	75
	b. Mulch, or	85
	c. Chemical dust suppressant	85
Overburden shaping	a. Leaving ridges	-
	b. Establishing windbreaks	-
	c. Rapid revegetation	-
	d. Orienting piles perpendicular to prevailing wind	-
Product removal	Minimizing full distance	-
Product dumping	a. Negative pressure, or	85
	b. Spray system on dumped material	50
Product storage	a. Enclosure, or	99
	b. Wetting	50
Transfer points	a. Enclosed and vented to baghouse	90
	b. Ducting to a central baghouse	90
Crushing	Baghouse	-
Screening	Baghouse	-
Transportation	Bus service to employees	-
Construction	a. Chemical dust suppression of disturbed areas	50
	b. Confining traffic to specified roads	50
	c. Minimizing area of land disturbed	-
	d. Prewatering areas to be disturbed	-

The Alabama Power Company v. EPA court ruling on June 18, 1979, has had ramifications on the PSD process. On September 5, 1979, EPA proposed new regulations in response to the recent court decision. The important proposed regulations that have significant impact on the mining industry follow:

- Calculation of potential to emit to determine if a source is major and, thus, must undergo PSD review; was formerly based on uncontrolled emissions. The proposed regulations require that potential emissions be calculated by the maximum design capacity and any control equipment that will be installed at the source.

- Fugitive emissions and fugitive dust; formerly, fugitive emissions were discerned from fugitive dust. In the proposed regulations, there is no difference. Fugitive emissions including fugitive dust are proposed not to be considered when determining the annual potential emissions of a stationary source, except when such emissions come from "specified" industry types. Conversation with Region VIII Office of EPA indicated that in the near future EPA will seek an amendment to the proposed regulations that would place surface mining in the source group with 100-ton per year limit for PSD review and would include fugitive dust in the determination of potential emissions.

- The existing regulations included a provision that exempted a source from a detailed review if its increased allowable (with controls) emissions were less than 50 tons per year. The proposed regulations would require a complete review if the source is classified as "major" (i.e., emissions after controls exceed 100 tons per year for specified source categories or for any source that emits 250 tons per year or more).

3.2.3 Mine Safety Health Administration

The Department of Labor established MSHA to provide for the safety and health of the public who work at all mining activities.

Regulations have been promulgated to control dust at all mines. Dust control must be applied to reduce the hazard of impaired visibility when vehicles are moving or the safety of the workers involved is in jeopardy. The men at mines are sampled on a regular basis with personnel monitors for silica content. If the concentration of silica exceeds 0.10 mg/cu m, then more stringent control of dust is required or else the plant must cease operations.

Specifically, for emission sources, MSHA provides that haul roads must be wetted and that drills must be equipped with either a water spray or a dry collection system.

3.3 Air Quality Permit Requirements

Permits are generally required for construction of new mines and their operation. Operating and construction permits are required by the state air pollution control agencies and OSM. Information pertinent to air quality requirements in permit applications are discussed in this section.

3.3.1 State Permits

The state air quality agencies that were contacted in this study were also requested to send mining permit requirements. Basically, there are two levels of permit requirements. The first is a general permit which requires specification of equipment, description of process operations, and a map detailing the process and equipment to be constructed. Nearly all states require this general information. Second is a requirement for a detailed air quality impact statement which includes an emission inventory, modeling (either long-term annual or short-term 24 hr), and detailed output which would indicate any violations of NAAQS or PSD increments. Table 9 presents the type of information required for air quality permits.

TABLE 9. STATE PERMIT INFORMATION

Information Required	Description	State Requiring Such Information
Equipment description	Make, model, size, and type of equipment, fuel type quantity consumed annually, and sulfur and ash content.	All
Process description	Note of emission points, quantities and types (stack parameters). Description of all control eqiupment and its efficiency. Operating schedule, materials input and output rate.	All
Drawing of all facilities	--	All
Air quality impact	Emissions (fugitive and point) must be calculated. Air quality modeling (short- or long-term) of worst case conditions.	Wyoming, Colorado, Missouri

3.3.2 OSM Permit

As discussed in Section 3.2, the Final Regulatory Program of the Surface Mining and Reclamation Act (1977) requires the submission of a permit of air quality assessment. The information required on a permit that is pertinent to air quality is reiterated here.

* For all surface mining activities with projected production rates exceeding 1 million tons of coal per year and located west of the 100th meridian west longitude, the application shall contain an air pollution control plan which includes the following:

    1. Air quality monitoring program to evaluate the effectiveness of the fugitive dust control practices proposed under (2) to comply with federal and state air quality standards; and

    2. A plan for fugitive dust control practices.

* For all other surface mining activities the application shall contain an air pollution control plan which includes the following:

    1. An air quality monitoring program, <u>if required by the regulatory authority</u>, to provide sufficient data to evaluate the effectiveness of fugitive dust practices to comply with applicable federal and state air quality standards; and

    2. A plan for fugitive dust control practices.

3.4 Status of Governmental Regulations

At both the federal and state levels, regulations to achieve fugitive dust control of nontraditional sources are at present in a state of uncertainty. The complete lack of regulations or older, nonspecific regulations are being replaced by much stricter fugitive dust regulations. At the same time, these stricter regulations are being challenged in the courts and, at times, remanded. In this section the ramifications of the state and federal regulations presented in Section 3.0 and future trends are discussed.

3.4.1 State Regulations

At present, many states have submitted or will submit their SIP revisions. SIP revisions must include additional or more stringent regulations and controls that will reduce particulate concentrations in nonattainment areas to the level of the standards. Both primary and secondary standards must be addressed in the SIP revisions. The plan must demonstrate attainment of the primary standard by 1982 and the secondary standard as expeditiously as practicable. Many states have addressed specific fugitive sources in their SIP revisions and have mandated strict control of emissions. However, most of the major mining states did not propose regulations for mining activities in their SIP revisions. States such as Colorado, Wyoming, Montana, and North Dakota, which require a rigorous demonstration of attainment of the standards by modeling and monitoring at surface mines have had such a regulatory process for some time. But no state has strict emission limitations specifically aimed at fugitive dust sources at mines. The typical state fugitive dust regulation calls for (a) reasonable precautions to prevent particulates from becoming airborne and (b) a visible emission limitation, neither of which is source-specific at mining operations. It appears that no further regulations at the state level will be directed at mining operations in the future.

3.4.2 Federal Regulations

OSM's Final Regulatory Program for surface mines was in force as of March 1980. A stringent fugitive dust control plan and a monitoring network are required for mines. Control of road dust is mandated either by paving, chemical stabilization, control of vehicle speed, or periodic watering. This regulatory program is the most strict of all the federal regulations. Industry, in 1979 and 1980, has argued in court the merits of the regulations. Whether the OSM regulations will be modified due to the court cases is unknown.

EPA requires the PSD for clean air areas, requires "major" sources to secure a permit to construct, and requires permitted sources to have BACT. Further impact analyses are necessary to demonstrate that clean air areas will not deteriorate significantly. The Alabama Power/EPA court case exempted surface mines from the PSD review process because of the difficulties in quantifying fugitive emissions from these sources. However, EPA will add surface mines to the list of major sources subject to review as soon as reliable fugitive emission factors are developed. Currently, MRI and PEDCo Environmental are attempting to establish reliable and valid emission factors. Fugitive dust sources at several surface coal mines are being sampled to determine the emission factors so that in the near future EPA will have the option to include surface mines in PSD reviews.[1]

EPA has also promulgated a draft of New Source Performance Standards (NSPS) for the nonmetallic mineral processing plants. Sources such as crushed and broken stone, sand and gravel, and products of many other nonmetallic processing plants are subject to NSPS. NSPS requires that process fugitive emissions be visible less than 10% of the time over an observation period of 1 hr. However, these standards do not apply to fugitive dust from haul roads.

The MSHA of the Department of Labor does require the control of fugitive dust to protect the safety and health of mine workers. Dust controls must be applied to reduce the hazard of impaired visibility when vehicles are in movement and to provide health protection from hazards of dust inhalation.

3.4.3 Outlook--Now and the Future

At present, it appears that the state and federal regulatory programs overlap each other. As a result, it is difficult to ascertain which regulatory agency, whether it be state, EPA, OSM, or MSHA, has authority to regulate mining activities. Future court cases may clarify each agency's regulatory authority.

4.0 DUST CONTROL INFORMATION SEARCH

The purpose of this task was to gather information on the identification/characterization, and quantification of unpaved road dust controls. A computerized data search and contact with trade associations, mining companies, researchers active in the fugitive dust field, and various vendors of dust suppressant materials were undertaken to achieve this goal. The computerized data search and personnel contacts are discussed in the following sections.

4.1 Computerized Data Search

The project team conducted computerized literature searches with four agencies: the Air Pollution Technical Information Center (APTIC), the National Technical Information Service (NTIS), the Smithsonian Scientific Exchange, and the American Geological Institute (GEORAF).

The key words or phrases used in the search are as follows:

- Haul road dust emissions
- Unpaved road dust emissions
- Fugitive dust emissions
- Fugitive particulate emissions
- Service road dust emissions
- Access road dust emissions
- Open dust sources
- Dust control techniques
- Dust suppressants
- Fugitive dust related air quality regulations
- Fugitive emission factors
- Environmental impact - fugitive emissions
- Air quality impact
- Air quality analysis
- Fugitive emissions characterization and quantification
- Wind erosion and dust control
- Classification - mine haul roads
- Control techniques - costs

The resulting bibliography is shown in Appendix C.

4.2 Trade Associations

MRI made an effort to identify the major trade associations who might be aware of fugitive dust control techniques at mines by reviewing the Encyclopedia of Associations.[10] The National Coal Association (NCA) and the National Crushed Stone Association (NCSA), two organizations active in air quality matters, were contacted. The two contacts are summarized in Table 10.

TABLE 10. CONTACT WITH TRADE ASSOCIATIONS

Association	Person Contacted
National Coal Association	Charles Drevna
National Crushed Stone Association	Frederick Renninger

MRI sent the program's scope of work and information needs to both trade associations. Letters sent to NCA and NCSA are in Appendix D.

4.3 Mining Companies

Various mining firms were contacted about their experience in using fugitive dust control methods. MRI made selections based on previous contacts, results of the literature search, and recommendations of NCA and NCSA. Summaries of contact information are in Appendix E.

4.4 Researchers in the Fugitive Dust Field

An effort was made to contact research scientists who have undertaken investigations into fugitive dust control methods, their applicability, efficiency, and cost. Contact with mining companies, OSM and previous MRI experience provided a list of key individuals. The researchers contacted, their affiliations, and the result of the contact are also in Appendix E.

4.5 Vendors of Dust Suppressant Materials

Through the computerized literature search and contacts with trade associations, mining companies, and researchers, a list of vendors who produce dust suppressants was developed. Included were any vendors who actively market any type of suppressant for fugitive dust control. Thus, the initial list of vendors included those who might not necessarily market a specific product for haul road dust control. From the contacts made and from previous MRI experience in assessing fugitive dust control techniques for haul roads, the list was narrowed to only those vendors who currently sell control materials for haul roads. The entire list of vendors marketing dust suppressants is presented in Appendix F. Section 6.0 presents those products specific to haul road dust control.

5.0 MINE ROADWAY CHARACTERIZATION

This chapter presents the roadway properties which affect the efficiency of dust suppressants in controlling mine roadway fugitive dust. Subsections detail: physical properties of the roadway aggregate, ideal and actual roadway construction techniques, and a general classification scheme for mine roadways as a function of roadway strength.

5.1 Physical Properties of Roadway Aggregate

Aggregate is the part of a soil-aggregate mixture retained on a No. 200 U.S. standard sieve. It is normally referred to as the granular fraction. Aggregate is commonly separated into two fractions, coarse and fine. The size difference between these fractions is determined by a No. 10 U.S. standard sieve with an opening of 2.00 mm (0.079 in.). Aggregate is the basic material for soil-aggregate construction because the major portion of the road body is made up of this element. It bears the main stresses in the road and resists wear from surface abrasion. Since the behavior of a soil-aggregate road is affected considerably by the quality and character of the aggregate, careful selection of the material is necessary. This section deals with methods of measuring these properties to ensure a high quality aggregate.

5.1.1 General Aggregate Classification

Considering the United States as a whole, there is a wide variety of aggregates used in the construction of soil-aggregate roads. The American Association of State Highway Officials has classified this material into reasonable forms. A brief description of these materials is presented in Appendix G.

5.1.2 Necessary Qualities of Aggregates

In selecting granular materials for soil-aggregate roads, a good practice is to use aggregates from sources known to make good roads, or to procure them from reliable dealers. If it is necessary to use materials of unknown quality, they should be examined and tested to make sure they are suitable for soil-aggregate road construction. Important physical properties that are commonly considered are (a) undesirable substances, (b) resistance to wear, (c) soundness, (d) gradation, (e) maximum size, and (f) particle shape. Each of these properties is discussed in the following paragraphs.

Undesirable substances in aggregates include soft and unsound materials such as shale, coal, mica, or other objectionable matter. An excess amount of these materials in road surfaces or bases is not allowable because it lowers the strength and durability of the road structure.

An aggregate, to make a good roadbuilding material, should be composed of stones that are hard and tough and, therefore, will not readily disintegrate under traffic. The ability of an aggregate to resist wear and breakdown under traffic is indicated by abrasion tests. The most common one is the Los Angeles Abrasion Test. Standard procedures for performing this test are given in Ref. 11.

An important quality of aggregates is their ability to withstand climatic forces. An aggregate is considered to be physically sound if it is strong enough to resist weathering without disruption or decomposition. Aggregate particles are regarded as unsound if they are physically weak, extremely absorptive, easily cleavable, they swell when saturated, or are susceptible to breakdown through exposure to natural weathering processes.

The soundness of an aggregate can best be determined by its service record. However, it is commonly evaluated by accelerated soundness tests using either sodium sulfate or magnesium sulfate or the freezing and thawing method. The latter method is recognized as the best test.

The distribution of particle sizes throughout an aggregate is known as the gradation of the aggregate. It is determined by separating a representative sample of the aggregate into various size groups or fractions by shaking it through a series of sieves of decreasing size. This process is called a mechanical analysis. The method for determining aggregate gradation is given in Ref. 12.

An aggregate which contains a good representation of particles of several sizes ranging from coarse to fine is called well-graded. If all the particles of an aggregate are approximately the same size, the material is called poorly graded. Field experience has shown that the most desirable aggregates for soil-aggregate roads are those which are well graded from coarse to fine. Well-graded materials can be more readily compacted than poorly graded mixtures, and they generally have greater stability after compaction. For this reason, well-graded aggregates are generally required by specifications for soil-aggregate construction.

There is considerable variation as to the maximum size of aggregate. Experience indicates that it is undesirable to use aggregate larger than 1 in. in a surface course. Roads built with aggregates larger than this are usually rough and difficult to maintain. The grader blade catches on the large aggregates and tears up the surface, leaving loose material and a rough finish.

The performance of a soil-aggregate road is dependent, to a certain degree, on the shape of the aggregate particles. Stability, density and durability are all promoted by good interlocking of the aggregates. The more angular and rough-surfaced particles an aggregate contains, the more effective interlocking is between the particles, and the better suited the material is for soil-aggregate construction.

5.1.3 Silt and Clay Materials

The stability of a soil-aggregate mix depends upon particle size distribution, particle shape, relative density, internal friction, and cohesion. A granular material designed for maximum stability should possess high internal friction to resist deformation under load. Internal friction and subsequent shearing resistance depend to a large extent upon density, particle shape and grain size distribution. Of these factors, the size distribution of the aggregate, particularly the proportion of the fine-to-coarse fraction, is considered to be most important. Figure 1 shows three physical states of soil-aggregate mixtures.[13]

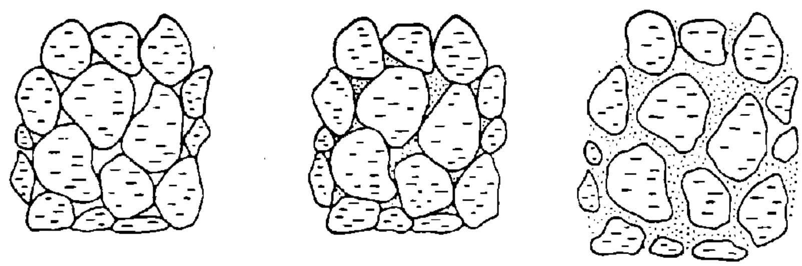
Silt and clay materials constitute the fine soil fraction of a soil-aggregate mixture. Both silt and clay pass the No. 200 U.S. standard sieve. Silt includes the coarser grains of the fine soil fraction and can be readily distinguished from clay by its grittiness. Silt alone can become spongy and very unstable when wet but does not produce a sticky mud. Clay particles are smaller than silt and give no sensation of grittiness. They become cohesive when wet and, therefore, produce sticky mud.

The function of silt and clay materials in a soil-aggregate mixture are to fill the voids within the aggregate and to bind the aggregate into a strong durable mass. As filler, they are helpful in producing high density, impermeability, and high load-carrying capacity. As binder, they supply cohesion, or the resistance of soil particles to being separated or pulled apart. They also diminish the loss of materials by wind or water erosion or traffic abrasion when the soil-aggregate mixture is used as a surface course.

Silt and clay materials are stable when relatively dry and are unstable when wet. Small amounts of water apparently serve as an effective binding agent for soil grains, while excessive quantities act as a lubricant. Furthermore, material containing highly active clays may swell to several times their dry volume in the presence of water and destroy the proper arrangement of aggregate particles. For these reasons, both the amount and the nature of silt and clay materials must be carefully controlled.

An aggregate which contains little or no fines and is well-graded gains its stability from grain-to-grain contact. An aggregate which contains no fines (material which passes a No. 200 U.S. standard sieve) usually has a relatively low density but is pervious and nonfrost-susceptible. However, this material is very difficult to handle during construction because of its noncohesive nature.

An aggregate which contains sufficient fines to fill all the voids between the aggregate grains will still gain its strength from grain contact but with increased resistance against deformation. Its density is high, its permeability is low, and it may be frost-susceptible. This material is moderately difficult to compact but is ideal from the standpoint of stability, for it has a relatively high shearing resistance in either confined or unconfined conditions.



(a) (b) (c)

(a) Aggregate with no fines	(b) Aggregate with Sufficient Fines for Maximum Density	(c) Aggregate with Great Amount of Fines
Grain-to-grain contact	Grain-to-grain contact with increased resistance against deformation	Grain-to-grain contact destroyed, aggregate "floating" in soil
Variable density	Increased density	Decreased density
Pervious	Low permeability	Low permeability
Nonfrost susceptible	Frost susceptible	Frost susceptible
High stability if confined, low if unconfined	Relatively high stability in confined or unconfined conditions	Low stability
Not affected by adverse water condition	Not greatly affected by adverse water condition	Greatly affected by adverse water condition
Difficult to compact	Moderately difficult to compact	Not difficult to compact

Source: Yoder, E. J., Principles of Pavement Design, John Wiley and Sons, Inc., 3rd Edition, Salt Lake City, Utah, 1959, p. 285.

Figure 1. Aggregate properties as function of amount of fines present.

At the other extreme, a material which contains a great amount of fines has no grain-to-grain contact, and the aggregate merely "floats" in the soil. Its density is low, it is practically impervious, and it is frost-susceptible. In addition, the stability of this type of mixture is greatly affected by adverse water conditions. Paradoxically, the material at times is quite easy to handle during construction and compacts quite readily.

5.1.4 Quality of Silt and Clay Materials

The amount of silt and clay materials used in a soil-aggregate mixture should be sufficient to supply adequate cohesion so that the quantity required may be kept within desirable limits.

Two tests are used to measure the degree of cohesion possessed by the fine soil materials: the liquid limit test and the plastic limit test. The results of these tests are used to compute the plasticity index. The plasticity index is the numerical difference between the liquid limit and plastic limit. The liquid limit of a soil is the smallest moisture content at which the soil exhibits liquid properties. The plastic limit is the smallest water content at which a soil exhibits plastic properties.[14]

The most common application of the test results to highway problems is in soil classification. Those soils with comparable limits and indices are classed together. Generally, soils with high liquid limits are clays with poor engineering properties. A high plasticity index indicates a granular soil with little or no cohesion and plasticity. Both the liquid limit and the plasticity index are used to some degree as quality measuring devices for pavement materials in order to exclude those granular materials with too many or not enough fine-grained particles that have cohesive plastic qualities.

5.1.5 Quantity of Silt and Clay Materials

The quantity of silt and clay materials is controlled by the quality of the materials. The higher the plasticity index of the silt and clay materials, the smaller the amount that should be used in the soil-aggregate mixture. The grain size distribution of a material can be represented by the following equation:

$$p = 100 \left(\frac{d}{D}\right)^n$$

In this expression, p is the percentage by weight finer than the sieve, d represents the sieve opening dimensions (opening width in inches), and D is the maximum size of aggregate (diameter in inches). Maximum density generally occurs when the exponent, n, equals 0.5. For example, this expression yields 4.4% passing a No. 200 mesh sieve for materials which have a maximum grain size of 1.5 in.

In the above discussions of soil quality, fines were not segregated into their silt and clay portions. In discussing plasticity, the clay fraction of the fines is meant.

The physical properties of the binder soil have a great effect on stability especially when grain-to-grain contact is destroyed (Figure 1(c)). Specifications limit the liquid limit for base courses to a maximum value of 25% and the plasticity index to 6%. For surface courses, it is desirable to use more binder to provide some cohesion to the mass. When used for this purpose, plasticity is extremely critical.

5.2 Roadway Construction

This section presents information on haul road and access road construction techniques. The section presents the ideal or recommended procedures for construction and the procedures observed through mine visits by the project team.

5.2.1 Ideal Roadway Construction

The information presented in this section represents the established procedure for ideal unpaved roadway construction. By applying these principles, a safe, durable, and comfortable road will result. Building a safe, durable, and comfortable road will cost more than simply clearing a path over existing terrain. But the benefits of such a road will far outweigh the added cost factors. One example of a benefit is that less maintenance is necessary on ideally constructed roads. Also, as discussed subsequently, if dust suppressants are to be used on the road, good road construction will increase the longevity and efficiency of the suppressants.

This section deals briefly with the major principles involved in roadway construction of soil-aggregate pavements. For more details the reader is encouraged to consult a good text on soil-aggregate roadway construction. Two good references are Eugene Y. Huang, Manual of Current Practice for Design, Construction and Maintenance of Soil-Aggregate Roads, University of Illinois Engineering Experiment Station Circular No. 67, Urbana, Illinois, 1959, and E. J. Yoder, Principles of Pavement Design, John Wiley and Sons, Inc., New York, 1959.

Principles of Construction

Regardless of what kind of material is used, the principal requirements for the construction process are relatively uniform. Major road construction procedures include preparing the subgrade; excavating, hauling, and stockpiling the materials; pulverizing the fine-grained soils, if necessary; proportioning materials in accordance with the laboratory design; blending the materials together; adding the specified amount of water and, if desired, admixtures; mixing all materials to a high degree of uniformity; spreading the mixture in a thin layer of uniform thickness; and compacting and shaping to the desired cross-section. The various steps may be performed separately, or certain of the steps may be combined into one operation, depending upon the method of construction and the equipment to be used.

Subgrade Construction

The strength of the subgrade is as important to the stability of a haul or access road as a strong foundation is to the stability of a house. The entire load of all the vehicles traveling the road is ultimately borne by the subgrade. The fact that these loads are not only large in some instances but also cyclic in nature, makes the preparation of the subgrade important.

The subgrade supports a load via two mechanisms: internal friction and cohesion. Internal friction occurs when the angular edges of the larger subgrade particles interlock. Cohesion occurs when various adhesive forces act between the fine subgrade particles.

Supporting power of subgrade soils can be measured by numerous methods. One well-known and much-used is the California Bearing Ratio (CBR) test. Basically, the pressure needed to deflect a sample of the subgrade a given amount is measured. This value is then divided by the pressure needed to deflect a standard sample (crushed stone of a specific size gradation) the same distance. This ratio is then expressed as a percent.

The two techniques most important to maximizing subgrade strength are: compaction at optimum moisture and installation of adequate drainage. Most subgrade soils will compact to their maximum density at a given moisture. Below or above this moisture, maximum compaction will not be achieved. The subgrade soil should be scarified and the proper amount of water needed to achieve optimum moisture added before compaction with a steel roller or other type of compactor begins. The subgrade should contain a crown so that water runs off to the sides of the road and does not collect in pools on the surface. The side of the road should have properly sloped drainage ditches to carry the water away.

If the subgrade is comprised of clay-sized particles over its entire surface or only in selected spots, the strength of these areas can be upgraded by mixing in the larger silt and sand particles. This strengthens weak areas in the road during wet conditions. This strengthening of the subgrade permits a thinner base to be applied, as described in the following subsection.

Base Construction

Roads which are built on subgrades with inadequate CBR's require that a thicker aggregate base be placed over the subgrade, assuring that a given surface load will be distributed over a larger subgrade area (see Figure 2). The pressure on the subgrade in Figure 2(a) is F/L^2 where the base thickness is T, while the pressure on the subgrade in Figure 2(b) is $9/25\ F/L^2$ (less than half) where the base thickness is 2T. Thus, a doubling of the base thickness produced more than a twofold reduction in pressure on the subgrade. This fact has often been neglected in the past, and, consequently, incorrectly constructed roads have deteriorated rapidly.

The base course material should be well graded; that is, it should have particles in each size range and should not be biased toward any one size.

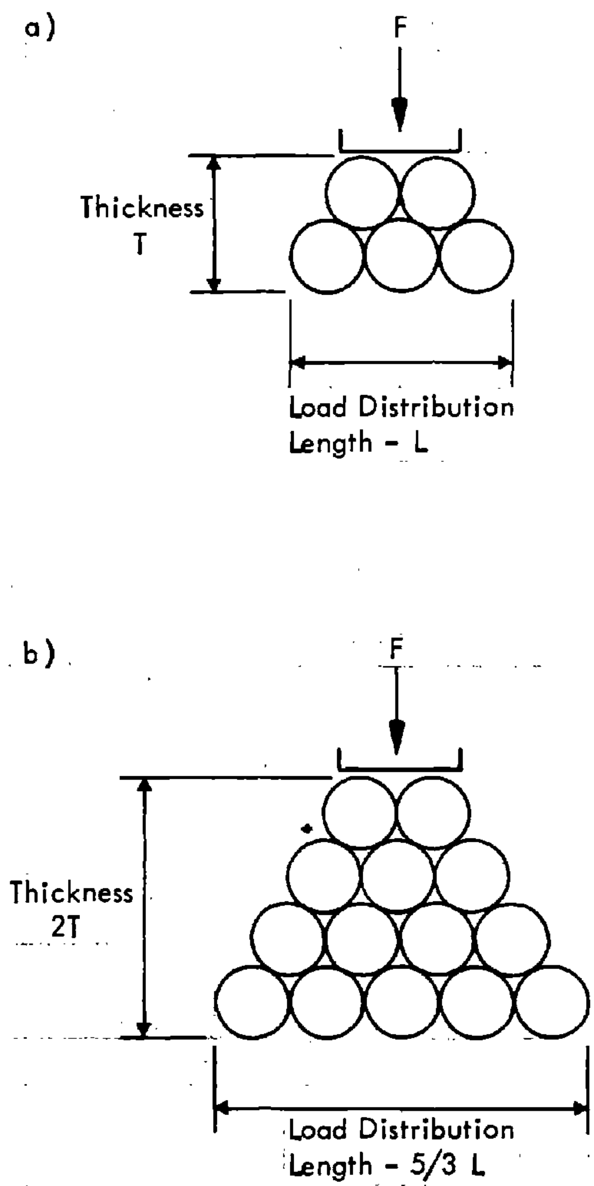


Figure 2. Effect of base thickness on subgrade load distribution.

The base course should also have a maximum size not exceeding 3 in. Often, the maximum size of an actual base course may be 1-1/2 in. for roads carrying mainly light duty traffic.

The well-graded base course should be compacted at optimum moisture to achieve maximum strength. A well-graded base course with enough fines just to fill the voids between the larger particles will provide maximum strength when compacted.

Wearing Surface Construction

The wearing surface must display three properties: resistance to grinding, resistance to weathering, especially the freeze-thaw cycle, and resistance to large particle displacement from the road. The AASHO standards specify a Los Angeles Abrasion Loss, a measure of grinding resistance, of not more than 50%. This value was developed for light duty traffic. One might expect that it should be less for heavy duty haul truck traffic. The AASHO also specified that the materials should not break up when alternately frozen and thawed or wetted and dried. Finally, a well-graded surface material should be used. Enough fines to fill the voids between the larger particles will minimize large particle loss.

The surface, like the base and subgrade, should be compacted at optimum moisture to achieve maximum strength. A proper crown should be preserved to carry water to the drainage ditches.

5.2.2 Actual Roadway Construction Techniques and Materials

While ideal construction techniques and premium types of construction materials can be defined, their higher initial costs usually result in the use of techniques and materials which are less than ideal. For example, if no adequate wearing surface materials exist on the mine site, it is usually less expensive to use less than adequate on-site material than it is to purchase adequate off-site material from another company.

The following subsections list the actual construction techniques and construction materials at six mines (two coal mines and four stone quarries) visited during the course of the project.

. Belle Ayr Mine (Amax Coal Company - Gillette, Wyoming)

Detailed information on the construction of the paved road providing access to the main office of the Belle Ayr Mine was available. The construction of the paved access road was contracted to an outside road construction company. The procedure for road construction consisted of the following:

1. Clay subgrade graded and compacted
2. Pit run sand added (6 to 8 in.)
3. Soil binder (lignin sulfonate) added to sand

4. Binder allowed to cure for 10 days

5. Chip (minus 3/8 in. limestone) and soil seal added; put on in two 1-1/2 in. lifts.

The haul road construction at the Belle Ayr Mine consisted of grading the natural shale-clay material and adding scoria (naturally scorched sandstone) to the surface for traction. There were two practical reasons why the classic rules for ideal road construction were not followed. First, there was no adequate road construction stone available on site. Second, the cost of purchasing the stone from an outside source was thought to be prohibitive by mine personnel, especially in view of the fact that pit roads are rerouted frequently (estimated at once per month) in the mine's moving pit operation.

. Bridger Coal Company - (Rocks Springs, Wyoming)

Bridger Coal Company has approached haul road construction using classical engineering techniques. Core samples from the subgrade along proposed haul routes were analyzed for physical size distribution, plastic limit, liquid limit, plasticity index, in-place density, natural water content, small load-bearing capacity, and optimum moisture to achieve maximum compaction. Proposed base and wearing surface materials were analyzed to quantify the Los Angeles Abrasion ratio (resistance to grinding), the Sodium Soundness (resistance to weathering), and the CBR. Some example values for proposed base and wearing surface materials are shown in Table 11.

TABLE 11. PROPOSED BASE AND SURFACE MATERIALS

	CBR (%)	Los Angeles abrasion (grading B) (%)	Sodium soundness (%)
Mine scoria	50	65.2	21.2[a]
Outside scoria	56.3	51.5	3.2
Leucite	80+	30.1	1.8
Parting	35	74.0	79.6
Cemented sandstone	N/A	28.4	3.9

a Only material retained on No. 4 screen.

Given the engineering data above, leucite was obviously the best choice since there was not enough cemented sandstone. Unfortunately, the leucite has to be brought in from outside whereas the mine scoria was available on site. The cost differential (a factor of over 3) forced the mine management to choose scoria, but this material could be chipped apart by just rubbing two pieces together, as the Los Angeles Abrasion loss of 65.2% shows. Because this road is traveled by 120-ton haul trucks, the scoria is ground very rapidly.

This is the only company visited that owned its own compactor, a sheepsfoot roller and a cylinder roller.

. Pomona Granite Quarry (Aggregate Division of Martin Marietta - Raleigh, North Carolina)

As with most mines which do not backfill their pits, Pomona Quarry has relatively permanent roads into the pit. Many hard stone quarries have a definite advantage over other mining operations in that their product is ideal for roadway construction. But Pomona Quarry tries not to use its merchantable product for roadway construction. They prefer to use stone which is nonmerchantable because it is beyond consumer specification limits.

. Ashboro Slate Quarry (Aggregate Division of Martin Marietta - Raleigh, North Carolina)

Unlike Pomona Quarry, Ashboro Quarry does use some of its merchantable product to surface roads. A 3-in. depth of aggregate base coarse (ABC) crusher run material is used to surface the road (see Table 12).

TABLE 12. SIZE DISTRIBUTION FOR AGGREGATE BASE COARSE MATERIAL

U.S. Series sieve size	Percent passing
1.5 in.	100
1.0 in.	94
0.5 in.	71
No. 4	48
No. 10	33
No. 20	17
No. 200	10

The liquid limit of the material is 18%, and the material is nonplastic.

The Los Angeles Abrasion Loss (grading A) is 21%.

. Texas Limestone Quarry (Flintkote Stone Products - Texas, Maryland)

As in many quarries, the access and the haul roads in the Texas Limestone Quarry are relatively permanent. There are many stretches of road which have solid stone as a subgrade and consequently have high load-bearing capacity.

In addition to properly constructed roads, this quarry used a number of other means to reduce dust emissions from vehicles and stockpiles. Unpaved roads were regularly watered and access roads not normally traveled were oiled. Customer trucks entered a water spray system upon exiting the plant to mitigate wind loss. Open fine material stockpiles were wetted automatically by a water spray system when wind erosion conditions were prevalent.

. Monarch Cement Company (Humboldt, Kansas)

Monarch Cement Company has approximately 10 miles of unpaved roads 20 to 30 ft wide at its plant in Humboldt, Kansas. The roads are constructed with limestone mined in the quarry. Nearly all the unpaved roads are traveled by haul trucks with occasional medium duty (service trucks) and light duty (cars and pickups) traffic.

Road construction consists initially in the placement of minus 5-in. limestone, which is the gyratory crusher product, over the subgrade to fill the holes and raise the road level approximately another 3 in. above the highest point in the subgrade. Another 2 to 3 in. of minus 1-in. limestone, which is the hammermill product, is placed over the base as a surface layer. A size distribution for the surface materials is shown in Table 13.

TABLE 13. HAMMERMILL PRODUCT SIZE DISTRIBUTION

U.S. Series sieve size	Percent passing
1 in.	100
3/4 in.	98.2
1/2 in.	86.6
3/8 in.	73.2
No. 4	52.9
No. 8	40.0
No. 14	30.5
No. 30	22.7
No. 48	17.3
No. 100	12.5

Water is added to the material after it is placed down. Compaction is achieved only by the truck and grader traffic involved in the road construction and the subsequent traffic that utilizes the road. Grading is performed to maintain a proper crown in the center of the roads, which provides proper water drainage.

The subgrade in the pit is blue limestone, and the subgrade in the shale areas is white limestone. The white limestone surface is very uneven. The low spots are filled with silt and clay materials that cannot be removed by the grader, which leads to weak spots in the shale area of unpaved roads. The pit roads on blue limestone are relatively strong. The blue limestone deposit surface is fairly smooth, and, consequently, there is less accumulated material to require grading.

General maintenance consists of patching holes that form with additional minus 1-in. surface material and regrading the surface to maintain a proper crown in the road.

Problems in road construction include the silt and clay deposits associated with the subgrade white limestone deposit serving as subbase for the shale area roads; the lack of proper compaction equipment; and the lack of an optimum moisture content in the road material to promote maximum compaction.

5.3 Effect of Road Construction on Dust Suppressant Performance

As a vehicle wheel passes over an aggregate road, certain forces are developed within the entire road structure. Two of these forces, horizontal shear stress and tire-road surface friction, are unimportant from the standpoint of dust suppressant performance related to road construction. The third force, normal shear stress, is very important, however, for two reasons. First, it determines the load carrying capacity of the road; and second, it directly affects the crushing and/or abrasion of large aggregate particles into smaller ones, which form dust.

Normal shear stresses are cyclic in nature. As the vehicle wheel passes over a section of road surface, the entire structure is put in compression. When the wheel has passed, the roadbed and surface spring back to their initial position, due to the elastic properties of the system. However, if the road is not designed to carry the load, the design elasticity is exceeded and permanent deformation occurs. This causes surface pot hole formation, cracking, or rutting.

A roadway dust suppressant agglomerates the fine particles that are easily entrained by vehicle wheel action. Therefore, any force which tends to break down these agglomerated particles after their initial formation will decrease the dust suppressant's longevity.

In summary, structural failure of the roadbed will decrease the performance of a roadway dust suppressant in two ways: (a) by increasing cyclic action and normal shear stress, which will likely cause the dust suppressant's bonding strength to be exceeded in a short period of time, and (b) by enhancing the abrasive action between aggregate particles, which will cause new dust particles to form. Therefore, the ability of the constructed roadway to withstand structural failure is directly related to roadway dust suppressant performance.

5.4 Roadway Property Classification

The purpose of this section is to provide a roadway property classification system so that mine personnel can determine what dust control techniques are most appropriate. Currently, there is no detailed classification system available, and much on-site testing would be required to quantify the effects of road construction techniques and vehicle characteristics on the effectiveness of various dust control strategies. This section presents a general classification system derived mainly from road construction experience.

There are three general properties which should be estimated in order to classify a road in terms of strength and longevity: (a) the combined strength of the subgrade and base, (b) the surface material silt and clay content, and (c) the surface material Los Angeles Abrasion Loss. The classification system is shown in Table 14. The subcategories for roadway strength are: weak, average, and strong. The subcategories for surface silt and clay content and surface Los Angeles Abrasion Loss are: low, medium, and high. The range of values associated with each subcategory is not exact and is listed only to give the reader a general idea of what constitutes each subcategory.

TABLE 14. GENERAL ROAD CLASSIFICATION

Road property classification
1. Combined subgrade and CBR strength
. Weak (< 60%)
. Average (60-80%)
. Strong (> 80%)
2. Wearing surface silt and clay content
. Low (0-4%)
. Medium (4-8%)
. High (> 8%)
3. Wearing surface Los Angeles Abrasion Loss
. Low (< 15%)
. Medium (15-30%)
. High (> 30%)

In Section 8.2, this classification system is related to the types of dust suppressants determined by the project team to be qualitatively compatible.

6.0 IDENTIFICATION AND USAGE OF DUST SUPPRESSANTS

This chapter presents those dust suppressants identified in the program information search as being used in some form for mining dust control. Also, this chapter discusses the equipment and application techniques necessary for a successful roadway dust control program.

6.1 Classification of Dust Suppressants

Table 15 presents a classification scheme of the various dust control products identified as being used in the mining industry. Seven major categories are identified. These include salts, lignin sulfonate, wetting agents, latexes, plastics, petroleum products, and fabrics. For each category, various companies and respective products are presented. Product composition and a few physical properties of the products upon purchase are identified. The use of the product within the mining industry is also presented.

In Section 7.0, the products most commonly used in the mining industry for road dust control are evaluated.

6.2 Road Surface Preparation Procedures

Equipment that is necessary for the application of dust suppressants to unpaved mine roads can generally be classified in two categories: (a) equipment for the application of liquid suppressants and (b) equipment for the application of solid suppressants. The four major types of equipment for the application of liquid suppressants are storage tanks, graders, distribution trucks, and compactors. For the application of solid dust suppressants, the equipment is similar; however, there are differences in the hardware of the storage tank and the manner of distribution.

To apply liquid suppressants, a storage tank is needed. Most storage tanks for dust suppressants are of carbon steel, have welded seams, and range in capacity between 5,000 and 25,000 gal. They can be stored either above or below ground and can be placed horizontally or vertically depending on the configuration of available space.

The choice of tank size usually depends on the amount of suppressant to be used per season, the difference in price between small and bulk shipments of the suppressant, and the money available for the purchase of a storage tank. The tank size should be selected to minimize the amount of suppressant remaining at the end of a season, (especially in areas of extreme climates), but should allow enough surplus suppressant to remain in case delay in shipment occurs. The difference in costs between small and bulk shipments of a suppressant is a function of the transportation distance and the costs of the particular product. The most important factor in determining tank size is the amount of capital available for its purchase. The average price for the 21 above-ground tanks listed in Table 16 was 29¢ per gal.; and for the 32 below-ground tanks listed in Table 17 31¢ per gal.

TABLE 15. DUST CONTROL PRODUCTS

Classification	Company name	Product name	Composition	Use in mining industry
Salt	Dow Chemical	Liquidow Dowflake Peladow	Calcium chloride Calcium chloride Calcium chloride	Dust control on unpaved roads.
Lignin sulfonate	Arthur C. Trask	Trastan CM-50 Trastan CM-57	50% Calcium lignin 57% sulfonate	Dust control on unpaved roads.
	Crown Zellerbach	Orzan AL-50 Orzan GL-50	50% Ammonium lignin sulfonate	Dust control on unpaved roads.
	American Can Company	Norlig 50 Norlig 58	50% Calcium lignin 58% sulfonate	Dust control on unpaved roads.
	Flambeau Paper Co.	Flambinder	50% Calcium lignin sulfonate	Dust control on unpaved roads.
Wetting agents	The Fire Water Company	SV 100		Logging road dust control.
	Dow Chemical	S 65		Stockpile and transportation control.
	Oxford Chemical Co.	Sanafax 299		Dust control on unpaved roads
	Johnson March	MR	A sulphur compound	Fixed source dust control.
Latexes	Bordon Chemical	Polyco 2440	Styrene-butadine latex	Tested for roads, stockpiles, and transportation.
	Firestone Company	FR-S 275	Latex in oil emulsion	Agricultural seed germination.
	Dow Chemical	M 167 M 166	Latex binder Latex binder	Stockpile and transportation control.
	Alcoa Chemical	Soil Guard	A latex oil emulsion	Agricultural.

(continued)

TABLE 15. (continued)

Classification	Company name	Product name	Composition	Use in mining industry
Plastics	Bordon Chemical	Polyco 2607	Vinyl chloride	Tested for roads, stockpiles, and transportation.
	Rohm and Hass Company	Acrylic DLRMS	An acrylic emulsion	Transportation and stockpile control.
	Celtite, Inc.	Polybind DLR	An acrylic base resin	Mine reclamation and haul roads.
	Heuley and Company, Inc.	Soil stabilizer 801	Alphatic polymer	Stockpile control.
	E. F. Houghton	Rezusol	Organic polymer	Stockpile and transportation.
	The Fire Water Company	Crust 500	Polyvinal acitate	Mine reclamation.
	American Hoechst	Curasol	A polymer	Agricultural seed germination.
Petroleum product	Hercules	XDS-1	Emulsified resin	Road dust, stockpile control, tailings control.
	Phillips Petroleum	Arcatia	Asphalt blend	Light and medium duty road dust control.
		Dust palliative	Residual oils	Light and medium duty road dust control.
	Armak	Slow cure asphalt emulsion.	Asphalt emulsion	Dust control on roads.
		Medium cure asphalt	Asphalt emulsion	Dust control on roads.
	Witco Chemical	Coherex	Emulsified petroleum by-products	Dust control on unpaved roads.
Fabric	Monsanto Textiles Co.	Bidim	Polyester fiber	Road construction aid, dust control.

Note: Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

TABLE 16. ABOVE-GROUND STORAGE TANKS

Company name	Tank size: Capacity (gal.)	Diameter (ft)	Length (ft)	Wall thickness (in.)	Current price ($) [5/22/79]
Airmark	1,055	6	5	0.135-0.075[a]	647
	4,136	8	11	0.135-0.075[a]	1,494
	7,500	10	12	0.135-0.105[a]	3,566
	15,000	11	21	0.188-0.105[a]	4,954
	29,600	12	35	0.25 -0.135[a]	7,924
Richmond Engineering	15,000	10.5	23.33	0.25	3,196
	20,000	10.5	31	0.25	3,968
	25,000	10.5	39	0.25	5,053
	30,000	10.5	46.5	0.25	5,921
We-Mac	1,000	5.33	6	0.105-0.075[a]	339
	3,005	8	8	0.135[a]	927
	6,000	8	16	0.179-0.135[a]	1,477
	12,000	11	17	0.179-0.135[a]	2,396
	25,380	12	30	0.25 -0.135[a]	4,638
Highland Tank and Mfg. Co.	4,000	8	10.5	0.25 -0.313	1,512
	6,000	8	16	0.25 -0.313	1,961
	10,000	10	17	0.25 -0.313	2,697
	15,000	10	25.5	0.25 -0.313	3,919
	20,000	10	34	0.25 -0.313	4,841
	25,000	10.5	38.75	0.313	6,426
	30,000	10.5	46.5	0.25 -0.313	6,667

[a]Thickness calculated assuming a density of 40.8 lb per sq ft per inch of thickness.

TABLE 17. UNDERGROUND STORAGE TANKS

Company name	Tank size: Capacity (gal.)	Diameter (ft)	Length (ft)	Wall thickness (in.)	Current price ($) [5/22/79]
Airmark	1,060	5.33	6	0.135[a]	595
	2,500	6	12	0.188	1,282
	4,000	5.33	24	0.188	2,004
	6,000	8	16	0.25	2,886
	10,000	8	27	0.25	4,170
	12,000	8	32	0.25	4,812
	15,000	11	21	0.313	6,128
	20,000	11	28	0.313	7,600
	34,120	11	48	0.375	12,948
Richmond Engineering	5,000	8	13.5	0.25	1,619
	10,000	8	26.5	0.25	2,685
	15,000	10.5	23.33	0.313	3,932
	20,000	10.5	31	0.313	4,962
	25,000	10.5	39	0.375	6,803
	30,000	10.5	46.5	0.375	8,305
We-Mac	520	4	5.5	0.075[a]	120
	2,500	5.3	15	0.135[a]	676
	5,000	6	24	0.179[a]	1,392
	7,000	9	15	0.25	2,113
	8,250	8	22	0.179[a]	1,833
	11,750	10	20	0.179[a]	2,395
	20,000	11	28	0.25[a]	4,422
Faubion	5,000	18	7	0.25	1,650
	10,000	27	8	0.25	2,800
	20,000	28	11	0.313	5,300
Highland Tank and Mfg. Co.	5,000	8	13.3	0.25	1,580
	10,000	10	17	0.25	2,390
	12,000	10	20.5	0.25	2,850
	15,000	10	25.5	0.313	4,200
	20,000	10	34	0.313	5,075
	30,000	10.5	46.5	0.375	8,390

[a] Thickness calculated assuming a density of 40.8 lb per sq ft per inch of thickness.

After a decision is made on the size of tank to be used, it must be determined whether the tank is to be placed above or below ground. Above-ground tanks are much less expensive to purchase because they are usually constructed of thinner material and require less effort to install. Also, above-ground tanks are easier to repair when a leak occurs. Below-ground tanks are, on the other hand, advantageous in extreme climates where the suppressant must be protected from freezing and whenever ground space is not available for an above-ground tank.

In addition to the tank itself, hardware pertaining to the operation of the tank must be installed. Hardware for a typical storage tank consists of a pump, miscellaneous pipe fittings, a level indicator, and a filler hose. The pump should be capable of pumping 500 to 1,500 gal/min directed against 20 to 40 psi impedance. Pumps of this size cost from $5,000 to $6,000. The remaining hardware is specific to an operation and cannot be generalized.

For an effective control program utilizing a liquid suppressant, a grader is needed. Most mines already have graders that can be incorporated into a chemical dust suppressant program. If such a grader is not available, purchased graders should have at a minimum a 150-hp rating, not less than a 12-in. blade, and should be equipped with a scarifier capable of a 6 in. deep cut. Table 18 gives specifications and prices for several graders.

Another piece of equipment for implementing a program of liquid suppressant dust control is a distributor truck. For most applications any oil or water distributor will suffice. But for an efficient distribution it is recommended that the truck be of the pressure feed type rather than gravity feed. Such pumps should be capable of not less than 250 gal/min at an impedance of approximately 50 psi. It is also recommended that the tank be not less than 2,000 gal. although capacity is a function of the amount of road to be controlled. Table 19 lists a variety of distributor trucks and their specifications for use in any application.

The final piece of equipment for the application of a liquid suppressant is a compactor. For most applications a multiple-wheeled, rubber-tired compactor is recommended, but it should be realized that any compactor capable of applying a dynamic force of not less than 20,000 lb is adequate. In many applications, satisfactory compaction can be achieved with heavy duty vehicles such as haul trucks. Table 20 provides information on compactors that could be used for compaction of a dust suppressant into an unpaved road.

For the application of a solid chemical dust suppressant, much of the equipment needed is the same as that for liquid suppressant. Since the techniques for road preparation are similar for each procedure, the grader recommended for liquid suppressants could also be used for dry suppressants. Similarly, compactors recommended for liquid suppressants may be used for dry suppressants.

TABLE 18. GRADERS

Company name	Model no.	Horsepower	Weight (lb)	Blade width (ft)	Scarifier teeth	Scarifier width (in.)	Current price ($)[5/29/79]
Fiat Allis	200c	172	28,760	13	11	46	72,000
	150c	147	28,175	12	11	46	77,000
	100c	147	27,175	12	11	46	81,000
Galion Mfg.	T-600-C	208	30,000	12	11	48	84,700
	T-500-M	177	27,800	12	11	48	76,200
	T-400	125	24,300	12	11	48	65,150
Caterpillar	16G	250	54,060	16	7	117	185,000
	14G	180	40,650	14	7	102	130,000
	140G	150	30,030	12	11	86.5	96,000
	12G	135	29,525	12	11	86.5	94,000
Champion	715	152	26,950	12	11	48	70,915
	740	228	30,500	12	11	48	83,147
	760	240	37,000	14	11	48	98,840

TABLE 19. DISTRIBUTOR TRUCKS

	Truck name (if any)	Tank size (gal.)	Pump drive[a]	Pump capacity at given head: Pump capacity (gal/min)	Head (psi)	Max. spray width (ft)	Recommended max. spraying speed (mph)	Current price (ready to use) ($) [5/16/79]
Rosco Mfg. Co.	M.F.W.	1,000	PTO, gravity, sep. eng.	275	40	12	20	7,481[b]
	M.F.W.	1,500	PTO, gravity, sep. eng.	275	40	12	20	7,772[b]
	M.F.W.	2,000	PTO, gravity, sep. eng.	275	40	12	20	8,400[b]
	M.F.W.	2,500	PTO, gravity, sep. eng.	275	40	12	20	8,815[b]
	M.F.W.	3,000	PTO, gravity, sep. eng.	275	40	12	20	9,330[b]
	M.F.W.	3,500	PTO, gravity, sep. eng.	275	40	12	20	30,000-35,000[c]
	M.F.W.-S	3,000	PTO	400	60	50	20	10,395[b]
	M.F.W.-S	3,200	PTO	400	60	50	20	10,825[b]
	M.F.W.-S	3,500	PTO	400	60	50	20	11,183[b]
Rimpull	WT 15	15,000	PTO	700	60	70	35	260,000[b]
	WT 20	20,000	PTO	700	60	70	35	320,000[b]
McLellan Equipt.	-	3,600	Sep.eng.	750	70	100	NA	45,000-48,000[c]
Entyre Co.	-	1,900	PTO, sep. eng.	335	NA	50	5	NA
	-	2,200	PTO, sep. eng.	335	NA	50	5	NA
	-	2,500	PTO, sep. eng.	335	NA	50	5	NA
	-	3,000	PTO, sep. eng.	335	NA	50	5	NA
	-	3,500	PTO, sep. eng.	335	NA	50	5	NA

[a] PTO = power take off; sep. eng. = separate engine
[b] Installed but without truck.
[c] Estimated.

TABLE 20. COMPACTORS

Company name	Compactor name	Drum type	Vibratory or nonvibratory	Weight (lb)	Horsepower	Max. dynamic force (lb)	Max. speed (mph)	Price ($) [5/29/79]
Dynapac	CA-25	Steel	V	20,000	125	36,000	15	51,000
	CA-25s	Steel	V	22,245	125	44,000	15	55,000
	CA-25d	Steel	V	20,750	125	36,000	6.5	56,000
	CA-25pd	Sheeps foot	V	24,400	125	44,000	6.5	63,500
	CA-25pdb	Sheeps foot	V	25,500	125	44,000	6.5	67,350
Caterpillar	815	Sheeps foot	NV	40,000	170	40,000	NA	97,500
	825c	Sheeps foot	NV	69,577	315	69,577	NA	175,000
Ray Go	300A	Steel	V	12,800	70	16,000	NA	40,675
	420C	Sheeps foot	V	25,160	114	32,000	8	69,705
	600A	Steel	V	29,600	119	45,000	17.5	66,980
	Ram 45	Sheeps foot	NV	42,000	228	42,000	15	115,170
	Ram 65	Sheeps foot	NV	48,000	304	48,000	16	141,725
Galion	VOS2-66A	Steel	V	17,430	125	38,715	NA	NA
	VOS 84A	Steel	V	20,900	125	47,300	NA	NA
	S-10-14A	Steel	NV	28,000	NA	28,000	NA	NA
Hyster	C610B	Steel	V	14,750	75	25,000	NA	37,000
	C612B	Sheeps foot	V	15,855	82	25,000	NA	48,000
	C620B	Steel	V	15,505	75	25,000	NA	42,000

NA = Not available.

For most applications, however, a storage tank is not necessary for solid dust suppressants. Dry warehouse space is sufficient for storage because most solid suppressants are shipped in bags weighing between 50 and 100 lb. In some instances, however, storage tanks may be desired for dry suppressants that are mixed with water and applied in liquid form. An example would be a solid suppressant such as calcium chloride. The distribution of a dry dust suppressant is also different. In most cases a mechanical spreader is recommended. However, when any water-soluble solid suppressant is to be mixed with water, a distributor truck should be used.

Although some of the equipment listed may seem unnecessary and some of the specifications excessive, they represent the most effective equipment for the application of chemical dust suppressants to unpaved roads. The above recommendations represent a substantial initial investment but in the long run they will contribute greatly toward a cost-effective roadway dust control plan.

6.2.2 Dust Suppressant Application Techniques

At the present time, chemical dust suppressants are most effective when applied in a systematic fashion. This entails the mixing of materials thoroughly into the soil-aggregate surface by means of a blade grader or, preferably, by a mixing machine. Construction of stabilized road surfaces does not present any unusual problems so long as several techniques and principles are thoroughly understood. Usually, a train of ordinary construction equipment is used, including scarifiers, graders, pulverizers, water distributors, and compaction equipment. Depending on the type of dust suppressant, there are two basic types of application techniques, those for spraying water-based chemicals and those for the mechanical spreading of solid suppressants.

Scarification

When a road surface is so irregular that traffic cannot use it in safety and comfort, scarifying and resurfacing may be necessary. Conditions which require these operations are: a large number or large area of pot holes or deep ruts, serious corrugations or washboard formations, and extensive areas of disintegration. The usual procedure is to scarify the entire surface to the full depth of the surface material. Some engineers prefer, however, that the depth of scarifying be sufficient only to correct the irregularities or to get to the bottom of the irregularities, and care should be taken to loosen no more of the existing compacted surface than is necessary.

Scarifying or loosening of the old surface is usually done by a blade grader and sometimes by suitable farm equipment such as a disc, plow, and toothed harrow. Deep scarifying to the subgrade must be avoided. Undesirable material from the shoulders should not be mixed with the surface material. The loosened material must be processed until the lumps are adequately broken, and any oversized aggregate or objects from the scarified material must be removed. Sometimes additional material, either fine or coarse or in combination, may be required to improve the surface material. For instance, a fine grained soil is added to road sections having an excess of coarse aggregate to lessen corrugations. Likewise, where an excess of fine material exists, the addition of angular coarse material and a reduction of fine grained material tend to alleviate this condition. When additional material must be added, it should be selected with care. Usually, the selection of new materials is based on visual inspection and a knowledge of local materials. Laboratory and field testing of the materials is generally necessary if the extent of road to be repaired is considerable.

Application of Suppressant

Calcium chloride and other solid type suppressants are commonly applied dry, using mechanical spreaders. The best times to apply the material are following a rain and after any necessary blading or patching operations are completed. If it is necessary to apply this type of suppressant during dry weather, good results can be obtained by making the application at night or in the very early morning. Water may be added to the surface before application if suitable equipment is available.

Actual steps that have produced high quality surfaces are:

1. Scarify and blade the road (discussed in previous section) to eliminate corrugations and pot holes and to loosen the road surface material to the depth that penetration is desired. All materials that will not pass through a 1-in. ring should be bladed to one side. The final aggregate should consist of a good gradation of sizes. Some roads work easier if a light application of water is applied before the first grading to soften the surface of the road.

2. Blade most of the loose material into windrows on both sides of the road to prevent runnoff and to assure uniform mixing of the chemical.

3. After the windrows are formed, apply the solid suppressant to the road surface material and mix it in thoroughly. The rate of application should follow the product manufacturer's specifications in conjunction with proven examples.

Emulsified petroleum by-products and other water-soluble suppressants are commonly applied wet by using a sprayer-equipped tank truck. Steps that have produced high quality surfaces are:

1. Perform the first two steps above.

2. After the windrows are formed, apply the liquid by spraying from a tank truck. The rate of application can be regulated either by valves if the truck is equipped with a pump, or by adjusting the speed of the truck if gravity-flow equipment is employed. Best wetting and dispersing action is obtained with the product manufacturer's recommended solution concentration. The concentration generally used depends on the moisture content of the soil. High concentrations are more practical for sand and very moist soils. To obtain best results, it should be mixed thoroughly with the soil.

   a. Spray one-third to one-half of the liquid suppressant, specified total treatment, between the windrows.

b. Blade windrows to center, spreading evenly.

c. Spray approximately one-third of total specified roadbinder on surface and blade or mechanically mix the solution and the aggregate with a grader or pulverizer. Save part of roadbinding solution for final top-dressing treatment.

The remaining steps in the actual road building process are common to both liquid and solid chemical suppressants.

1. The best type of crown is a modified A-type cross-section with a uniform side slope of about 1/2-in. per ft from the center line to the edge of the road. The rounded crown commonly used on concrete pavement is not suitable for these roads as it allows pools of water to collect on the relatively flat center part of the road. Standing water can increase the plasticity of the road material to the point that traffic causes pot holes to develop. The importance of a proper A-type crown or equivalent cannot be stressed too much.

2. After the final shaping and formation of the A-type crown, a top dressing of liquid type suppressant should be used to touch up any dry spot that might have been exposed during grading. The spray should be relatively light especially when the soil is wet, in order to avoid excess surface plasticity and runoff of valuable roadbinding material.

3. The final step in compaction. This is best done with a multiple-wheeled, rubber-tired roller, but satisfactory results can be obtained by letting traffic do the compaction. Compaction must be done before the roadbinder dries, while the road material is still plastic.

4. A few dust suppressants require time to cure. No traffic should be allowed on the roadway during this process.

The information discussed in this section represents a mixture of much research and practical experience. Although the application procedure may be time consuming, it should produce maximum efficiencies for chemical suppressant performance. By incorporating the suppressants into the road surface, a more stable road surface will be effected and less generation of additional dust will occur over time.

7.0 EVALUATION OF DUST SUPPRESSANTS COMMONLY USED IN THE MINING INDUSTRY

The following sections present a discussion of the various roadway dust suppressants which are prevalent in the mining industry. Information is presented pertaining to specific application procedures; associated costs; performance, which includes product advantages/disadvantages, durability, and control efficiency; and cost effectiveness. The dust suppressants which will be discussed include: (a) lignin sulfonate, (b) petroleum resins, (c) salts, (d) water, and (e) wetting agents.

7.1 Lignin Sulfonate

7.1.1 Introduction

Lignin sulfonate has been utilized as a dust suppressant since the early 1900's. At that time the suppressant was used in Sweden to reduce rural roadway dust. Because it was a by-product of the country's paper mills, the supply of suppressant was abundant. The use of lignin sulfonate in this country dates to the 1940's. Its use on roadways started as another outlet to dispose of lignin sulfonate as a waste product.

Lignin is a generic term referring to the natural binder in trees which holds together the cellulose fibers. Lignin sulfonate is derived in the following manner. The sulfonate solution is formed during the paper milling process. After the tree has been debarked, it is placed in a sulfonate solution which absorbs the lignin from the wood. This process produces wood fibers which are in a 10% lignin sulfonate liquor solution. The 10% solution is concentrated by evaporation to a 50% solution, which is the usual state in which lignin sulfonate is marketed.

As a waste by-product from more than 110 sulfite pulping mills in the United States, lignin sulfonate is a readily available commodity. Over 30 million gallons per day of the lignin liquor is produced.

7.1.2 Application Procedures

Tables 21 and 22 present application procedures for various lignin sulfonate products. Initial application procedures apply to previously untreated roadways, or to roadways in need of major repair; and subsequent application procedures apply to normal road dust control maintenance procedures. The information contained in the tables was obtained from four representative vendors. The products reviewed are: (a) calcium lignin sulfonate from the Arthur C. Trask Company, Flambeau Paper Company, and American Can Company; and (b) ammonium lignin sulfonate from Crown Zellerbach Corporation.

TABLE 21. LIGNIN SULFONATE INITIAL APPLICATION PROCEDURES

Company/product	Road surface preparation	Dilution ratio (gal. H_2O:gal. product)	Density (gal. solution/sq yard)	Finishing procedures
Arthur C. Trask Co. . Trastan CM50 . Trastan CM51	1. Blade surface to either crown or slope. 2. Scarify 5 in.	4:1 (CM50) 5:1 (CM51)	a	1. Mix and reform the road surface with a grader.
Crown Zellerbach Corp. . Orzan AL50 . Orzan GL50	1. Moisten and blade surface to a modified crown. 2. Windrowing all loose material.	2-5:1[b]	1.0	a
American Can Co. . Norlig A . Norlig G	1. Blade surface, windrowing all loose material. 2. Scarify to 2 in.	3-4:1[c]	1.6-2[d]	1. Blade windrows onto road mixing soil with Norlig. 2. Form modified A crown. 3. Compact.
Flambeau Paper Co. . Flambinder	1. Blade surface, windrowing all loose material. 2. Scarify to 3 in.	4:1[e]	2-2.4	1. Blade windrow onto road mixing aggregate with flambinder. 2. Form a modified A crown. 3. Compact.

[a]Data not available from vendor.

[b]2:1 very porous material - minimum clay content.
3:1 moderately porous - somewhat less than sufficient clay content.
4:1 normal compacted gravel road - average penetration.
5:1 Tight surface - very slow penetration

[c]Graded soil 3:1, clay 4:1.

[d]Graded soil 1.6 gal/sq yard, clay 2.0 gal/sq yard.

[e]5:1 for access roads.

TABLE 22. LIGNIN SULFONATE SUBSEQUENT APPLICATION PROCEDURES

Company/product	Road surface preparation	Dilution ratio ($gal. H_2O$:gal. product)	Density (gal. solution/sq yard)	Finishing procedures
Arthur C. Trask Co. . Trastan CM50 . Trastan CM51	1. Blade surface to either crown or slope 2. Scarify 5 in.	4:1 (CM50) 5:1 (CM51)	a	1. Mix and reform the road surface with a grader.
Crown Zellerbach Corp. . Orzan AL50 . Orzan GL50	1. Moisten and blade surface to a modified crown.	2-5:1[b]	0.3-0.5	a
	2. Windrow loose material.	3-4		
American Can Co. . Norlig A . Norlig G	1. Blade surface to 1 in., windrow loose material.	3-4:1	1.6-2[c]	1. Blade windrows onto a road mixing soil with Norlig.
	2. Scarify to 2 in.			2. Form modified A crown. 3. Compact.
Flambeau Paper Co. . Flambinder	1. None, if surface is in good condition.	4:1[d]	2-2.4[e]	1. Blade windrow onto road mixing aggregate with flambinder.
	2. If surface is badly worn, repeat initial application procedures.			2. Form a modified A crown. 3. Compact.

[a]Data not available from vendor.

[b]2:1 very porous material - minimum clay content.
3:1 moderately porous - somewhat less than sufficient clay content.
4:1 normal compacted gravel road - average penetration.
5:1 tight surface - very slow penetration.

[c]Graded soil 1.6 gal/sq yard.

[d]5:1 for access roads.

[e]2.0 for haul roads (15% solids solution by weight), 2.4 for access roads (12% solids by weight).

7.1.3 Associated Costs

Table 23 presents example cost data for lignin sulfonate. Information given is basic purchase cost and the total cost, which includes railroad transportation. The product in this example is originating from the Flambeau Paper Company located in Park Falls, Wisconsin. The cost data are current for spring of 1980. The three geographic locations were chosen to illustrate costs to the western coal region (Gillette), the eastern coal and stone region (Louisville), and the southwestern copper region (Phoenix).

TABLE 23. LIGNIN SULFONATE COST DATA

		Total Cost[b]		
Product	Purchase Cost[a] ($/gal.)	Gillette, Wyoming ($/gal.)	Louisville, Kentucky ($/gal.)	Phoenix, Arizona ($/gal.)
Calcium lignin sulfonate	0.12	0.30	0.27	0.35

a Cost based on 20,000-gal. purchase.
b Includes purchase cost and rail transportation from northern Wisconsin.

7.1.4 Performance

Advantages/Disadvantages

The following product advantages are associated with lignin sulfonate.

1. Because it is a waste product from a large industry, it is usually available.

2. It is noncorrosive.

3. Because the product is water-soluble, it will wash off vehicles.

4. The associated LD_{50} is 20,000 mg/kg. The product is relatively nontoxic.

The following product disadvantages are associated with lignin sulfonate.

1. It can cause problems with ore processing, namely, the flotation process.

2. Because it is water-soluble, it will wash away from the road surface with large amounts of rainfall. This may be minimized by the addition of clay-sized particles to the road surface. These particles are tightly held by the product, thus the bonds are less likely to be broken by rainfall.

3. Once roadways are treated properly, over a period of years the roadway can become quite compacted, making reclamation of the roadway difficult.

Durability

When properly applied, lignin sulfonate has kept access roads relatively dust free for periods from 6 months to 2 years.[15,16] Periodically, the road surface should either be watered to rejuvenate the lignin sulfonate or sprayed with a light application of solution to bind loose surface material.

It is reported that lignin sulfonate can keep mine haul roads relatively dust free for periods of 3 to 4 weeks.[15,17] After this time period, it is recommended that the original application strength solution be applied to the road surface to bind loose surface materials. If the road surface is in poor condition, it is recommended that the surface be scarified and graded during application of the suppressant.

Control Efficiency

Very few test data are available pertaining to the control efficiency of lignin sulfonate in reducing dust emissions. Limited control efficiency testing of a haul road treated with lignin sulfonate after 1 day of application was performed by MRI. Figure 3 presents the results.[18] Because of the lack of control efficiency data, approximations of control efficiencies as determined by the project team have been utilized.

For this study, control efficiencies were assumed identical among the various products assessed. This assumption was made because control efficiency variations among products is not known. The project team believes that these products would have essentially the same control efficiencies, given the application densities associated with them.

It is estimated that over a period of 1 year on mine access roads lignin sulfonate can achieve a control efficiency of 70%. This control efficiency is related to an annual application density of 2.4 gal. of 12% solution per square yard of roadway.

On mine haul roads over a period of 1 year, lignin sulfonate can achieve a control efficiency of 75%. This control efficiency is based on an application density of 2 gal. of 15% solution per square yard of roadway applied six times per year on an as needed basis.

7.1.5 Cost Effectiveness

The cost effectiveness of applying lignin sulfonate to mine roadways is presented in the following section. The following cost-effectiveness analysis is based on a hypothetical coal mine near Gillette, Wyoming, having 2 miles of haul roads and 3 miles of access roads within the plant.

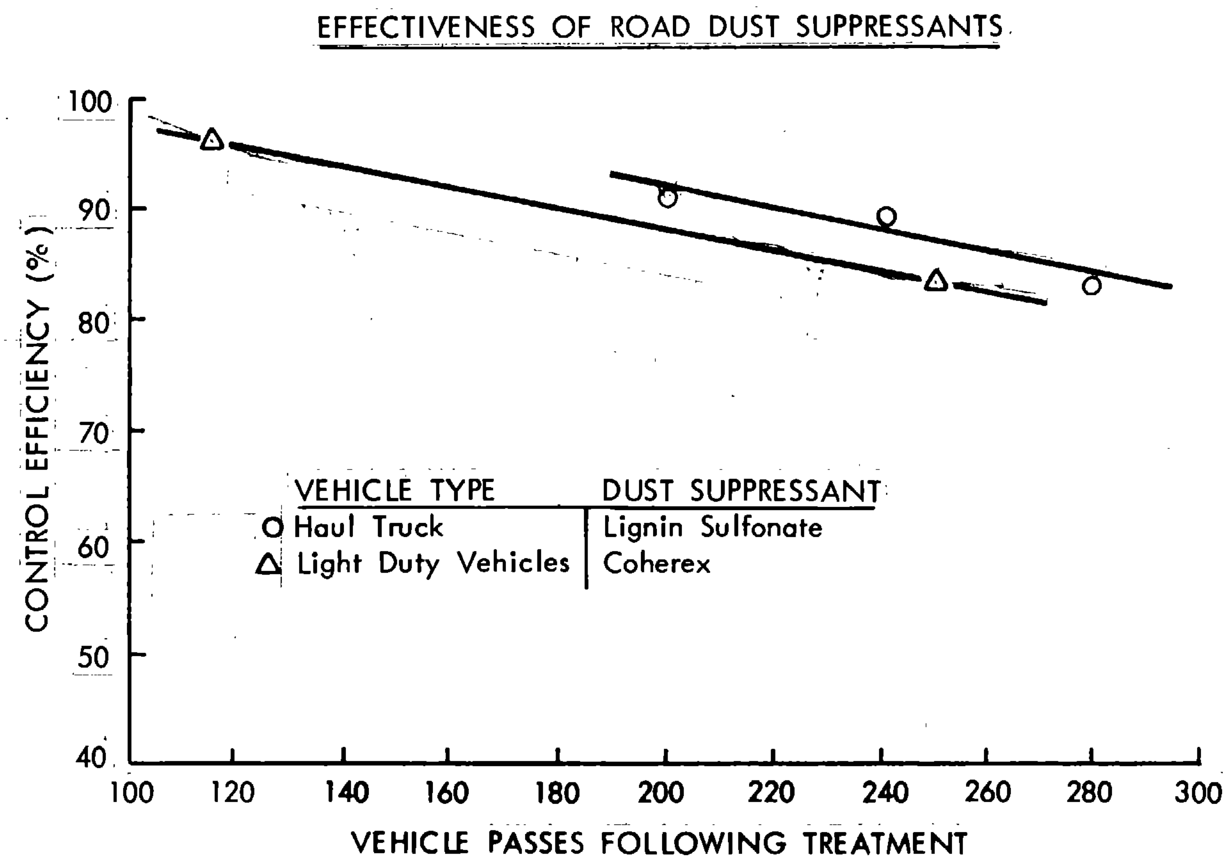


Figure 3. Effectiveness of road dust suppressants.

The following data are utilized in the cost-effectiveness analysis:

Emission Factor

1. Figure 4 presents the emission factor equation which is used to determine annual uncontrolled mine emissions from unpaved roadways.[19]

where for haul roads:
- s = 10%
- S = 15 mph
- w = 8 wheels
- W = 140 tons, truck weighs 80 tons unloaded and 200 tons loaded
- d = 265 dry days/year

where for access roads:
- s = 10%
- S = 30 mph
- w = 4 wheels
- W = 5 tons
- d = 265 dry days/year

2. The fine particle (< 5 μm diameter) emission factor for the haul vehicles is 15 lb/VMT (vehicle mile traveled). This is determined by multiplying the emission factor presented in Figure 4 by the fine particle ratio of the emission factor, 40%.[20,21] The fine particle emission factor for vehicles traveling on access roads is 2.0 lb/VMT.

Source Extent

1. There are 2 miles of mine haul roads which are 75 ft wide (88,000 sq yards) and 3 miles of access roads which are 25 ft wide (44,000 sq yards).

2. Haul roads have an ADT (average daily traffic) of 360. Access roads have an ADT of 480.

3. This amounts to 720 VMT/day for haul trucks or 262,800 VMT/year. For access roads, this amounts to 1,440 VMT/day or 525,600 VMT/year.

Uncontrolled Emissions Data - Fine Particulate

- Haul Roads: 15 lb/VMT x 262,800 VMT/year = 1,971 tons/year.
- Access Roads: 2.0 lb/VMT x 525,600 VMT/year = 526 tons/year.

Control Efficiency - Lignin Sulfonate

- Haul roads: 75% annual, apply product to road surface six times a year.
- Access roads: 70% annual, apply product to road surface once a year.

OPEN DUST SOURCE: Vehicular Traffic on Unpaved Roads
QA RATING: B for Dry Conditions
C for Annual Average Conditions

$$EF = 1.7\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right) \text{ kg/veh-km}$$

$$EF = 5.9\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right) \text{ lb/veh-mi}$$

Determined by profiling of emissions from light-duty vehicles on gravel and dirt roads under dry conditions.

Estimated factor to account for mitigating effects of precipitation over period of one year.

Determined by profiling of emissions from medium- and heavy-duty vehicles on gravel and dirt roads under dry conditions.

	metric	non-metric
EF = suspended particulate emissions	kg/veh-km	lb/veh-mi
s = silt content of road surface material	%	%
S = average vehicle speed	km/hr	mph
w = average number of wheels per vehicle	–	–
W = average vehicle weight	tonnes	tons
d = dry days per year	–	–

Figure 4. Predictive emission factor equation for vehicular traffic on unpaved roads.

Emissions Reductions

- Haul roads: 1,971 tons/year x 75% = 1,478 tons/year reduced.
- Access roads: 526 tons/year x 70% = 368 tons/year reduced.

Annual Operating Cost

- Haul Roads

1. An equivalent of 1 man-year is estimated to be devoted to the application and maintenance of the dust suppressant. This annual cost is estimated to be $30,000 with 80% of the cost related to haul roads and 20% related to access roads ($24,000 and $6,000).

This 1 man-year of effort consists of activities by the following mine personnel: (a) a distributor truck driver to apply a total of six applications per year of dust suppressant as well as infrequent roadway watering (once per week), (b) a grader operator to prepare and maintain the road surface treatment, and (c) a supervisor to procure the dust suppressant and see that it is stored and applied properly.

2. Application cost for haul roads:

- 2 gal. of 15% solution per square yard is recommended for haul roads.[15]
- 2 gal/sq yard x 88,000 sq yards of haul roads = 176,000 gal. of 15% solution required per application.
- A dilution ratio of three parts water to one part of 50% solution by weight is recommended for application.[15]
- 1 gal. of 50% solution equates to 4 gal. of 15% solution.
- 176,000 gal. of 15% solution = 44,000 gal. 50% solution.
- It is estimated that six applications are required per year or 44,000 gal. x 6 = 264,000 gal./year of 50% solution required.
- Product cost to Gillette, Wyoming is $0.30/gal. of 50% solution.
- 264,000 gal. x $0.30/gal. = $79,200.
- Manpower costs = $24,000/year.

3. Total annual operating cost = $103,200. (Note: This includes only the cost of the product and the associated manpower costs.)

. Access Roads

1. From the previous annual manpower cost assessment for the haul roadways, the annual manpower cost for application and maintenance of the dust suppressant to access roads is $6,000/year.

2. Application cost for access roads.

- 2.4 gal. of 12% solution per square yard is recommended for access roads.[15]
- 2.4 gal./sq yard x 44,000 sq yards of access roads = 105,600 gal. of 12% solution is required per application.
- A dilution ratio of four parts of water to one part of 50% solution by weight is recommended per application.[15]
- 1 gal. of 50% solution equates to 5 gal. of 12% solution.
- It is estimated that one application is required per year.
- Product cost to Gillette, Wyoming, is $0.30/gal. of 50% solution.
- 105,600 gal. x $0.30/gal. = $31,680/year.
- Manpower costs = $6,000/year.

3. Total annual operating cost = $37,680.

Annual Operating Cost Effectiveness

. Haul Roads

- $103,200 expended per year for haul road dust control.
- 1,478 tons of fine particulate emissions reduced per year due to dust control (2,956,000 lb).
- $103,200 ÷ 2,956,000 lb = $0.035/lb.
- $0.035 expended per pound of fine particulate emissions reduced.

. Access Roads

- $37,680 expended for haul road dust control.
- 368 tons of fine particulate emissions reduced per year due to dust control (736,000 lb).

- $37,680 ÷ 736,000 lb = $0.051/lb.

- $0.051 expended per pound of fine particulate emissions reduced.

- Total Mine Roadway Dust Control

  - $103,200 expended annually for haul roads.

  - $ 37,680 expended annually for access roads.
    $140,880 total expenditures.

  - 2,956,000 lb of haul road fine particulate reduced.
    736,000 lb of access road fine particulate reduced.
    3,692,000 total pounds reduced.

  - $140,880 ÷ 3,692,000 = $0.038/lb.

The annual operating cost effectiveness of using lignin sulfonate to reduce total mine roadway dust emissions is:

- $0.038 expended per pound of fine particulate emissions reduced.

7.2 Petroleum Resins

7.2.1 Introduction

The petroleum resin product most commonly used in the mining industry for dust control is Coherex® manufactured by Witco Chemical Corporation.

The use of Coherex® for dust control dates to the early 1950's. It was originally developed as a mitigation measure against wind erosion. By the 1960's the product was used to reduce dust emissions from unpaved roads.

Coherex® is an emulsion of petroleum resins. The parent petroleum resins are high boiling by-products of lubrication oil manufacturing. These parent materials include petroleum residuals, solvent extracts, and acid sludges. The emulsified product is stable and nonvolatile and consists of approximately 60% semiliquid natural petroleum resins and 40% wetting solution.

7.2.2 Application Procedures

Tables 24 and 25 present information pertaining to mine roadway application procedures for Coherex®, including initial and subsequent procedures. Initial application procedures apply to previously untreated roadways, or to roadways in need of major repair; subsequent application procedures apply to normal road dust control maintenance procedures. The information contained in the tables was obtained from Witco Chemical Corporation.

TABLE 24. PETROLEUM RESIN APPLICATION PROCEDURES

Company/product	Road surface preparation	Dilution ratio (gal. H_2O: gal. product)	Density (gal. solution/sq yard	Finishing procedures
Witco Chemical Co. Coherex®	1. Grade surface to remove pot-holes, etc. 2. Scarify to 1 in.	4:1[a]	2[b]	1. Compact road surface 2. c

[a] For haul roads, initial dilution ratio can range from 4:1 to 7:1. For access roads, initial dilution can range from 4:1 to 10:1.

[b] 4:1 dilution, 2 gal/sq yard density.
7:1 dilution, 1/2 to 1 gal/sq yard density.
10:1 dilution, 1/2 gal/sq yard density.

[c] Ideally the treated surface should be left to cure for 24 hr before it is ready for vehicular traffic. This procedure mitigates the raveling of the treated surface.

TABLE 25. PETROLEUM RESIN SUBSEQUENT APPLICATION PROCEDURES

Road surface preparation	Dilution ratio (gal. H_2O:gal. product)	Density (gal. solution/sq yard)	Finishing procedures
1. None if surface is in good condition. 2. Grade and scarify if surface is worn.	10:1	0.25-0.5[b]	a

[a] Ideally the treated surface should be left to cure for 24 hr before it is ready for vehicular traffic. This procedure mitigates the raveling of the treated surface.

[b] Access roads, 0.25 gal/sq yard; haul roads, 0.5 gal/sq yard.

7.2.3 Associated Costs

Table 26 presents example cost data for Coherex®.

7.2.4 Performance

Advantages/Disadvantages

The following product advantages are associated with Coherex®.

1. The product is noncorrosive.

2. The material is not water-soluble; it will not be displaced by rain; and it will not evaporate or percolate away.

3. It is relatively nontoxic; LD_{50} is 16 g/kg of body weight.

4. It will not adversely affect plant growth.

5. It is relatively nonflammable. Flashpoint is 400°F.

6. Product is distributed from several locations throughout the country.

The following product disadvantages are associated with Coherex®.

1. The treated road surface is not amenable to vehicular traffic until approximately 24 hr after application.

2. The product will not tolerate boiling or freezing conditions.

3. Travel by tracked vehicles will destroy the treated surface.

4. The material is not water-soluble; it requires a solvent to remove it entirely from clothing, building walls, or vehicles.

5. The price may rise significantly with decontrol of American oil prices.

Durability

When properly applied, Coherex® reportedly has kept access roads relatively dust free for periods of 6 months to 1 year, on an initial application of 7:1 dilution of 1 gal/sq yard.[22]

For haul roads, Coherex® reportedly has kept roadways relatively dust free for periods of 3 to 4 weeks during the dry periods of the year. This is based on an initial application of 4:1 dilution of 2 gal./sq yard. Subsequent monthly applications of 10:1 dilution of 0.5 gal./sq yard are recommended.[23]

TABLE 26. PETROLEUM RESIN COST DATA

Product	Purchase cost			Total cost		
	Gillette, Wyoming ($/gal.)	Greensboro, North Carolina ($/gal.)	Phoenix, Arizona ($/gal.)	Gillette, Wyoming ($/gal.)	Greensboro, North Carolina ($/gal.)	Phoenix, Arizona ($/gal.)
Witco Chemical Coherex®	0.88	1.30	1.01	1.10[a]	1.62[a]	1.07[b]

[a]Based on purchase of 20,000 gal. railcar.

[b]Based on purchase of 6,000 gal. truck.

Control Efficiency

Very few test data pertaining to the control efficiency of Coherex® in reducing dust emissions are available. MRI has performed limited control efficiency testing of an unpaved road at an iron and steel plant. The roadway was tested 1 day after an initial application of Coherex® 10% strength solution in water.[24] Figure 4 presents the results of the testing.

Because of this lack of control efficiency data, approximations of control efficiencies, as determined by the project team, have been utilized.

It is estimated over a period of 1 year that on mine access roads Coherex® can achieve a control efficiency of 70%. This control efficiency is related to an annual application density of 1 gal./sq yard of 7:1 dilution Coherex® and water.

On mine haul roads over a period of 1 year, Coherex® is estimated to have a control efficiency of 75%. This value is dependent on an initial annual application density of 2 gal/sq yard of 4:1 dilution and five subsequent applications of 10:1 dilution at 0.5 gal/sq yard. These subsequent applications are performed on an as needed basis.

7.2.5 Cost Effectiveness

The following cost effectiveness analysis for Coherex® is based on a hypothetical coal mine near Gillette, Wyoming, having 2 miles of haul roads and 3 miles of access roads within the plant.

The following data are used in the cost-effectiveness analysis:

Emission Factor

The same uncontrolled fine particulate emission factors that were used in Section 7.1.5 are used in this analysis: (a) 15 lb/VMT for vehicles traveling on haul roads and (b) 2 lb/VMT for vehicles traveling on access roads.

Source Extent

The source extent data are also similar to the data used in Section 7.1.5. The data include: (a) 262,800 VMT for haul roads and (b) 525,600 VMT for access roads.

Uncontrolled Emissions Data - Fine Particulate

The annual emissions determined in Section 7.1.5 for the mine roads are: (a) 1,971 tons/year for haul roads and (b) 526 tons/year for access roads.

Control Efficiency

- Haul roads = 75% annual, apply product to road surface six times a year.

- Access roads = 70% annual, apply product to road surface once a year.

Emissions Reductions

As per Section 7.1.5:

- Haul roads = 1,478 tons/year reduced.

- Access roads = 368 tons/year reduced.

Annual Operating Cost

- Haul Roads

1. An equivalent of 1 man-year is estimated to be needed for application and maintenance of Coherex®. As per Section 7.1.5, $24,000 is expended for haul roads and $6,000 for access roads per year.

2. Application cost for haul roads:

   - 2 gal. of 4:1 dilution per sq yard for initial annual treatment.

   - 2 gal./sq yard x 88,000 sq yards of haul road = 176,000 gal. of 4:1 dilution required annually.

   - 1 gal. of concentrate = 5 gal. of applied solution.

   - 176,000 gal. of solution = 35,200 gal. of concentrate.

   - In addition, five subsequent applications throughout the year are required at a dilution of 10:1 and an application density of 0.5 gal./sq yard.

   - 0.5 gal./sq yard x 88,00 sq yards x 5 = 220,000 gal. of 10:1 dilution required per year.

   - 1 gal. of concentrate = 11 gal. of solution to be applied five times per year.

   - 220,000 gal. of 10:1 dilution = 20,000 gal. of concentration.

   - 35,200 gal. of concentrate (initial) + 20,000 gal. of concentrate (subsequent) = 55,200 gal. of concentrate required annually for haul road dust control.

- 55,200 gal. x $1.10/gal. = $60,720/year.
- Manpower costs = $24,000/year.

3. Total annual operating cost = $84,7200.

. <u>Access Roads</u>

1. As stated above, the annual manpower cost for the access road program is $6,000/year.

2. Application cost for access roads:

- An annual application of 7:1 dilution of 1 gal/sq yard is recommended.
- 1 gal/sq yard x 44,000 sq yards of access roads = 44,000 gal. of solution required annually.
- 5,500 gal. of concentrate required for access road program annually.
- 5,500 gal. x $1.10 = $6,050/year.
- Manpower costs = $6,000.

3. Total annual operating cost = $12,050.

<u>Annual Operating Cost Effectiveness</u>

. <u>Haul Roads</u>

- $84,720 expended per year for dust control.
- 2,956,000 lb (1,478 tons) of fine particulate emissions reduced per year.
- $84,720 ÷ 2,956,000 lb = $0.029/lb.
- $0.029 expended per pound of fine particulate emissions reduced.

. <u>Access Roads</u>

- $12,050 expended per year for dust control.
- 736,000 lb of fine particulate (368 tons) reduced per year.
- $12,050 ÷ 736,000 lb = $0.016/lb.
- $0.016 expended per pound of fine particulate emissions reduced.

- Total Mine Roadway Dust Control

  - \$84,720 expended annually for haul roads.
  - \$12,050 expended annually for access roads.
  - \$96,770 total annual expenditures.
  - 2,956,000 lb of haul road dust reduced.
    736,000 lb of access road dust reduced.
    3,692,000 total lb reduced.
  - \$96,770 ÷ 3,692,000 = \$0.026.

The annual operating cost effectiveness of using Coherex® to reduce total mine roadway dust emissions is:

  - \$0.026 expended per pound of fine particulate emissions reduced.

7.3 Salts

7.3.1 Introduction

The type of salt used most commonly in the mining industry for dust control is calcium chloride. The use of calcium chloride for roadway maintenance and the reduction of dust from unpaved roadways has been prevalent in this country since the 1920's. Calcium chloride was originally used to treat rural secondary roadways.

Calcium chloride is produced from natural brine deposits found underground. It is a deliquescent; that is, calcium chloride is able to absorb and retain moisture from the atmosphere at relative humidities as low as 40%. Once the calcium chloride has absorbed all the moisture it can hold, it dissolves and spreads as it changes phase into a liquid state. This phase change is exothermic which explains its use as a deicer on roadways.

7.3.2 Application Procedures

Tables 27 and 28 present information pertaining to mine roadway application procedures for calcium chloride. The tables include initial and subsequent application procedures. As stated in earlier sections of this report, initial application procedures apply to previously untreated roadways, or to roadways in need of major repair. Subsequent application procedures apply to normal road dust control maintenance procedures. The information contained in the tables is for the products distributed by Dow Chemical USA.[25]

7.3.3 Associated Costs

Table 29 presents example cost data for the various Dow Chemical products. All transportation for the product is by rail.

TABLE 27. CALCIUM CHLORIDE INITIAL APPLICATION PROCEDURES

Product	Road surface preparation	Dilution ratio (gal. H_2O:gal. product)	Density (gal. Solution/sq yard)	Finishing procedures
Dow Chemical USA Liquidow®	Scarify 3-5 in.	-	0.6-1.0[a]	1. Mix and blade to a modified "A" crown. 2. Apply a 0.1 gal/sq yard optional top dressing. 3. Compact.
Dow Chemical USA Dowflake®	Scarify 3-5 in.	-	2.5-4.2 lb/sq yard	1. Mix and blade to a modified "A" crown. 2. Compact.
Dow Chemical USA Peladow®	Scarify 3-5 in.	-	2.1-3.4 lb/sq yard	(same as Dowflake®, bracketed)

[a] 30% strength solution.

TABLE 28. CALCIUM CHLORIDE SUBSEQUENT APPLICATION PROCEDURES

Product	Road surface preparation	Dilution ratio (gal. H_2O:gal. product)	Density (gal. solution/sq yard)	Finishing procedures[a]
Liquidow®	Scarify 3-5 in if needed.	-	0.2-0.3[b]	1. Blade to a modified "A" crown. 2. Compact
Dowflake®	Scarify 3-5 in. if needed.	-	0.8-1.3 lb/ sq yard	1. Blade to a modified "A" crown. 2. Compact
Peladow®	Scarify 3-5 in. if needed	-	0.7-1.0 lb/ sq yard	1. Blade to a modified "A" crown. 2. Compact

[a] If required.

[b] 30% strength solution.

TABLE 29. CALCIUM CHLORIDE COST DATA

Product	Purchase cost ($/gal.)	Purchase cost ($/ton)	Total cost: Gillette, Wyoming ($/gal.)	Gillette, Wyoming ($/ton)	Greensboro, North Carolina ($/gal.)	Greensboro, North Carolina ($/ton)	Phoenix, Arizona ($/gal.)	Phoenix, Arizona ($/ton)
Liquidow®	0.50[a]	85.97[b]	0.32	140.21[c]	0.72	123.77	d	d
Dowflake®	e	153.0	e	302.00	e	322.12[f]	e	d
Peladow®	e	214.00	e	357.40[e]	e	376.76[f]	e	d

a Cost per gallon of 38% solution.

b Expressed on a dry basis. Equivalent to the same amount of Dowflake®.

c Approximate total cost of Dowflake® equivalent product. Delivered to Colstrip, Montana, which is in the vicinity of Gillette, Wyoming. Liquidow® is not shipped in dry form. Expression of equivalence to dry ton basis of Dowflake® is for illustration purposes.

d Not shipped to Arizona because of excessive transportation cost.

e Product is not shipped in liquid form.

f Based on minimum purchase of 80,000 lb.

7.3.4 Performance

Advantages/Disadvantages

The following product advantages are associated with calcium chloride.

1. It is a deliquescent and as such absorbs moisture from the atmosphere, keeping the road surface moist.

2. It acts as a deicer; thus, in freezing conditions it can thaw snow and ice on the roadways.

3. It does not require time to cure after application.

4. It can be applied in either a liquid or a dry state.

Disadvantages

1. The material is potentially corrosive.

2. The product is water-soluble; under heavy rainfall it may wash away.

3. The material will affect plant growth.

4. If it comes in contact with eyes or skin, 30% solution can be injurious.

5. The liquid solution is potentially hard on pumps in distributor trucks.

Special precautions must be taken in applying the material.

Durability

Calcium chloride has been used for many years to treat rural secondary roadways. Mine access roads, having somewhat similar travel characteristics to the characteristics of rural secondary roads, can be expected to evidence similar degrees of durability. When properly applied, calcium chloride is reported to keep rural secondary roads dust free for a period of 1 year.

Members of the project team visited the Western Energy Company mine in Colstrip, Montana, and assessed a test segment of access roadway treated with calcium chloride. The road was also being watered two or three times daily because the daytime relative humidities in the summer in Colstrip typically are < 30%, and at this low relative humidity, the deliquescent effect of the calcium chloride is not activated. Road watering supplies the moisture necessary for the material to become effective. With this occasional road watering, there were no visible dust emissions from the traffic after a treatment period of 3 months. This performance was achieved by applying Peladow® dry to the scarified surface at a rate of

2.5 lb/sq yard, which is equivalent to 0.6 gal/sq yard of 30% solution.[26] A water truck ran over the treated surface to activate the treatment.

The project team estimates that calcium chloride, when properly applied on mine access roads, can keep these roads relatively dust free for a period up to 1 year. This performance is based on applying a 30% solution of calcium chloride at an application density of 0.6 gal/sq yard.

For haul roads, calcium chloride reportedly has kept roadways relatively dust free for periods of 4 to 6 weeks, based on an initial application of 30% solution of calcium chloride at an application density of 1.0 gal/sq yard. Subsequent monthly applications of 0.3 gal/sq yard are recommended on an as needed basis.[27]

Control Efficiency

Very few test data pertaining to the control efficiency of calcium chloride in reducing dust emissions are available. MRI recently performed limited control efficiency testing of the access road in Colstrip, Montana. However, the results of this testing are not yet available. Because of this lack of control efficiency data, approximations of control efficiencies determined by the project team have been utilized.

It is estimated that over a period of 1 year on mine access roads, calcium chloride can achieve a control efficiency of 70%. This control efficiency is related to an annual application density of 0.6 gal/sq yard of 30% solution. In addition, road watering is required at least once a day during periods of dry weather. "Dry" is defined as days having no rainfall and an average relative humidity less than 40%.

On mine haul roads, over a period of 1 year calcium chloride is estimated to have a control efficiency of 75%. This value is based on an initial application density of 1.0 gal/sq yard and five applications of 0.3 gal/sq yard of 30% solution during the year on an as needed basis. To achieve the stated control efficiency, road watering should be performed in the manner of the previously mentioned access roads.

7.3.5 Cost Effectiveness

The following cost-effectiveness analysis for calcium chloride is based on a hypothetical coal mine near Gillette, Wyoming, having 2 miles of haul roads and 3 miles of access roads within the plant.

The following data are used in the cost-effectiveness analysis:

Emission Factor

The uncontrolled fine particulate factors that were used in Section 7.1.5 are used in this analysis: (a) 15 lb/VMT for vehicles traveling on haul roads and (b) 2 lb/VMT for vehicles traveling on access roads.

Source Extent

The source extent data are also similar to the data used in Section 7.1.5. The data include: (a) 262,800 VMT for haul roads and (b) 525,600 VMT for access roads.

Uncontrolled Emissions Data - Fine Particulate

The annual emissions determined in Section 7.1.5 for the mine roads are: (a) 1,971 tons/year for haul roads and (b) 526 tons/year for access roads.

Control Efficiency

- Haul roads = 75% annual; apply product to road surface six times a year. Infrequent road watering may be required.

- Access roads = 70% annual; apply product to road surface once a year. Road watering may be required.

Emissions Reductions

As per Section 7.1.5:

- Haul roads = 1,478 tons/year reduced.

- Access roads = 368 tons/year reduced.

Annual Operating Cost

- Haul Roads

1. An equivalent of 1 man-year is estimated to be needed for the application and maintenance of calcium chloride. As per Section 7.1.5, $24,000 is expended for haul roads. Because of the addition of water to the road surface for proper effectiveness, an additional $1,000 is added to the $6,000 manpower figure for access roads that was presented in Section 7.1.5. To perform this task, 72 man-hours of road watering is estimated to be required.

2. Application cost for haul roads:

   - 1 gal. of 30% solution per square yard for initial annual application treatment.

   - 1 gal/sq yard x 88,000 sq yards of haul road = 88,000 gal. of 30% solution required annually.

   - 1 ton of Dowflakes® produces 475 gal. of 30% solution. Dowflakes® are mixed with water for this example analysis.

   - 88,000 gal. of solution ÷ 475 gal/ton of flakes = 185 tons of flakes required for initial application.

- In addition, five applications are required during the year at an application density of 0.3 gal/sq yard of 30% solution.

- 0.3 gal/sq yard x 88,000 sq yards of haul roads = 26,400 gal. of 30% solution required for one subsequent application.

- 26,400 gal. of 30% solution x five applications ÷ 475 gal/ton of flakes = 278 tons of flakes required for subsequent applications.

- 185 tons of Dowflakes® (initial) + 278 tons of flakes (subsequent) = 463 tons of Dowflakes® required annually for haul road dust control.

- 463 tons x $302.00/ton = $139,826 of Dowflakes® required per year.

- Manpower costs = $24,000/year.

3. Total annual operating cost = $163,826

. Access Roads

1. From the previous haul road discussion, annual manpower cost for the access road program is $6,000/year.

2. Application cost for access roads:

- 0.6 gal/sq yard of 30% solution for annual application treatment.

- 0.6 gal/sq yard x 44,000 sq yards of access roads = 26,400 gal. of 30% solution required annually.

- 26,400 gal. of 30% solution ÷ 475 gal. of 30% solution per ton of Dowflakes® = 56 tons of flakes required annually.

- 56 tons x $302.00/ton = $16,912 of Dowflakes®/year.

- Manpower costs = $7,000/year.

3. Total annual operating cost = $23,912/year.

Annual Operating Cost Effectiveness

. Haul Roads

- $163,826 expended per year for dust control.

- 2,956,000 lb (1,478 tons) of fine particulate emissions reduced per year.

- $163,826 ÷ 2,956,000 lb = $0.034/lb.

- $0.034 expended per pound of fine particulate emissions reduced.

- Access Roads

  - $23,912 expended per year for dust control.

  - 736,000 lb of fine particulate (368 tons) reduced per year.

  - $23,912 ÷ 736,000 lb = $0.032/lb.

  - $0.032 expended per pound of fine particulate emissions reduced.

- Total Mine Roadway Dust Control

  - $163,826 expended annually for haul roads.
    $ 23,912 expended annually for access roads.
    $187,738 total annual expenditures.

  - 2,956,000 lb of haul road dust reduced.
    736,000 lb of access road dust reduced.
    3,692,000 total pounds reduced.

  - 187,738 ÷ 3,692,000 = $0.051/lb.

The annual operating cost effectiveness of using calcium chloride to reduce total mine roadway dust emissions is:

- $0.051 expended per pound of fine particulate emissions reduced.

7.4 Water

7.4.1 Introduction

Roadway watering is the most commonly used method of reducing dust emissions in the mining industry. Nearly all mines in the nation apply water at some time during the year to their unpaved roads to reduce fugitive dust emissions. Water usually must be removed from surface mines for efficient material extraction. Many surface mines must pump out water which collects from runoff and seepage into the mined areas. Many operations in the processing plants discharge water as a waste by-product. The water pumped out of the mines or discharged from processes usually has a high suspended solids content. Because of this, settling ponds are constructed on mine sites so the large particles may settle before the water is discharged from the plant property. These settling ponds are usually the source of water for roadway dust control.

7.4.2 Application Procedures

The required amount and frequency of applying water to unpaved roads is dependent on a number of factors primarily related to evaporation phenomena. A few of these include cloud cover, ambient temperature, relative humidity, wind speed, days since last rainfall, density of roadway wearing surface, particle size of wearing surface, frequency of roadway traffic, and types of traveling vehicles. For example, hot, dry, windy days will require a greater commitment toward roadway watering than cloudy, cool days. Roadways with a densely compacted surface may require more water than a surface of less compaction due to the reduction of the ability of water to penetrate through a well-compacted surface. Also, road surfaces with a high clay content will require less water since clays swell when wet, disturbing both the wearing surface and creating a slippery road surface.

Table 30 presents an equivalency table relating inches of rainfall to the identical amount of water which must be applied by a water truck expressed on a gallon-per-square-yard basis. From this table, one can determine the application density of water required to equal a rainfall amount that is known to reduce dust emissions for a certain time period during the year.

Table 31 presents the number of gallons of water (or any other dust suppressant) required for a given application density per road mile for various road widths. This table illustrates the amount of water required per road mile to achieve the equivalent rainfall amounts presented in Table 30.

Most mines typically water roads at an application density of less than 0.03 and up to 0.5 gal/sq yard. Application densities below this range are marginally effective, while application densities above the range result in either water running off the surface or water pooling on the surface, which in time will weaken the road structure.

A mine visited during this study had a road watering program objective of applying 0.056 gal/sq yard or the equivalent of 0.01 in. of rain hourly to the road surface during the dry periods of the year.[29] This application effort provided a high control efficiency. The mine was using two 12,000-gal. water trucks to cover approximately 4 miles of haul roads. Both trucks operated during the day and evening shifts while one truck operated during the midnight shift. It was estimated that overall the mine watering program was 70% effective in reducing dust expressed on an annual basis.

7.4.3 Associated Costs

Since water is a relatively "free" product at mines, no product cost data are presented.

TABLE 30. EQUIVALENCY OF RAINFALL TO APPLICATION BY WATER TRUCK

Inches of rain	Equivalent gallons/sq yard
0.005	0.028
0.01	0.056
0.02	0.112
0.03	0.168
0.04	0.224
0.05	0.281
0.06	0.337
0.07	0.393
0.08	0.449
0.09	0.504
0.1	0.561
0.2	0.112
0.3	0.168
0.4	2.24
0.5	2.81
0.6	3.37
0.7	3.93
0.8	4.49
0.9	5.04
1.0	5.61

$$1 \text{ in. of rain} = \frac{1 \text{ in. of rain} \times 7.48 \text{ gal/cu ft} \times 9 \text{ sq ft/sq yard}}{12 \text{ in/ft}} = 5.61 \text{ gal/sq yard}$$

TABLE 31. GALLONS OF WATER REQUIRED PER MILE FOR VARIOUS ROAD WIDTHS AND APPLICATION DENSITIES

Application density (gal/sq yard)	Road width (ft)					
	1	20	40	60	80	100
	gal/mile	gal/mile	gal/mile	gal/mile	gal/mile	gal/mile
0.05	29.4	587	1,176	1,764	2,352	2,940
0.10	58.7	1,173	2,348	3,522	4,696	5,870
0.25	147	2,940	5,880	8,820	11,760	14,700
0.50	293	5,867	11,720	17,580	23,440	29,300
0.75	440	8,800	17,600	26,400	35,200	44,000
1.00	587	11,733	23,480	35,220	46,960	58,700
1.25	733	14,667	29,320	43,980	58,640	73,300
1.50	880	17,600	35,200	52,800	70,400	88,000
1.75	1,027	20,533	41,066	61,599	82,132	102,665
2.00	1,173	23,467	46,934	70,401	93,868	117,335
2.25	1,320	26,400	52,800	79,200	105,600	132,000
2.50	1,467	29,333	58,666	87,999	117,332	146,665
2.75	1,163	32,267	64,534	96,801	129,068	161,335
3.00	1,760	35,200	70,400	105,600	140,800	176,000

7.4.4 Performance

Advantages/Disadvantages

The following advantages are associated with roadway watering:

1. The water usually is a free commodity at the mines.

2. The water has no detrimental effect on humans or plants.

3. The water aids in the compaction of the road surface.

4. Roadways are easier to grade when wet.

5. Water does not adversely affect the mined materials as they are processed.

The following disadvantages are associated with roadway watering:

1. Roadway wearing surfaces may swell and become slick with the application of water because they have a high percentage of clay materials.

2. This control measure is effective only over a short time period.

3. It is labor intensive, involving regular watering and grading personnel.

4. Vehicles will track mud onto paved surfaces, creating a subsequent fugitive dust problem.

5. If watered in the winter, roads are potentially hazardous due to ice formation.

Durability

Road watering is a short-lived control measure. At best, a single application can be effective for a day if it is accompanied by a cool, cloudy day and high relative humidity. At worst, it can be effective for only a half-hour on a hot, dry day with low relative humidity.

Typically, roads need to be watered hourly during the day in summer and during part of the spring and fall. During the winter, depending on ambient conditions, heavily traveled roads may need to be watered only once a day.

Control Efficiency

Very few test data pertaining to the control efficiency of road watering in reducing dust emissions are available. One source reports a control efficiency of 50% for unpaved road watering based on watering construction site roadways twice a day but the determination of the value is vague.[30]

Because of the lack of control efficiency data, approximations of control efficiencies, determined by the project team, have been utilized.

It is estimated over a period of 1 year on mine access roads that watering can achieve a control efficiency of 70%. This control efficiency is related to an annual application density of 0.05 gal/sq yard. Water is applied every 2 hr during the summer, every 3 hr during the spring and fall, and once every 2 days in the winter. This application rate is specified for the hypothetical coal mine near Gillette, Wyoming.

On mine haul roads, over a period of 1 year watering is estimated to have a control efficiency of 75%. This value is dependent on an initial annual application density of 0.05 gal/sq yard. Water is applied to the haul roads once an hour during the summer, once every 2 hr during the spring and fall, and once a day during the winter.

7.4.5 Cost Effectiveness

The following cost-effectiveness analysis for watering is based on a hypothetical coal mine near Gillette, Wyoming, having 2 miles of haul roads and 3 miles of access roads within the plant.

The following data are used in the cost-effectiveness analysis.

Emission Factor

The same uncontrolled fine particulate factors that were used in Section 7.1.5 are used in this analysis: (a) 15 lb/VMT for vehicles traveling on haul roads and (b) 2 lb/VMT for vehicles traveling on access roads.

Source Extent

The source extent data are also similar to the data used in Section 7.1.5. The data include: (a) 262,800 VMT for haul roads and (b) 525,600 VMT for access roads.

Uncontrolled Emissions Data - Fine Particulate

The annual emissions determined in Section 7.1.5 are: (a) 1,971 tons/year for haul roads and (b) 526 tons/year for access roads.

Control Efficiency

- Haul roads = 75% annual; see "Control Efficiency" section above.

- Access roads = 70% annual; see "Control Efficiency" section above.

Emissions Reductions

As per Section 7.1.5:

- Haul roads = 1,478 tons/year reduced.
- Access roads = 368 tons/year reduced.

Annual Operating Cost

From the previous discussions, it is evident that the haul road watering program requires more effort than does the access road program. The split of this effort is estimated to be 80% haul and 20% access. On an annual basis, for the day and evening shifts, one water truck driver and one accompanying grader operator are needed for the overall dust control program. For the midnight shift, an equivalent of one operator is required. This equates to five annual full-time employees required for the watering dust control program. At $30,000 a year cost per employee, the total is $150,000. Of this amount, approximately $120,000 is attributed to the haul roads and $30,000 is attributed to the access roads.

Annual Operating Cost Effectiveness

- Haul Roads
  - $120,000 expended per year for dust control.
  - 2,956,000 lb (1,478 tons) of fine particulate emissions reduced per year.
  - $120,000 ÷ 2,956,000 lb = $0.041/lb.
  - $0.041 expended per pound of fine particulate emissions reduced.
- Access Roads
  - $30,000 expended per year for dust control.
  - 736,000 lb of fine particulate (368 tons) reduced per year.
  - $30,000 ÷ 736,000 lb = $0.041/lb.
  - $0.041 expended per pound of fine particulate emissions reduced.
- Total Mine Roadway Dust Control
  - $120,000 expended annually for haul roads.
  - $30,000 expended annually for access roads.

- 2,956,000 lb of haul road dust reduced.
  736,000 lb of access road dust reduced.
  3,692,000 total pounds reduced.

- $150,000 ÷ 3,692,000 = $0.041/lb.

The annual operating cost effectiveness of using water to reduce total mine roadway dust emissions is:

- $0.041 expended per pound of fine particulate emissions reduced.

7.5 Wetting Agents

7.5.1 Introduction

Wetting agents or surfactants can be used to extend the effect of roadway watering. By itself, water is poor as a dust suppressant due to its high surface tension. However, through the additions of wetting agents, the surface tension of water is reduced, thereby promoting the following advantages.[31]

1. Allowing particles to penetrate the water droplet and, thus, exposing a large water surface.

2. Agglomerating particles in the droplet.

3. Increasing the number of droplets per unit volume, the surface area, and the contact potential through increased efficiency of atomization.

4. Causing the liquid to wet faster and deeper and to spread farther, the main advantage of using wetting agents with water for roadway dust control.

None of the mines contacted in this study were currently using wetting agents. A few mines had used these products briefly in the past, however, and reported satisfaction with the products. The main reason given for dropping them was that the wetting agents did not reduce the cost of the roadway watering effort enough to be a viable control measure.[32]

The following analysis of wetting agents is brief and only approximate, due to the limited information available on the subject.

7.5.2 Application Procedures

Table 32 presents the application procedures for two wetting agents. The product SC-100, distributed by Compaction Engineering, is currently being used in California to reduce dust from logging roads and construction site roadways.[33] Sanafax 299, manufactured by Oxford Chemical Company, was used briefly to treat stone quarry roadways.[32]

TABLE 32. WETTING AGENT APPLICATION PROCEDURES

Company/product	Initial application procedures: Road surface preparation	Initial: Dilution ratio (gal. H_2O:gal. product)	Initial: Density (gal. solution/sq yard)	Initial: Finishing procedures	Subsequent application procedures: Road surface preparation	Subsequent: Dilution ratio (gal. H_2O:gal. product)	Subsequent: Density (gal. solution/sq yard)	Subsequent: Finishing procedures
Compaction Engineering SC-100	Blade away loose surface dust	10,000:1-3[a]	b	b	Blade away loose surface dust	10,000:0.5[c]	b	b
Oxford Chemical Sanafax 299	b	2,500:0.5-1[d] 2,500:1-2[f]	b	b	b	e	b	b

[a] 1 gal. required for noncompacted surface; 3 gal. required for well-compacted surfaces.

[b] None specified; assume normal road watering activities.

[c] After 2 or 3 months application of 10,000:1-3 dilution.

[d] Loose noncompacted soil.

[e] No information supplied; assume same as initial.

[f] Compacted soil.

7.5.3 Associated Costs

Table 33 presents example cost data for the two wetting agents.

TABLE 33. WETTING AGENT COST DATA

Company product	Purchase cost ($/gal.)
Compaction Engineering SC-100	5.40[a]
Oxford Chemical Sanafax 299	8.10[a]

a Product is shipped in 55-gal. drum. No shipping costs were provided by the vendors.

7.5.4 Performance

Advantages/Disadvantages

The advantages associated with wetting agents are listed in the Introduction of this section. The primary advantage is their ability to penetrate and wet the road surface to a greater extent than water. Instead of wetting only the road surface, the treated water also wets a few inches of the subsurface. Evaporation can quickly remove the surface moisture; however, with the treated subsurface, capillary action between the moist subsurface and dry surface layer replaces the lost surface moisture. Thus, the penetrating characteristic of the wetting agent aids in producing a water reservoir effect, keeping the road surface moist.

It is also reported that once a road has been treated with wetting agents, the residual agent effect on the road surface can incorporate the moisture from morning dew into the road surface.[33]

Product disadvantages are similar to those for water.

Durability

Very little information could be obtained on assessing the relative durability of wetting agents. One individual mentioned that the addition of wetting agents can extend the usefulness of road watering by 33%,[33] while another individual stated a value of 50%.[32] However, no test data were provided to substantiate these claims.

Control Efficiency

No test data have been reported on assessing the relative control efficiency of wetting agents. For this study, no attempt has been made to judge the control efficiency directly. However, because of the ability of the material to replenish reduced surface moisture by capillary action from the subsurface, it is assumed that fewer watering trips are needed to achieve the control efficiencies presented in Section 7.4.4 for roadway watering. This reduced manpower effort is reflected in the following cost-effectiveness analysis.

7.5.5 Cost Effectiveness

The following cost-effectiveness analysis for wetting agents is based on a hypothetical coal mine near Gillette, Wyoming, having 2 miles of haul roads and 3 miles of access roads within the plant.

The following data are used in the cost-effectiveness analysis:

Emission Factor

The same uncontrolled fine particulate emission factors used in Section 7.1.5 are used in this analysis: (a) 15 lb/VMT for vehicles traveling on haul roads and (b) 2 lb/VMT for vehicles traveling on access roads.

Source Extent

The source extent data are also similar to the data used in Section 7.1.5. The data include: (a) 262,800 VMT for haul roads and (b) 525,600 VMT for access roads.

Uncontrolled Emissions Data - Fine Particulate

The annual emissions determined in Section 7.1.5 for the mine roads are (a) 1,971 tons/year for haul roads, and (b) 526 tons/year for access roads.

Control Efficiency

- Haul roads = 75% annual.
- Access roads = 70% annual.

Emissions Reductions

As per Section 7.1.5:

- Haul roads = 1,478 tons/year reduced.
- Access roads = 368 tons/year reduced.

Annual Operating Cost

. Manpower Costs

The same basic rationale used for determining road watering annual operating costs is used to assess wetting agents. However, because of the effect wetting agents have on extending the ability of water to keep the road surface moist, it is assumed for the purpose of this analysis that no midnight shift road watering is required with the use of wetting agents.

This reduces the number of annual full-time employees required for the watering program from five to four. As a result, an overall annual reduction of $30,000 is achieved relative to the road watering program. Thus, $120,000 is spent annually for the entire program, of which $96,000 is attributed to haul roads and $24,000 to access roads.

. Product Costs

Annually, 710 and 203 gal. of wetting agent SC-100 are needed to control haul roadway and access roadway dust emissions, respectively. The annual cost at $5.40/gal., exclusive of transportation costs, is $3,834 for haul roads and $1,096 for access roads.

. Total Annual Operating Cost

- Haul roads = $98,834.
- Access roads = $25,096.

Annual Operating Cost Effectiveness

. Haul Roads

- $98,834 expended per year for dust control.
- 2,956,000 lb (1,478 tons) of fine particulate emissions reduced per year.
- $98,834 ÷ 2,956,000 lb = $0.033.
- $0.033 expended per pound of fine particulate emissions reduced.

. Access Roads

- $25,096 expended per year for dust control.
- 736,000 lb of fine particulate (368 tons) reduced per year.
- $25,096 ÷ 736,000 lb = $0.034 lb.
- $0.034 expended per pound of fine particulate emissions reduced.

- Total Mine Roadway Dust Control

  - $98,834 expended annually for haul roads.
  - $25,096 expended annually for access roads.
  - $123,930 total annual expenditures.
  - 2,956,000 lb of haul road dust reduced.
736,000 lb of access road dust reduced.
3,692,000 total pounds reduced.
  - $123,930 ÷ 3,692,000 = $0.034 lb.

The annual operating cost effectiveness of using a wetting agent to reduce total mine roadway dust emissions is:

- $0.034 expended per pound of fine particulate emissions reduced.

8.0 COMPARATIVE EVALUATION OF DUST SUPPRESSANTS

This chapter outlines recommended roadway dust control strategies as a function of road structure classification. In addition, a summary of the cost-effectiveness of the most commonly used roadway dust suppressants is presented.

8.1 Dust Control Strategies for Various Road Classifications

Table 34 presents a brief description of the recommended types of road dust control techniques which should be used as related to specific properties of the road structure. These properties include: (a) combined subgrade CBR, (b) wearing surface silt and clay content, and (c) wearing surface Los Angeles Abrasion Loss. Because of the lack of quantifiable background data, these recommended strategies should be considered as general guidelines.

The following points form the basis for the recommendations in Table 34.

1. Longevity and effectiveness of control technology is enhanced by (a) a strong combined subgrade and base (CBR > 80), (b) a medium wearing surface silt and clay content (4 to 8%), and (c) a low abrasion loss (Los Angeles Abrasion ratio < 15%).

2. Dust suppressants used to form long-lasting adhesive bonds in the surface material display minimal effectiveness after a short time when applied to roads with a weak combined subgrade and base strength.

3. Wearing surfaces with a low silt and clay content provide a minimal surface area for adhesive bonds to perform properly and are expected to provide limited effectiveness.

4. Wearing surfaces with a high silt and clay content are expected to flex to such an extent that adhesive bonds formed by chemical dust suppressants will be quickly broken.

5. Wearing surfaces with a high silt and clay content can become slippery if overwetted.

6. Wearing surfaces with a high abrasion loss, and consequently, a low resistance to grinding will fracture and will produce high silt and clay contents. Treating such a road with a chemical dust suppresssant to reduce dust will be circumvented in a short time by the production of a new untreated dust layer.

As a general rule, the weaker the road structure the less effective the longer term binding properties of materials such as lignin sulfonate or petroleum resins will prove. This is due to the weak road structure causing destruction of the stabilized roadway surface. The only materials useful in these weak structures are water or salts. A greater degree of application intensity and road maintenance is associated with weak road structures.

TABLE 34. RECOMMENDED ROADWAY DUST CONTROL TECHNIQUES AS A FUNCTION OF VARIOUS ROADWAY PROPERTIES

Road property	Recommended control techniques
1. Combined subgrade and base CBR	
. Weak (< 60%)	Avoid chemical treatments such as lignin sulfonates or petroleum resins. Use water, wetting agents, and salts.
. Average (60-80%) . Strong (> 80%)	Use most cost-effective controls for the given area where the mine is located.
2. Wearing surface silt and clay content	
. Low (0-4%)	Avoid chemical treatments such as lignin sulfonates or petroleum resins. Use water only.
. Medium (4-8%)	Use most cost effective controls for the given area where the mine is located.
. High (> 8%)	Avoid chemical treatments such as lignin sulfonates or petroleum resins. Use water, wetting agents, and salts. Do not overapply water or wetting agents.
3. Wearing surface Los Angeles Abrasion Loss	
. Low (< 15%) . Medium (15-30%)	Use most cost effective controls for the given area where the mine is located.
. High (> 30%)	Avoid chemical treatments such as lignin sulfonates or petroleum resins. Use water, wetting agents, and salts.

In summary, it should be emphasized that a successful road dust control program is directly related to the performance properties of the roadway structure.

8.2 Road Dust Suppressant Cost Effectiveness

The relative annual operating cost effectiveness was the measure used in this study to quantify the differences between the roadway dust suppressants used most commonly in the surface mining industry. Table 35 presents the information as developed in Section 7.0.

TABLE 35. DUST SUPPRESSANT COST EFFECTIVENESS

Material	Annual operating[a] cost effectiveness ($/lb)	($/kg)	Annual operating cost[b] ($)
Calcium chloride	0.051	0.0231	188,000
Lignin sulfonate	0.038	0.0172	141,000
Petroleum resins	0.026	0.0118	97,000
Water	0.041	0.0186	150,000
Wetting agents	0.034	0.0154	124,000

a Dollars expended per unit weight reduction in fine particulate (< 5 µm in diameter) emissions.

b The annual operating cost (manpower and product costs) necessary to control dust from 3 miles of access roads and 2 miles of haul roads.

Because the information presented in the table is based on approximate data, the results must be reviewed in that light. However, the information presented does show a spread of about a factor of 2 in cost effectiveness between the various materials. Although in this analysis the petroleum resin product is the most cost-effective dust suppressant, future decontrol of American oil prices would most likely influence the cost of this petroleum by-product dust suppressant. Besides product cost changes, other factors such as shipping costs, specific road conditions, traffic conditions, climate, and different application procedures could affect the cost effectiveness of all these materials both in an absolute sense and relative to each other.

This analysis does show that roadway watering is one of the least cost-effective control measures due to its ineffectiveness over a reasonable length of time and its labor intensity.

9.0 CONCLUSIONS

The following conclusions have been derived from this investigation.

1. Roadway dust emissions constitute the largest source of particulate at surface mines. Emission inventories of mining operations show that mine roadway dust emissions range from about 50 to 90% of the particulate emissions.

2. Governmental regulations requiring the control of fugitive dust at surface mines are not well developed. The most specific regulations are those from the Office of Surface Mining, requiring that fugitive dust control plans be submitted.

3. Although over 30 products have been used for road dust control, sparse quantitative data are available for the assessment of roadway dust control techniques.

4. Criteria for selecting a proper roadway dust suppressant are strongly related to the performance properties of the road structure. A well constructed road is necessary to realize optimum control from a dust suppressant. Poorly constructed roads do not favor use of even the most effective dust suppressants.

5. Road watering was shown to be one of the least cost-effective control measures.

6. A successful road dust control program is related to:

   a. The performance properties of the road structure.

   b. The knowledge the mine operator has pertaining to dust suppressant performance characteristics.

   c. The manner in which the dust suppressant is applied to the roadway and maintained.

   d. The type and frequency of vehicular traffic over the road surface.

10.0 RECOMMENDATIONS

The generation of dust from vehicles traveling on unpaved mine roadways is the largest source of particulate emissions at surface mines. Although a number of control techniques are used to mitigate this dust, little quantitative information is available to assess the merits of the various control techniques. This chapter presents recommendations to alleviate the problem of inadequate assessment data.

10.1 Additional Research

The cost-effectiveness analyses presented in Section 7.0 can be strengthened only by obtaining valid quantitative field performance data on the dust suppressants used in the mining industry. The acquiring of this information could be performed by: (a) close monitoring over a period of time a number of mine dust control programs throughout the industry, and (b) field testing to quantify the decay rate of the control efficiency of the various control measures.

10.1.1 Field Monitoring of Dust Control Techniques

During this study, it was evident from the site visits and telephone conversations with mining personnel that a wide range of information concerning dust control programs exists within the industry. Information concerning these programs, however, has not been properly documented within the industry, which leads to problems in assessing control programs.

One measure proposed to alleviate this problem is to request periodic information from a number of mines concerning their roadway dust control programs. This request would be in the form of a monthly questionnaire mailed to at least four mines with similar products (coal, crushed stone, taconite, copper). Information requested on the monthly questionnaire would be related to the amount of dust suppressant placed on their roadways during the previous month, the costs associated with the program during that month, and observed product performance characteristics.

Before beginning the monthly questionnaires, the initial survey of the roadway control program at each mine would be performed. This survey would seek information concerning: (a) the extent of roadways within the mine, (b) the type and frequency of vehicles traveling on the roadways, (c) physical properties related to the construction of the mine roadways, and (d) equipment and application procedures associated with the control method utilized at the mine.

The collection of this type of information over a period of at least one year is necessary to strengthen future cost-effectiveness evaluations. By requesting information from a number of different types of mines, a more thorough data base across industry lines will be realized.

10.1.2 Control Efficiency Testing

The parameter which currently has the least confidence associated with it in the cost-effectiveness analysis is the actual control efficiency of the dust suppressants. Little work has been performed in the past to quantify this parameter.

While data relating to labor, equipment, and product costs can be documented by mine personnel, the determination of control efficiency through quantitative means requires an effort which most mines would not be willing to perform. The effort would require periodic dust measurements downwind of a treated roadway to measure the decay in dust suppressant control efficiency versus time and application procedure.

Through the exposure profiling source quantification technique, emission factors can be determined at different levels throughout the control efficiency decay period. These emission factors can be made specific to a number of particle sizes. In addition, the properties controlling dust emissions from the roadway wearing surface can be measured in the field. These properties include: (a) combined subgrade and base CBR, (b) silt content of wearing surface, and (c) Los Angeles Abrasion Loss of the wearing surface.

This control efficiency information is necessary to adequately quantify the effectiveness of dust suppressants. In addition to improving confidence in future cost-effectiveness analyses, this information is necessary to quantify the contribution of haul roads to the annual emissions emanating from surface mines. This information is useful for emission inventories, air quality modeling, PSD review, and for air quality permits.

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APPENDIX A

GOVERNMENTAL CONTROL AGENCY CONTACTS

This appendix summarizes the contacts made concerning governmental regulations pertaining to fugitive dust. Table A-1 lists the agency contacted, the person in that agency who was contacted, their telephone number, and the course of action taken.

TABLE A-1. - CONTACTS WHO SENT INFORMATION PERTAINING TO FUGITIVE DUST REGULATIONS

Agency (states)	Person contacted	Title	Phone number	Course of action
California Air Resources Board (ARB)	Gary Aggat	Chief of Implementation	(916)-322-2990	No regulations yet proposed for fugitive dust.
Colorado Air Pollution Control Division	Steve Donahue	Engineer	(303)-302-8333	Sent regulations.
Florida Department of Environmental Regulation	John Syms	Engineer	(904)-488-1344	Sent regulations.
Illinois Department of Air Pollution Control	John Reed		(217)-782-7326	Information requested but never received.
Indiana State Board of Health	Susan Brambert	Section Chief, Air Quality	(317)-633-0600	Sent permits and regulations.
Kansas Department of Health and Environment	Ray Bergen	Engineer, Air Quality	(913)-862-9360	Sent regulations.
Kentucky Department of Air Pollution Control	Marty Hall	Engineer	(502)-564-6844	SIP regulations sent.
Maryland Bureau of Air Quality	Ralph Hall	Engineer	(301)-383-3147	SIP regulations sent.

TABLE A-1. - (continued)

Agency (states)	Person contacted	Title	Phone number	Course of action
Minnesota Pollution Control Agency	William Rottschaefer	Engineer	(612)-296-7272	SIP revision sent.
Missouri Department of Natural Resources	John Hoss		(324)-751-3241	Regulations sent.
New Mexico Environmental Improvement Division	Warren Slade	Chief Engineer	(505)-827-5271	Regulations sent.
Montana Department of Health and Environmental Sciences	Bob Raisch	Engineer	(406)-419-3454	Regulations sent.
North Dakota Department of Health	Bob King		(701)-224-2371	Regulations and SIP revision sent.
Pennsylvania Bureau of Air Quality	Charles Benson	Engineer	(717)-787-4310	Regulations sent.
Wyoming	Bernie Dailey	Engineer	(307)-777-7391	Regulations sent.
(Federal)				
EPA, Kansas City, Missouri (Region VII)	Craig Smith	Engineer	(816-374-3791	PSD & NSPS information sent..
MSHA	Mr. Lucas		(314)-364 8282	Informed about MSHA regulations.

APPENDIX B

SUMMARY OF STATE FUGITIVE DUST REGULATIONS AND HAUL ROAD REGULATIONS AS OF AUGUST 1979

Alabama

General regulations: Owner or operator shall take reasonable precautions to prevent dust from becoming airborne. Visible fugitive emissions are not permitted beyond property line. Abatement by A, B, C of federal model.

Haul road regulations: None

Arizona

General regulations: Owner or operator shall take reasonable precautions to prevent dust from becoming airborne. Abatement by A, C, D, E, G, of federal model plus wetting or covering of loads in transport.

Haul road regulations: None

California

General regulations: Fugitive regulations are at the discretion of each air quality control region (AQCR). Study projects are currently being evaluated to determine applicable fugitive dust regulation in each AQCR.

Haul road regulations: None

Colorado

General regulations: For open mining a permit must be submitted which requires description of sources, fugitive dust control plans, time schedule for implementation thereof, and description of monitoring methods.

Dust control plan: For mines, requires wetting, landscaping, and replanting with native vegetation, covering, shielding or enclosing the area, paving, chemical stabilization of mud-carryout onto improved streets, disturbing less topsoil and reclaiming as soon as possible, sequential blasting, and haulage equipment to be washed, wetted down, or covered to minimize dust.

Other sources: Twenty percent opacity may not be exceeded when observed sights along a line not crossing the property line. Unpaved roads with ADT greater than 165, must apply above control measures. Earth and construction material moving, same as above. Demolition, wrecking, and explosives--permit and dust control plan as above.

Haul road regulations: Fugitive dust control plan above which includes paving, chemical stabilization, detouring or speed control. Also, haulage equipment must be covered or washed. These regulations are similar to those of OSM (see next section).

Florida

General regulations: Owner or operator of resource must meet PSD requirements (see federal regulations) and visible emissions of fugitive dust are not permitted past property line for existing or new sources.

Haul road regulations: None

Georgia

General regulations: Owner or operator shall prevent dust from becoming airborne. Abatement by A, B, C, D, and G of federal model.

Haul road regulations: None

Indiana

General regulations: An allowable particulate standard and respirable particulate standard may not be exceeded and visible restrictions are placed on fugitive emissions. Mobile sources may not cause fugitive dust. Exceptions are: adverse meteorological conditions; publicly maintained unpaved roads; demolition and construction if reasonable precautions undertaken; agricultural activities; plumes from stacks or chimneys; and uncombined water.

Haul road regulations: None

Kansas

General regulations: Dust may not exceed 20% opacity, and ground-level particulate concentrations at the property line may not exceed 2.0 mg/cu m above background for any time period aggregating more than 10 min during any hour.

Haul road regulations: None

Kentucky

General regulations: Owner or operator shall take reasonable precautions to prevent dust from becoming airborne. Abatement by all of federal model plus: (1) open bodies trucks must be covered when in motion; (2) agricultural activities shall not create a nuisance to others in the area; (3) numbers (1) and (2) do not apply to temporary blasting or construction; and (4) no one shall allow mud-carryout onto a paved street.

Haul road regulations: None

Maryland

General regulations: Owner or operator shall take reasonable precautions to prevent dust from becoming airborne. Abatement by federal model, with agricultural practices exempt.

Haul road regulations: None

Minnesota

General regulations: Owner or operator shall prevent avoidable amounts of particulate from becoming airborne. Abatement by paving or frequent cleaning of roads, driveways, or parking lots; and planting and maintenance of vegetative groundcover.

In the Minneapolis-St. Paul, Duluth, and International Falls areas, the following must be done (nonattainment areas):

1. Materials transport - watering, application of dust suppressant, or covering the load.
2. Building opening - may not exceed 5% opacity.
3. Storage piles - if greater than 100,000 tons/year of material, then must enclose and spray with water or dust suppressants; and utilize telescopic chutes to minimize fall of materials or use spray systems.

4. Access areas, roads, or parking facilities - all areas and roads paved or treated with dust suppressants. All paved roads cleaned to minimize dust.

5. Materials handling - use of water or dust suppressants; minimize disturbance of the pile.

6. Materials transfer - visible emissions may not exceed 10% opacity.

7. Any other operation - may not exceed 10% opacity.

8. Sand blasting - reasonable measures such as water injection, enclosing, or vacuuming.

9. Construction and demolition - reasonable measures such as watering or treating with dust suppressants.

10. Exemption - Numbers (6) and (7) above do not apply when average 1-hr wind speed exceeds 25 mph.

Haul road regulations: Control fugitive dust by paving or treating with dust suppressants as required by (4) above.

Missouri

General regulations: The following standards may not be exceeded: fugitive dust may not be visible at property line and particulate matter not permitted larger than 40 μm in diameter. Abatement by: frequent cleaning of roads; application of dust-free surfaces; application of water and planting and maintenance of vegetative groundcover.

Haul road regulations: None

Montana

General regulations: No "controllable" particulate matter may be emitted. Abatement by specific measure ordered by the Director.

New Mexico

General regulations: None

Haul road regulations: Haulage roads are to be sprayed or treated where reasonably necessary to prevent particulate matter from becoming airborne.

North Carolina

General regulations: None

Haul road regulations: All sand, gravel, and crushed stone plants and light-weight aggregate process access roads must be maintained by paving, oil treatment, or other suitable measures; crushers must employ water spray. No ambient air quality standards may be exceeded at the property line.

North Dakota

General regulations: Reasonable precautions must be taken by the owner or operator to prevent dust from becoming airborne and particulate matter may not exceed 240 μg/cu m 8 hr average above background at property line; or may not exceed ambient air quality standards at property line; or exceed PSD increments; or exceed visible restrictions; agricultural practices exempt.

Abatement by specific source category:

1. Unpaved roads and parking areas - frequent wetting, addition of dust palliatives, detouring, paving, closure, speed control, or surface treatment with penetration chemicals is required.

2. Demolition, wrecking, earth and construction, mining and excavation: (a) wetting down, (b) landscaping, (c) covering, shielding or enclosing, (d) paving, (e) treating, use of dust palliatives or chemical stabilizers, (f) detouring, (g) speed restrictions, (h) prevention of mud or dust carryout onto paved roads, (i) minimize topsoil disturbance and reclaim as soon as possible, (j) sequential blasting employed, (k) revegetation, surface compaction and sealing, (l) haulage equipment washed or wetted down, treated or covered when necessary to minimize amount of airborne dust, (m) stockpiled materials treated or contained in enclosures, (n) waste disposal sites operated and constructed to prevent airborne particulates, (o) conveyor and transfer points, crushers, and screens and dryers treated to prevent airborne particulates, and (p) appropriate measures used during nonwork days.

<u>Haul road regulations</u>: As in (d), (e), (f), and (g) above in mining regulations, owner may either pave, treat with chemicals, detour, or restrict speed of the haul trucks.

Pennsylvania

General regulations: Owner or operator shall prevent dust from becoming airborne. Abatement by use of water or chemicals for control of dust in demolition, construction, grading of roads or clearing of land; application of asphalt, oil, or water; paving and maintenance of roadways; and prompt removal of earth from paved streets; agricultural activities are exempt.

Haul road regulations: None

West Virginia

General regulations: None

Haul road regulations: For coal and coal handling operations, owners or operators must have fugitive dust control system and demonstrate dust control of the premises and roads by paving or other suitable measures. Good operating practices shall be observed in relation to stockpiling, car loading, breaching, screening, and general maintenance to minimize dust generation.

Wyoming

General regulations: Owner or operator shall prevent particulates from becoming airborne. Abatement by federal model.

Haul road regulations: Surface coal mines are required to show and calculate all emissions; demonstrate air quality impact by modeling; and show all control equipment. Haul roads are traditionally controlled to prevent modeling from showing any violations.

APPENDIX C

PROGRAM BIBLIOGRAPHY

This appendix presents the bibliography compiled by the literature search.

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APPENDIX D

PROGRAM SCOPE OF WORK AND INFORMATION NEEDS

This appendix presents the content of the program scope of work and information needs requested from trade associations, mining companies, and researchers as detailed in Sections 4.2 to 4.4.

PROGRAM SCOPE OF WORK

Program Title	"Dust Control For Haul Roads"
Program Sponsor	U.S. Bureau of Mines Twin Cities Mining Research Center
U.S. B.M. Project Officer	H. William Zeller (612) 725-4600
Contractor	Midwest Research Institute (MRI)
MRI Project Leader	Russel Bohn (816) 753-7600
Project Objective	Establish technical guidelines for the mining industry on methods for selecting and implementing cost effective dust controls for haul roads. The program is divided into two phases.
Phase I	Conduct State of the Art Survey
Task 1	Conduct Information Search Purpose: Gather all known information pertaining to dust control measures for unpaved roads. A subtask consists of identifying past, current and planned research programs conducted by the mining industry and government dealing with fugitive dust sources other than haul roads within the surface mining industry.
Task 2	Characterize Mine Roadways Purpose: Identify road categories for which specific dust control techniques can be recommended.
Task 3	Assess Governmental Regulations Purpose: Summarize current and pending governmental regulations pertaining to fugitive dust control in the surface mining industry.

Task 4	Determine Control Effectiveness Criteria Purpose: Evaluate the cost effectiveness of road dust control techniques.
Task 5	Prepare Phase 1 Report Purpose: Prepare written summary of the state-of-the-art of unpaved roadway controls.
Phase II	Prepare Manual and Final Report
Task 1	Prepare Industry Guidance Manual Purpose: Prepare a manual which will provide guidelines to the mining industry on how to select and use cost effective dust controls on unpaved roads.
Task 2	Prepare Final Report Purpose: Summarize all work performed under the contract.

As part of this study, MRI will contact various mining organizations to gather information on fugitive dust controls. The following information needs are requested from mining personnel: (a) experience with dust control measures for haul roads; (b) costs associated with control techniques; (c) problems associated with control techniques; and (d) experience with dust control measures for fugitive dust sources other than haul roads.

MRI Information Needs

1. Information pertaining to road dust control measures:

   a. Control measures currently used on various road types (haul road versus access roads, etc.).

   b. Control measures used in the past and planned programs for the future.

   c. Current application methods (gallons applied per square yd, speed of vehicle, dilution ratio of dust suppressant, etc.).

   d. Frequency of application (expressed on a seasonal basis).

   e. Problems encountered with the above control techniques.

   f. Equipment utilized (type, capacity of water trucks, flow rate, etc.).

   g. Manpower requirements (number of people full time, part time, on a seasonal basis).

   h. Cost data (initial capital equipment cost, annual operating cost, annual manpower cost, annual fuel/vehicle maintenance costs, cost of dust suppressant--product cost and shipping cost).

   i. Benefits from control measures other than air quality (safety, equipment maintenance, etc.).

2. Information pertaining to unpaved roadway construction:

   a. Methods used to construct haul and service roads (type of materials used, depth of sub-base and surface aggregate, incorporation of dust suppressant with sub-base/surface aggregate, compaction/grading techniques, physical properties of aggregates--size--California bearing ratio, etc.).

   b. Methods used to maintain roads (procedures and frequency).

   c. Problems associated with roadway construction and maintenance.

3. Information pertaining to vehicles traveling on haul roads:

    a. Vehicle type.

    b. Vehicle weights.

    c. Vehicle speeds.

    d. Frequency of vehicular travel on haul, access and service roads.

4. Information pertaining to environmental regulations:

    a. What regulations require the control of road dust (state and federal).

    b. How effective are these agencies in enforcing the regulations.

5. Information pertaining to past, current and planned research programs conducted by your company dealing with fugitive dust mitigation from sources other than haul roads. Dust mitigation from:

    a. Overburden soil/rock piles.

    b. Exposed area wind erosion.

    c. Product storage piles.

    d. Materials transfer activities.

    e. Blasting.

    f. Dust reentrainment from paved roadways.

APPENDIX E

MINING COMPANIES CONTACTED

Coal Industry Contacts

Organization: Bridger Coal Company, Rock Springs, Wyoming

Name of contact: Jerry Ross, Mine Superintendent

Result of contact: A mine visit was arranged at Rock Springs mine to observe their Coherex® and road watering program. The mine visit occurred on June 13, 1979.

Organization: Consolidation Coal Company

Name of contact: Richard Kerch, Air Quality Scientist

Result of contact: A mine visit to observe fugitive dust control on haul roads was performed. In conjunction with an EPA program, MRI and PEDCo, Inc., performed source tests of vehicles traveling on mine roads, material handling and blasting.

Organization AMAX Coal Company, Gillette, Wyoming

Name of contact: Lyle Randen, Environmental Engineer

Result of contact: A visit to their mine to observe their watering abatement program was arranged. The mine visit occurred on June 12, 1979.

Organization: Western Energy Company, Colstrip, Montana

Name of Contact: Chris Cull, Environmental Engineer

Result of contact: In conjunction with an EPA program, MRI and PEDCo, Inc., performed source tests of vehicles traveling on mine unpaved roads. Sources tested included (a) scrapers traveling on an untreated roadway, (b) haul trucks traveling on an untreated roadway, and (c) light and medium duty vehicles traveling on untreated (calcium chloride) segments of unpaved roads.

Crushed Stone Contacts

Organization: Gifford Hill and Company, Inc., Dallas, Texas

Name of contact: Kenneth Cole, Head - Environmental Control

Result of contact: A variety of information was obtained about their use of watering and asphalt emulsion control, their costs and other information. They are not impressed with asphalt emulsion performance and have dropped it as a control technique.

Organization: FlintKote Stone Products, Hunt Valley, Maryland

Name of contact: Richard Cole, Manager - Environmental Control

Result of contact: A visit to a quarry near Baltimore was arranged where a watering program was observed. The visit occurred on June 19, 1979.

Organization: Martin-Marietta Aggregates, Raleigh, North Carolina

Name of contact: Horace Willson, Head - Environmental Control

Result of contact: A visit to two of their quarries was arranged to observe roadway watering control roadway dust. Cost information on this program also sought. They found that wetting agents were not cost effective. Also a unique sprinkler system at one quarry is used to control road dust emissions. The visit occurred on June 18, 1979.

Organization: Monarch Cement Company, Humboldt, Kansas

Name of contact: Russell Runnels, Manager of Environmental Affairs

Result of contact: A visit was made to a quarry to observe Coherex® as a road dust control. Information was received about application densities, frequencies, problems with Coherex®, costs, and equipment used to apply Coherex®.

Organization: Vulcan Materials, Inc., Birmingham, Alabama

Name of contact: Walter Fridley, Environmental Manager

Result of contact: They have used road oil and Coherex® and found both unacceptable. They may look into calcium chloride as a control agent. Currently they are using water as a control agent.

Copper Contacts

Organization: Kennecott Copper Company, Hurley, New Mexico

Name of contact: H. A. Billings, Mine Operations Superintendent

Result of contact: They stopped using lignin sulfonate in 1960's when two trucks overturned because of slippery areas in the road. They experimented with Coherex®, but found it interferes with the copper precipitation process.

Organization: Anaconda Company, Butte, Montana

Name of contact: John Spindler, Environmental Engineer

Result of contact: As a result of a program MRI had with the State of Montana, an emissions inventory was compiled of the mine operations. Visits were made to the mine in 1978 to observe operations and to obtain control efficiency information for their road watering program.

Taconite Mine Contacts

Organizations	Personnel contacted
Butler Taconite Company	Daniel Chelton
Erie Mining Company	Jim Stanhope
Eveleth Taconite	Thomas Malojich
Hibbing Taconite	Phillip Brich
Inland Steel (Minocra)	Gregory Feld
Minntac	Paul Haotaja
National Steel Pellet Plant	Daniel Chelton

Results of contacts: As result of a program MRI had with the State of Minnesota, the mining companies in the Minnesota taconite range listed above were visited in 1978, a fugitive dust emission inventory including emissions from haul roads was completed, and control techniques for haul roads were observed and their efficiencies assessed.

Researchers Contacted

Affiliation: Iowa State University, Ames, Iowa

Person contacted: J. M. Hoover

Result of contact: He is currently embarking on a field test to determine the effectiveness of various road dust suppressants on secondary roads in Iowa. Dust control products that will be tested include: Coherex®, ammonium lignin sulfonate, and emulsified asphalt. These materials will be applied in the following manner: (a) surface application, (b) incorporation into the upper 3 to 4 in., and (c) incorporation in the subbase with a chip and seal coat. Methods of testing are to include Hi-Vol and dust fall bucket measurements.

Affiliation: IITRE, Chicago, Illinois

Person contacted: Paul Ase

Result of contact: IITRE has a program with EPA to assess asbestos emissions from waste asbestos storage piles, crushed stone, and roads. They may perform testing of uncontrolled emissions and dust suppressants during 1979.

Affiliation: U.S. Bureau of Mines, Salt Lake City, Utah

Person contacted: Dick McDonald, Engineer

Result of contact: He is researching the stabilization of tailings piles by vegetation and chemical stabilization. He is not engaged in the research of haul road dust controls. He provided information on various dust control products.

Affiliation: U.S. Bureau of Mines, Spokane, Washington

Person contacted: Les Crow

Result of contact: He is involved in safety oriented programs (use of beams and guard rails on shoulders of haul roads). He is not familiar with road dust control but did say the only program implemented at the mines that he has observed is road watering.

APPENDIX F

DUST SUPPRESSANT VENDORS

This appendix is a compilation of vendors who actively market fugitive dust suppressant products. Table F-1 provides a listing of the companies, their product marketed, its chemical type, and whether or not the company was contacted. Contact of a company in this list depended on whether they market a fugitive dust suppressant which could control haul road dust.

TABLE F-1. - DUST SUPPRESSANT VENDORS

Company name, address	Product name	Chemical type of product	Haul road product sold (yes or no)
ALCO Chemical Corporation Philadelphia, Penn.	Soil Gard	Elastomeric Polymer emulsion	Yes, but main use for agricultural stabilization.
American Can Company Greenwich, Conn.	Norlig	Calcium Lignosulfonate	Yes
American Cyanamid Company Chicago, Ill.	Super Flol 16	Flocculent	Information not available
American Cyanamid Company Wayne, N.J.	Aerospray R	Water synthetic resin	Information not available
	DCA-70	Organic polymer	
American Hoechst Corporation Someville, N.J.	Curasol	Polymer elastics dispersion	Yes
Arthur C. Trask Company Chicago, Ill.	Trastan	Lignosulfonate	Yes
Bordon Chemical Company Columbus Ohio	Vinylac	Polyvinyl acetate	No
Bordon Chemical Company Leominister, Mass.	Polyco 2607 2440	Synthetic copolymer	Yes, also stockpiles and open railcars.
Celtite, Inc. Cleveland, Ohio	Polybind DLR	Polymer	Yes
Chevron Chemical Company San Francisco, Calif.	Ortho Soil Mulch	Liquid asphalt emulsion	No
Corn Products Sales Company Englewood Cliffs, N.J.	E802 Mazofern	Fermented corn extract	No
Crown Zellerbach Company East Hanover, N.J.	Orzan	Lignosulfonate	Yes
Deter Company East Hanover, N.J.	Deter Micro Foam	Foam dust control	No
Douglas Oil Company Costa Mesa, Calif.	Agri-Mulch	Petroleum asphalt	No
Dowell Division Dowell Chemical Company Tulsa, Okla.	Latex M145 Latex M166	Latex binder	Yes
E. I. Du Pont de Nemours and Company Kentt Square, Penn.	PB-4001 Elvanol	Polymer Polyvinyl alcohol	No
Firestone Tire and Rubber Company Akron, Ohio	FRS-275	Latex in oil or water	Yes, but main use agricultural
Fire Water Company Los Altos, Calif.	Crust 500 SC-100	Polyvinyl acetate organic polymer	Yes, but main use agricultural
Foremost Foods Company San Francisco, Calif.	MNG-129	Protein	No
GAF New York, N.Y.	Gantrez AN-119 Gantrez ES-3351	Polymeric anhydride Liquid resin	No
B.F. Goodrich Chemical Company Kansas City, Mo.	Geon 652 Geon Rite 2570X1	Latexes	No

TABLE F-1. - (continued)

Company name, address	Product name	Chemical type of product	Haul road product sold (yes or no)
Henley and Company, Inc. New York, N.Y.	Huls-801	Liquid plastic	Yes, but main use for agriculture and stockpiles.
Howard Hall Company Cos Cob, Conn.	Dextrin	Dextrose	No
Hercules Inc. San Francisco, Calif.	SDX-1	Resin emulsion	Yes, but in experimental stage.
E. F. Houghton Company Philadelphia, Penn.	Rozosal	Organic polymer	Yes, but main use for stockpile.
Johnson March Corporation Philadelphia, Penn.	SB	Chain polymer	No
	MR	Wetting agent	Yes, but main use for transfer points.
Monsanto Chemical Company St. Louis, Mo.	Kriluim	Vinyl acetate	No
	CRD-186 Bidim	Fabric	Yes
National Gypsum Company Dallas, Tex.	Gypsum heme-hydrate	Same	No
National Starch and Chemical Company Bridgewater, N.J.	Floc acid	Starch	
	Natron 8	Polymer	No
	Mmylon VII	Starch	
Pacific Lumber San Francisco, Calif.	Palcotan	Redwood bark chips	No
Philadelphia Quartz, Company Valley Forge, Penn.	PQ	Sodium silicate	No
Phillips Petroleum Company Bartlesville, Okla.	Arcatice	Liquid asphalt emulsion	Yes
	Dust palliative	Residual oil	Yes
Phillips Petroleum Company Great Falls, Mont.	Various oils	Residual oil	Yes
Rohm and Haas Company Philadelphia, Penn.	Polyacrylic acid	Same	Yes, but main use for stockpiles and transportation.
Rolzhem Company Teaneck, N.J.	Sodium algenate	Same	No
Shell Chemical Company Houston, Tex.	Eposand	Polymer	No
Standard Oil Company Lima, Ohio		Petroleum resin	No
3-M Company St. Paul, Minn.	Lanolock XA 2440	Adhesive binder	No
Union Carbide New York, N.Y.	DCA-70	Elastic polymer	No
Witco Chemical Bakersfield, Calif.	Coherex®	Water emulsion of petroleum resins	Yes
Zel Chemical Company Portland, Oreg.	Road Packer	Organic sulfur in sulfonated petroleum	No

APPENDIX G

AGGREGATE MATERIALS DESCRIPTION

Crushed stone is the angular fragments resulting from crushing of rocks by mechanical means. It may be obtained from commercial sources in a variety of sizes or as a crusher-run product. Crushed stone may also be produced on or near the job by crushing suitable local quarry stone in a portable crusher. The fine material resulting from crushing rock is known as stone screenings. According to the Standard Specifications for Road and Bridge Construction of the Illinois Division of Highways, crushed stone should be produced from the following types of rocks quarried from undisturbed consolidated deposits: granite and similar igneous rocks; calcareous or dolomitic limestone; or massive metamorphic quartzite or similar rocks.

Gravel is the coarse granular material resulting from the natural disintegration of rocks by the action of elements. It occurs as a natural deposit in many localities in both glaciated and unglaciated regions. During the process of deposition, the particles are worn down and become more or less rounded in shape, with smooth surfaces. Strictly speaking, gravel includes only the mineral particles larger than sand. The term, however, is often applied to mixtures of pebbles, sand, and perhaps soil. Gravel may be procured commercially in a variety of sizes in either the crushed or uncrushed form. In most cases it is obtained by excavating local deposits.

Bank-run or pit-run gravel is a natural mixture of gravel, sand, silt and clay as it comes from a gravel bank and is of such quality that it may be used with only minor processing. The deposit is generally of glacial origin and is typically characterized by variable grading and smooth or even somewhat rounded individual particles, although angular or subangular particle shapes are common.

Stream or river gravel is a deposit of gravel, sand, and perhaps soil occurring in channels of rivers and streams. It is characterized generally by rounded particles distributed with some uniformity throughout the various size grades. River gravel contains less fine material and is looser and more sandy than a bank gravel of the same locality, since the silt and clay materials have been washed out.

Novaculite gravel is the material occurring in natural deposits, composed of angular particles of siliceous origin and mixed with clay and iron oxide.

Crushed gravel is the product resulting from the artificial crushing of gravel.

Screened gravel is the material separated from the undesirably large or fine fractions by screening. It may be screened to any desired size. No binder soil is contained in this material.

Sand is the fine granular material formed by the natural disruption or disintegration of rocks. It occurs in deposits of varying size and character depending upon the condition of formation, transportation, and deposition. Sand is usually found mixed with gravel and perhaps some soil materials. Sand found in beds or bars in streams is usually intermixed with gravel but generally free from much clay or silt.

Slag is the nonmetallic product consisting essentially of silicates and alumino-silicates of lime and other bases, which is developed simultaneously with iron in a blast furnace. It may be either air-cooled or granulated and may be obtained in a variety of sizes.

Chats are mine tailings resulting from the separation of metals from the rocks in which they occur. Chats may be obtained in some areas as waste products from mining operations and form an important source of inexpensive aggregates.