Laboratory Procedure for Measuring the Effectiveness of Dust Control Palliatives

David L. Barnes, Ph.D., P.E.
Billy Connor, P.E.
Alaska University Transportation Center
University of Alaska Fairbanks

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for

the facts and the accuracy of the information presented herein. This document is

disseminated under the sponsorship of the U.S. Department of Transportation's University

Transportation Centers Program, in the interest of information exchange. The Pacific

Northwest Transportation Consortium, the U.S. Government and matching sponsor

assume no liability for the contents or use thereof

Technical Report Documentation Page

1. Report No. INE/AUTC	2. Government Accession No. N/A	3. Recipient's Catalog No. G10259	
4. Title and Subtitle Laboratory Procedures for Measuring the Effectiveness of Dust Control Palliatives		**5. Report Date** June 12, 2017	
		6. Performing Organization Code G10259	
7. Author(s) David L. Barnes, Ph.D., P.E. Billy Connor, P.E. Alaska University Transportation Center University of Alaska Fairbanks		**8. Performing Organization Report No.** INE/AUTC 17.11	
9. Performing Organization Name and Address University of Alaska Fairbanks Alaska University Transportation Center 245 Duckering Building, 306 Tanana Dr. Fairbanks, Ak 997750-5900		**10. Work Unit No. (TRAIS)**	
		11. Contract or Grant No. 3882	
12. Sponsoring Organization Name and Address Pacific Northwest Transportation Consortium University Transportation Center for Region 10 University of Washington More Hall 112, Seattle, WA 98195-2700 United States Department of Transportation Office of the Assistant Secretary for Research and Technology		**13. Type of Report and Period Covered** Final Report	
		14. Sponsoring Agency Code DTRT13-G-UTC40	

16. Abstract

Creation of fugitive dust on unpaved roads results in the loss of up to 25 mm (one inch) of surface aggregate annually (FHWA, 1998). On these roads, shearing forces created by vehicles dislodge the fine aggregate fraction (silt and clay) that binds the coarse aggregate. Turbulent airflow created by vehicles loft these fine particles in plumes of fugitive dust that impact health, safety, and quality of life. The loss of these particles results in raveling of the road surface, culminating in large annual losses of surface aggregate. Chemical dust control (palliatives) is an attractive option. However, there are currently no accepted field or laboratory performance testing procedures for chemical road dust palliatives. The lack of a method to predict palliative performance forces engineers and road managers into a trial-and-error methodology or reliance on personal judgment and supplier claims to determine what will work best on their unpaved road or runway surfaces. The overall objective of this research was to finalize the development of a laboratory test procedure for evaluating different dust control formulations and application rates required to effectively control the airborne suspension of dust particles in the size range (aerodynamic diameter) of 10 µm or less.

17. Key Words Fmbbe,Rbmduf, Dust, Dust Control		**18. Distribution Statement** No restrictions.	
19. Security Classification (of this report) Unclassified.	**20. Security Classification (of this page)** Unclassified.	**21. No. of Pages** 18	**22. Price** NA

Form DOT F 1700.7 (8-72)   **Reproduction of completed page authorized**

Table of Contents

Figures

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet square	0.093	square meters square	m^2
yd^2	yard	0.836	meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz gal	fluid ounces	29.57		mL
ft^3	gallons cubic	3.785 0.028	milliliters	L
	feet cubic	0.765	liters	m^3
yd^3	yards	meters NOTE: volumes greater than 1000 L s	cubic meters	m^3
			ubic hall be	
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
$\circ$F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	$\circ$C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters square	10.764 1.195	square feet square	ft^2
m^2	meters		yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters cubic	35.314 1.307	cubic feet cubic	ft^3
m^3	meters		yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
$_o$C	Celsius	1.8C+32	Fahrenheit	$_o$F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inc h	lbf/in^2

1. Introduction

Creation of fugitive dust on unpaved roads results in the loss of up to 25 mm (one inch) of surface aggregate annually (FHWA, 1998). On these roads, shearing forces created by vehicles dislodge the fine aggregate fraction (silt and clay) that binds the coarse aggregate. Turbulent airflow created by vehicles lofts these fine particles in plumes of fugitive dust that impact health, safety, and quality of life. The loss of these particles results in raveling of the road surface, culminating in large annual losses of surface aggregate. Pavement is an obvious dust control method, albeit at great expense. Chemical dust control (palliatives) is an alternative option. Unlike road pavements, for which there is a long history of proven and widely accepted laboratory test methods aimed at predicting performance, there are currently no accepted field or laboratory performance testing procedures for chemical road dust palliatives. The lack of a method to predict palliative performance forces engineers and road managers into a trial-and-error methodology or reliance on personal judgment and supplier claims to determine what will work best on their unpaved road or runway surfaces. The overall objective of this research was to finalize the development of a laboratory test procedure for evaluating different dust control formulations and application rates required to effectively control the airborne suspension of dust particles in the size range (aerodynamic diameter) of 10 µm or less.

2. Background

Multiple sources contribute to the generation of dust from unpaved roads. As vehicles pass over the surfacing aggregate, the shearing forces created at the interface between the vehicle tires and the aggregate break the cohesive or apparent cohesive forces binding particles, resulting in the generation of road dust. The weight of the vehicle also results in particle-to-particle grinding as the tires rolls over the aggregate. This repetitive grinding breaks down the particles generating dust (Pinnick et al., 1985). Airborne dust from other sources (agricultural fields, unpaved lots, etc.) can settle onto the road surface, also resulting in lofting as vehicles pass. A final likely source of dust is deposition of dust attached to vehicles and vehicle tires by vehicles entering the road. These processes result in fugitive dust from unpaved roads ranging over three orders of magnitude in size (equivalent particle radius), from as small as the sub-micrometer size to several hundred micrometers (Pinnick, et al., 1985, Hinds, 1999). To put this into prospective, these particles can range from the size of fine sand to as small as particles found in smoke.

The U.S. Environmental Protection Agency estimated that unpaved roads released over 10 million tonnes of particulate matter less than 10 μm in aerodynamic size (PM_{10}) to the atmosphere in the United States in 2014 (U.S. EPA, 2017). These emissions made up 51 percent of all the emissions from stationary sources of PM_{10} air pollution in the United States. Exposure to these small particulates has associated health effects. In 2009 the U.S. EPA discussed the health effects related to short-term exposure to $PM_{10-2.5}$ (particulate matter with aerodynamic diameters of between 2.5 and 10 μm). In that study, the U.S. EPA (2009) analyzed multiple epidemiological, controlled human exposure, and toxicological studies and concluded that these studies suggested a relationship between short term exposure to $PM_{10-2.5}$ and cardiovascular effects, respiratory effects, and mortality.

Dust affects safety in two different ways. On the dustiest of roads, dense dust clouds from leading vehicles can reduce the sight distances of the following vehicles to less than safe stopping distances (FHWA, 1998), as shown in figure 2-1. Additionally, the loss of small particles that bind the surface aggregate together results in degradation of the road surface. With the loss of the fine particles that bind the aggregate, loose gravel exists on the road surface creating projectile hazards to passing and following vehicles. Loss of the binding particles as fugitive dust also results in the development of corrugations (washboards) in the road surfacing, which can result in loss of driver control.

Figure 2-1. Example of the impact of fugitive dust on a driver's sight distance.

Degradation of the road surface has economic impacts as well. As previously mentioned, FHWA (1998) noted that as much as 25 mm of surface gravel may be lost annually from dusty roads, resulting in an annual aggregate replacement of approximately 70 tonne/km. This replacement aggregate requires mining, processing, transportation, and finally placement into service, which are all costly activities. Assuming an aggregate cost of $30/tonne, replacement

4

costs may be $2,100/ km annually for unpaved roads that do not incorporate some form of dust control measures.

Managing dust from unpaved roads starts with a well-designed and constructed road. Skorseth and Selim (2000) described proper design of gravel roads, and FHWA (2015) provided guidance on the construction and maintenance of gravel roads. In some cases, gravel roads that are well designed, constructed, and maintained will have minimal dust issues. On dusty unpaved roads, institutional controls and dust control palliatives are effective means of managing dust if implemented properly. Since this study focused on developing a laboratory test for the effectiveness of dust control palliatives, we will focus our discussion on chemical control.

Several categories of chemical dust palliatives make up the complete family of chemicals. Barnes and Connor (2014) and FWHA (2015) described these groups of palliatives. We developed the laboratory test described in this report primarily to test the effectiveness of the category of dust palliatives known as synthetic fluids. However, it is possible that this test will also be applicable to other categories of dust control chemicals.

By definition, a synthetic fluid is a fluid derived through a chemical transformation process. This definition separates this fluid from the category of petroleum-based organic fluids produced by physical separation (fractionation, distillation) in the refining process. Fluids that have gone through physical separation along with a minor chemical reaction such as cracking and hydroprocessing (e.g., mineral oils) are also excluded from the class of fluids that are considered synthetic (U.S. EPA, 1996; Federal Register, 2001).

Knowing where synthetic fluids reside in the pore space is important to our understanding of how these fluids control dust. Synthetic fluids used for dust control are immiscible in water. When present in the aggregate a synthetic fluid exists as an intermediate

wetting fluid, non-wetting with respect to water and wetting with respect to air. As an intermediate wetting fluid, a synthetic fluid suppresses the creation of dust from unpaved roads by two different mechanisms. The presence of both soil-water and synthetic fluid creates apparent cohesive forces that bind soil particles. If we consider the volumetric content of each of the liquids, water and synthetic fluid, to be a total volumetric content, then the magnitude of the apparent cohesive forces is a function of the total volumetric content. In coarse grain soil, such as surface aggregate, water added to the soil will rapidly drain to some value of residual volumetric water content. Rawls et al. (1982) presented a mean value of residual water content for sand (762 measurements) equal to approximately 1 percent on a volumetric basis. Though surface aggregate includes a range of particles from clays to gravel, the low value of residual volumetric content for a surface aggregate is most likely not that greatly different from the mean value for sand that Rawls et al. (1982) provided. This low value of volumetric water content indicates that the apparent cohesive forces developed by soil-water present at residual water contents are relatively small. The addition of a synthetic fluid that is slower to drain and does not evaporate increases the apparent cohesive forces created by the presence of both liquids over the forces created by water alone.

The second mechanism by which synthetic fluids control dust relates to the fluids' behavior as an intermediate wetting fluid. Once added to the surface aggregate, synthetic fluids spread to form a thin film coating over soil-water contained in the pore space. This thin film helps retain the apparent cohesive forces by reducing the loss of soil-water in the near surface aggregates by evaporation.

To be effective at controlling dust from unpaved roads, the applied dust palliative needs to be present and stay resident in the top approximately 2 centimeters of the surface aggregates.

With our understanding of how synthetic fluid palliatives control dust on unpaved roads it is clear that the effectiveness of synthetic fluid palliatives attenuate over time because of the downward movement of the fluid away from the top of the road surface through gravity and capillary forces. Mechanical shearing forces created by moving vehicles also degrade the effectiveness of synthetic fluid palliatives. Thus, the factors that control a synthetic fluid palliative's longevity and effectiveness include aggregate properties, fluid properties, and traffic characteristics. The laboratory test we present here evaluates the effectiveness of different synthetic fluids on the basis of aggregate and fluid properties. The test does not account for traffic characteristics.

The quantity of fines (silts and clays) present in the aggregate and a synthetic fluid's viscosity drive the retention of any particular fluid in surface aggregates. These small particles in the aggregate create small pore radii that result in greater fluid retention. Our previous work indicated that a fines content of between 8 and 14 percent is optimal for synthetic fluid retention in most surface aggregates (Barnes and Connor, 2014). This fines content is consistent with typical specifications for unbound surface courses. Increased viscosity of a synthetic fluid also slows the migration of the fluid downward. However, if the fluid's viscosity is too great, then infiltration of the fluid into the aggregate may be problematic. Furthermore, a highly viscous fluid is difficult to apply topically by pumping through sprayers. The compaction density of the surface aggregate also affects the effectiveness of synthetic fluid. Synthetic fluids will be unable to penetrate overly dense surface aggregates and will pond and possibly run off of the top of the road surface during application (Barnes and Connor, 2014). The water content of the aggregate influences the infiltration of applied synthetic fluid as well. Synthetic fluid will not infiltrate into dry aggregate, nor will it enter into saturated aggregate. In some cases, chemical reactions

between surface aggregate material and the applied synthetic fluid may also affect (positively or negatively) the ability of the fluid to control dust.

The many factors that control the effectiveness of a synthetic fluid to control road dust illustrate the need for a laboratory test to evaluate performance before application. The test we developed, known as the Dustfall Test, measures the ability of a palliative to bind particles smaller than 10 µm (aerodynamic diameter) in a surface aggregate. The test has three parts: (1) aggregate preparation and palliative application, (2) surface abrasion, and (3) quantification of fugitive dust potential. This report describes each of these parts of the test. The detailed procedure is included in Appendix A.

3. Test Description

The soil sample is prepared by screening off the material retained on the #4 sieve. The soil is then wetted to a moisture content of 70 percent of optimum moisture, as determined by AASHTO T180. This approximates typical moisture contents of surface courses found in the field and assures room for the synthetic fluid in the pores. The wetted soil is sealed and allowed to rest for 24 hours to assure uniform soil moisture. The soil is then compacted into three 6-inch diameter molds of either 4 or 6 inches in height, in accordance with AASHTO T180 Method A or Method B.

After a two-week maturation period, the technician abrades the top of the aggregate surface with a device known as an abrader. The abrader is a 4.54-kg (10-lb) weighted disk to which a hook-and-loop fastener attaches 40-grit sandpaper to the bottom of the disk (figure 3-1a). By rotating the abrader on the top of the aggregate surface, the technician obtains 50 g of abraded material. Carefully passing the abraded material through a #8 sieve removes aggregate of greater than 2.38 mm. Standard soil moisture tins store the abraded material for the next part of the test, which is quantification of fugitive dust potential.

We quantify the potential for the creation of fugitive dust by using a representative particle settling time in air. Settling occurs in a 1.83-m (6-ft) tall Dustfall Column (figure 3-1b). A cone-shaped device located at the top of the column holds the sample before introduction into the column through a trap door (figure 3-1c). As the sample initially drops through the column it impacts a screen (1.0-cm slot opening size) that disperses the sample (figure 3-1d). A sampling pump pulls a steady inflow from an intake located 1.52 m (5.00 ft) from the top of the column through a PM_{10} filter and into a nephelometer. In the nephelometer, reflectance of a steady light beam focused on the air stream quantifies the concentration of PM_{10} surrounding the intake at 1-

second intervals. The bottom of the column is submerged into a pool of water, known as the splash pool. The splash pool helps suppress the displacement of particles back up into the column's airspace upon reaching the bottom of the column. Moreover, the submergence of the bottom of the column into the splash pool eliminates airflow into the column from the bottom, eliminating the dilution of PM_{10} concentrations measured at the intake.

Particles settle in the column under three different mechanisms: as singular particles, as particles carried down by larger particles, and as aggregated particles (figure 3-2). The combination of the settling mechanisms is considered "dustfall." Owing to the movement of air through the column created by the vacuum-induced flow at the intake, turbulent eddies also influence the settling of particles in the column. However, even with turbulent eddies, the slowest particles to settle out in the column will be the smallest discrete particles. A well performing synthetic fluid palliative will act to retain these particles in the surface aggregate. Hence, in a well performing treated aggregate, the measurement of these small discrete particles by this test will be minimal. With the time dependent PM_{10} concentrations measured near the base of the Dustfall Column, we can assess the effectiveness of synthetic fluid to retain PM_{10}-sized particles in the aggregate.
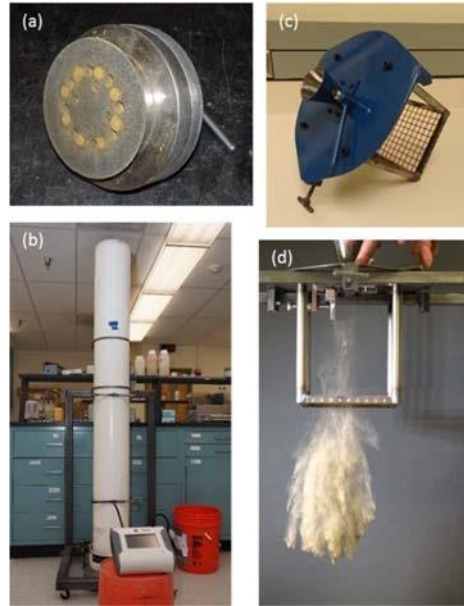
Figure 3-1. Sample abrader and Dustfall Column.
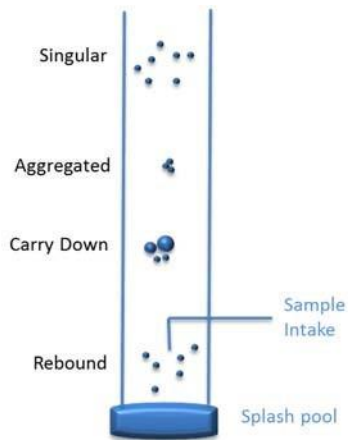
Figure 3-2. Dust settling mechanisms.

Figure 3-3 shows typical results for an untreated aggregate. The left panel of figure 3-3 shows the exponential decline in PM_{10} concentration with time since introduction (dropping) of the sample into the Dustfall Column. Converting PM_{10} concentration to natural log linearizes concentration with time, as the right-side panel in figure 3-3 shows. The linear relationship is broken into two distinct portions: settling that occurs before approximately 300 seconds and

settling after 300 seconds. As shown in the figure, the rate of concentration decline is greater in the first approximately 300 seconds, indicating two distinct modes of settling. The nature of the column's confined space causes these two distinct settling modes. As the sample approaches the splash pool following release into the Dustfall Column, displaced air created by the sample's descent puffs some of the smallest particles in the sample back up into the column to and past the elevation of the intake. Displacement of a portion of the sample back up into the column occurs rapidly (1 second or less) followed by a period of settling of these particles into the splash pool. The settling of these particles, along with any particles settling through the column by the three mechanisms previously described (dustfall), contributes to the PM_{10} concentrations measured by the nephelometer up to approximately 300 seconds. Continued settling after this first phase of settling consists of particles descending from the top of the column. The time required for the PM_{10} concentration to reach the initial background concentration before the start of the test is an indication of the size of the smallest particles in the sample.
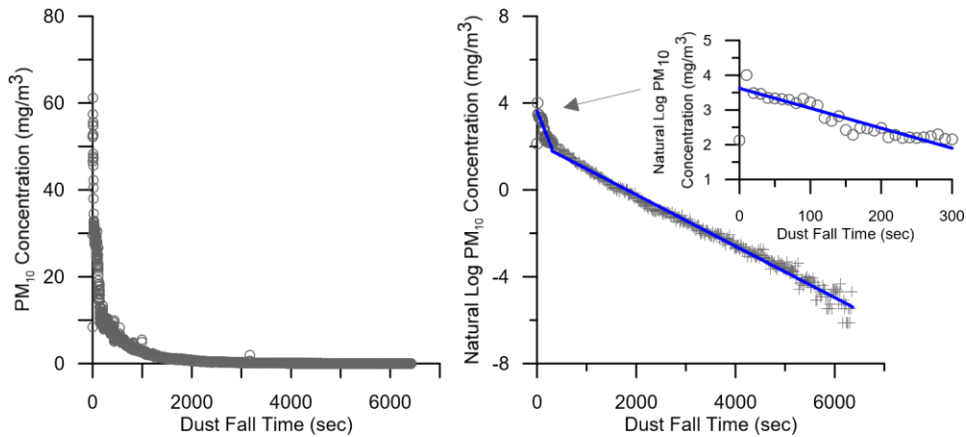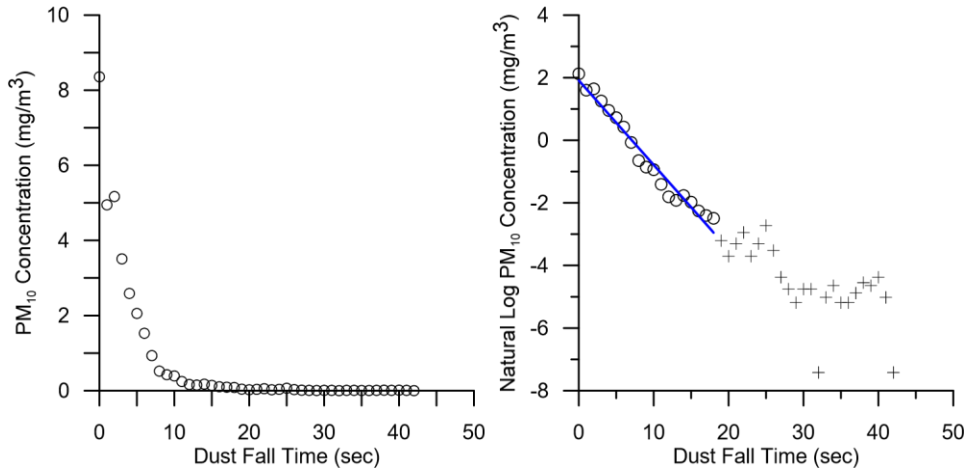

Figure 4. Typical Dustfall Column test results for an untreated aggregate.

Figure 3-3. Typical dustfall column test results for an untreated aggregate

In contrast to the time dependent PM_{10} concentration measured in the Dustfall Column for an untreated surface aggregate, figure 3-4 shows typical settling results from the same surface aggregate treated with a well performing palliative. As with the untreated sample results, the left panel of figure 3-4 shows the exponential decline in PM_{10} concentration with time since the sample was dropped into the Dustfall Column. The right panel of figure 3-4 shows the linearized results. As the figure shows, the second phase of settling does not exist in a surface aggregate treated with a well performing palliative. The apparent cohesive forces created by the synthetic fluid result in a minimal content of small discrete particles, which is the primary state of the particles revealed by the PM_{10} measurements in the second phase of settling in the untreated aggregate (figure 3-3). The particles that are puffed upwards back into the column rapidly settle in comparison to the untreated sample (figure 3-3), again indicating that the sample contains minimal discrete particles.

The results for the example shown in figure 3-4 are typical of treated aggregates. The first phase of settling (the puffed particles) will typical last 10 to 20 seconds. Following this first phase of settling, PM_{10} concentrations will approach initial (before dropping of the sample) background levels. The trend to background levels is indicated by PM_{10} measurements that no longer follow the linear relationship (represented by the x markers in the left panel in figure 3-4). These PM_{10} concentrations are a result of small discrete particles retained in the air space by turbulent vortices. Ultimately, the continuous removal of air from the column at the intake and the impact of particles with the surface of the splash pool remove these particles from the column's air space.

Figure 3-4. Typical Dustfall Column results for a well performing dust control palliative.

Theoretically, if we consider the total number of particles, either discrete or agglomerated, originally contained in the sample dropped into the column, then the inverse of the PM_{10} concentration decay rate (slope of the line) is representative of the average length of time that a particle remains in the column. This average length of time takes into account the particles that are initially puffed upwards, before they encounter the splash pool. We call this value the *mean particle residence time* (τ). Our experience with the Dustfall Column shows that values of τ of less than 6 seconds are associated with well performing palliatives. The mean particle residence time determined for the treated aggregate shown in figure 3-4 equals 3.7 seconds. For comparison, τ in the untreated sample, shown in figure 3-3, equals 175 seconds in the first phase of settling and 769 seconds in the second phase.

Figure 3-5 shows Dustfall Column results for an aggregate treated with an underperforming palliative. As with the results from the untreated aggregate (figure 3-3), a second phase of settling occurs in an aggregate treated with an underperforming palliative. Moreover, the mean particle residence time for the first phase of settling is longer in comparison to an aggregate treated with a well performing palliative.

14
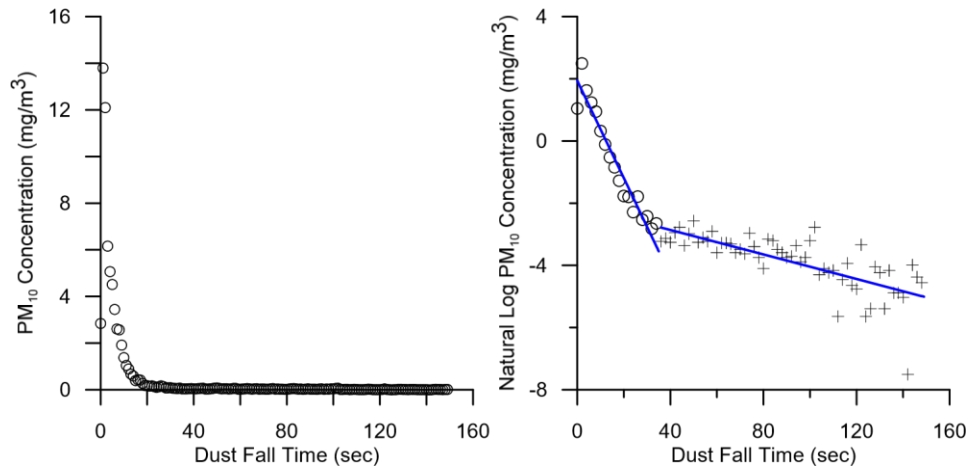
Figure 3-5. Typical Dustfall Column results for an underperforming dust control palliative.

For a well performing palliative, the only measurable particulates during the entire test are those that are puffed upwards from the bottom of the column. The puffing action separates out the smaller particles that can be displaced upwards in the column. These small particles are intermixed with larger particles in loosely formed aggregates of particles. A higher level of aggregation results in fewer small particles dislodging from aggregates by the shear forces created during the displacement of air, resulting in lower value for τ in the first phase of settling. Hence, better performing palliatives will have associated smaller values of τ. A test of an underperforming palliative will result in measurement of a second phase of particulate settling and associated larger τ values for the first phase of settling. The τ value associated with the first phase of settling for the results shown in figure 3-4 equals 6.4 seconds. A mean particle residence time can also be calculated for the second phase of settling. For the example shown in figure 3-4, this value equals 51 seconds.

4. Transferring the Test to the ADOT&PF

The Alaska Department of Transportation and Public Facilities (ADOT&PF) has a keen interest in a test method that will allow it to accept or reject dust palliatives before placing them in the field. We have been working with ADOT&PF to develop test methods to evaluate the performance of palliatives for a number of years. Consequently, this project was established to move the Dustfall Column test method from research to the production laboratory. The University of Alaska Fairbanks was responsible for providing ADOT&PF with

- two working Dustfall Columns

- a written description of the test method

- a video showing the details of the test method.

Using this formation, ADOT&PF agreed to prepare an Alaska Test Method, which will be used to test palliatives before acceptance for a project.

As agreed, we developed detailed training videos of each step involved in the three parts of the test methodology. The videos show the principal investigator (PI) discussing why each step is necessary, common errors that may occur in each step, and the relationship of these steps to other steps in the procedure. The videos also show the PI performing each step in the procedure. We provided these videos to the ADOT&PF.

We also worked with ADOT&PF technicians individually and in groups. These training sessions took place at ADOT&PF Central Region's materials laboratory and at the Northern Region material laboratory. We conducted two training sessions per group, with the invitation for further training if necessary. For this training we had fabricated a Dustfall Column and an abrader, and provided a nephelometer (DustTrak^{TM} model 8530) and supplies for both the Central and Northern regions' laboratories.

The Alaska Test Methods are patterned after the AASHTO Test Methods and are used for testing that is not found in the AASHTO Test Methods or to modify or clarify the AASHTO Test Methods for Alaska's needs. New test methods must be vetted through the Department's materials engineers for acceptance.

5. Summary

The lack of an accepted standard method for testing the effectiveness of dust control palliatives on unpaved roads before their application forces road managers to rely on suppliers' claims and on trial-and-error to determine whether a palliative will effectively control dust. To address this ambiguity, we developed a laboratory test for determining palliative effectiveness. The purpose of this project was to finalize and transfer the test to ADOT&PF.

The test distinguishes between well performing and underperforming dust control palliatives by evaluating the settling characteristics in air of treated aggregate samples. The steps to transfer the test to ADOT&PF included a written detailed methodology, on-site training, and training videos.

References

Barnes, D. L. and B. Connor. 2014. Managing Dust on Unpaved Roads and Airports. Alaska University Transportation Center, University of Alaska Fairbanks, INE/AUTC 14.14: 83p.

Federal Register. 2001. *Effluent Limitations Guidelines and New Source Performance Standards for the*

Oil and Gas Extraction Point Source Category; OMB Approval Under the Paperwork Reduction Act: Technical Amendment, 40 CFR Parts 9 and 435. Vol 66, No. 4, Washington D.C.: 70p.

FHWA. 1998. Problems Associated with Gravel Roads. U.S. Department of transportation, Federal Highway Administration, Publication No. FHWA-SA-98-045: 168p.

FHWA. 2015. Gravel Roads Construction & Maintenance Guide. U.S. Department of Transportation, Federal Highway Administration, Washington, DC: 153p

Hinds, W. C. 1999. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*, 2nd ed. John Wiley & Sons, Inc., New York: 504p.

Pinnick, R. G., G. Fernandez, B. D. Hinds, C. W. Bruce, R. W. Schaefer, J. D. Pendleton. 1985. Dust

Generated by Vehicular Traffic on Unpaved Roadways: Sizes and Infrared Extinction Characteristics. *Aerosol Science and Technology*, 4(1): 99-121.

Rawls, W. J., D. L. Brakensiek, K. E. Saxton. 1982. Estimation of Soil Water Properties. Transaction of the American Society of Agricultural Engineers, 65(3): 1316-1320.

Skorseth, K., and A. A. Selim. Gravel Roads Maintenance and Design Manual. South Dakota Local Transportation Assistance Program, Brookings, SD: 104p.

U.S. EPA. 2017. Nonattainment Areas for Criteria Pollutants (Green Book). U.S. Environmental Protection Agency, Washington, DC. Retrieved from https://www.epa.gov/green-book.

U.S. EPA. 2009. Integrated Science Assessment for Particulate Matter. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F: 1071p.

U.S. EPA. 1996. *Development Document for Final Effluent Limitations Guidelines and Standards for the Coastal Subcategory of the Oil and Gas Extraction Point Source Category*. EPA-821-R-96-023. United States Environmental Protection Agency, Office of Water. Washington, D.C.: 640p.

Appendix A – Stepwise Procedure

<u>Sample Preparation</u>

1.1   Dry sample to constant mass in accordance with ATM 202.

1.2   Seive over #4 sieve and discard material retained on the #4 sieve.

1.3   Add water to obtain 70% (+/- 5) of optimum moisture as determined by AASHTO T180.

1.4   Store in 1-gallon zip lock bags overnight.

1.5   Compact in 6-in.-dia. Proctor or CBR mold in accordance with AASHTO T180.

1.6   Determine quantity of palliative to be applied and apply evenly over the surface of the
        soil. Note, this may require multiple applications, allowing the palliative to soak in
        between applications.

1.7   Allow to maturate at room temperature in open air for 14 days.

<u>Abrading the Sample</u>

1.8   Place the compaction collar on the mold.

1.9   Using the 10-lb abrader with 80-grit sandpaper apply 10 full rotations of the abrader.

1.10   Carefully brush off the loose material and sieve through a #8 sieve. Discard the material

        retained on the sieve.

1.11   Place the material passing the #8 sieve in a moisture tin (known tare weight) carefully to

        ensure the soil is not broken down.

1.12   Determine the mass of sieved abraded material. If the mass is less than 30 g, repeat steps

        2.2 and 2.3. Do not exceed 20 rotations of the abrader in total.

1.13   Place the newly sieved material into the moisture tin with the previously abraded

        material.

1.14   Seal the tin.

<u>Preparing the Column</u>

1.15   Carefully clean the interior of the column with the cleaning pig provided.

1.16   Apply antistatic spray using the pig provided with a cloth treated with antistatic spray.

        Repeat this process twice.

1.17   Fill the water bath at the bottom of the column to a depth of approximately 3.5 inches

1.18   Set the bottom of the column into the water approximately 1 inch.

1.19   Install the intake tube facing downward into the column and attach to the nephelometer.

<u>Preparing the Drop Cone</u>

1.20   Clean the cone using a clean cloth dampened with acetone to remove any residual

        palliative.

1.21   Using a static free cloth treated with antistatic spray wipe the interior surfaces of the cone

        and the trap door.

1.22   Close and latch the trap door.

<u>Placing the Sample into the Drop Cone</u>

1.23   Carefully open the moisture tin and gently mix the sample to achieve a uniform sample.

1.24   Quarter the sample by scoring two orthogonal lines through the sample.

1.25   Weigh 5 grams of sample (+/- 0.1 g), taking small portions from each quarter until the

        required 5 grams have been sampled.

1.26   Carefully place the sample in the cone minimizing the contact with the sides of the cone.

1.27   Place the cone on the column.

        <u>Running the Test</u>

        (Review the DustTrak^{TM} manual, or equivalent instrument for operating instructions.)

1.28   Zero the DustTrak^{TM} using the procedure outlined in the manual.

24

1.29   Set the sample interval to 1 second on the DustTrak™ .

1.30   Set the testing time using the guidelines below. It is better to program longer time if in

doubt and stop the test once the background has been reached

- 4 minutes for a treated sample expected to work well

- 20 minutes for a sample that is anticipated to have marginal performance

- 100 minutes for an untreated sample.

1.31   Start the DustTrak™ and allow to run for 1 minute to obtain a background level. This

will be used in the analysis.

1.32   At approximately 1 minute trip the trap door.

1.33   Allow the test to run until the background values are reached.

1.34   Download the data onto a flash drive to transfer to a computer.

<u>Analyzing the Data</u>

1.35   Import the data into a spreadsheet.

1.36   Plot time on the horizontal axis and the natural log of concentration on the vertical axis.

1.37   Print the graph

1.38   Starting at the maximum concentration value (typically 1 to 2 seconds after dropping the

sample), draw a best-fit line through the initial linear portion of the data on the graph

until there is a break in the linearity (Refer to Figure A7, left side graph). This portion of

the data represents the rebound phase of the test.

1.39   Starting at the right, draw a line of best fit on the graph through the datum points that

comprise the phase following the initial linear portion of the datum set (Refer to Figure

A7, left side graph). This portion of the data represents the dustfall phase (if it exists).

1.40   Find the intersection of the two lines and select the time coordinate closest to the

intersection. Note this value.

1.41   Determine the slope of the rebound phase of settling. Using the linear regression

command in the spreadsheet software, plot and determine the equation for the best-fit line

using the datum point range from the maximum concentration value to the datum point

associated with the intersection of the two hand-drawn lines (steps 7.4 to 7.6). This is the

rebound phase. Note the slope of this best fit line ($slope_R$). Also note the coefficient of

determination (R^2) for the best-fit line. This value should be greater than 0.70. If it is

less than 0.70, repeat the testing with step 3 (*Preparing the Column*). Figure A-1 shows

an example of linear regressed line and associated slope and

1.42   Compute the mean residence time, τ_R, for the rebound phase as follows:

$$Mean\ Particle\ Residence\ Time\ for\ Rebound\ Phase\ (\tau_R) = {}^1/_{slope_R}$$

1.43   Report R^2 and mean particle residence time for the rebound phase.

1.44   Compute the mean particle residence time of the dustfall phase of settling. Using the

linear regression command in the spreadsheet software, plot and determine the equation

for the bestfit line using the range from the datum point following the end point of the

range used in step 7.7 to the last measured datum point. This is the dustfall phase (if it

exists). Note coefficient of determination (R^2) for the best-fit line. If R^2 is less than 0.70,

a dustfall phase does not exist. Note the value of R^2. If the R^2 value is greater than 0.70,

note the slope of the line for the dustfall phase (*slope_D*) determined by linear regression.

Calculate the mean particle residence time for the dustfall phase (τ_D) as follows:

$$\text{Mean Particle Residence Time for Dustfall Phase } (\tau_D) = {^1/_{slope_D}}$$

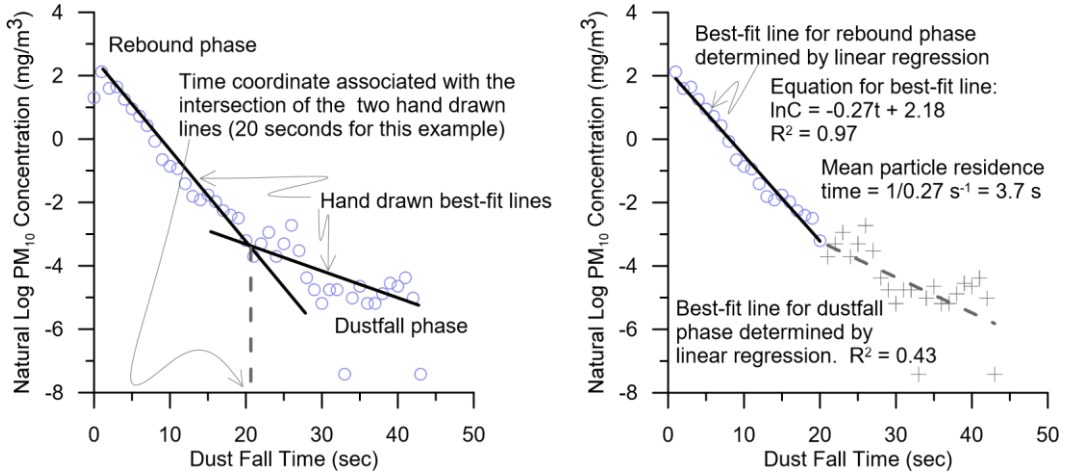1.45   Report R^2 and mean particle residence time for the dustfall phase.

Figure A-1. Example of the analysis of results from a Dustfall test.