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Project Summary

Field Evaluation of Windscreens as a Fugitive Dust Control Measure for Material Storage Piles

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The Air and Energy Engineering Research Laboratory (AEERL) has instituted a coordinated program for development of a technology for the control of fugitive particulate sources. The AEERL has identified windscreens as a promising control technique for one of the major sources—storage piles. Before this technology can be effectively applied, however, application criteria need to be developed. These criteria are screen porosity, screen width, screen height, and the distance between the screen and the pile.

AEERL and the Environmental Sciences Research Laboratory (ESRL) have completed an in-house study designed to determine changes in windspeed (not changes in emissions) due to windscreens. The ESRL wind tunnel was used in experiments conducted to determine the optimal windscreen porosity, size, and location for control of fugitive dust emissions from storage piles. Before this information could be applied to the design of windscreens, it was necessary to conduct a field study to validate the wind tunnel studies with respect to windspeed changes, and to determine the relationship between changes in windspeed and changes in fugitive dust emissions.

This field study was conducted during the summer of 1985. Testing was performed simultaneously on two cone shaped piles of shredded topsoil 8 ft* high with a base diameter of 25 ft. One pile was exposed, and the other was controlled with a 50 percent porosity windscreen. Sensors were located at the surface of each pile to determine windspeed. Exposure profiling towers with samplers at four heights were used to determine total particulate emissions. Windspeed data were collected continuously by an onsite computer. Profiler data were averaged for a complete test, and selected filters were subjected to laser diffraction analysis to obtain particle size data.

The windscreen parameters found to be most effective in the field for reducing windspeed on the pile surface under perpendicular winds were 1.25 pile heights high, 1.5 pile heights wide, and 2.0 pile heights upwind. Both the wind tunnel study and this study recorded negative screen efficiencies in the lee of the pile, but the field study showed this result to a much greater extent.

Regression analyses of data for particulate emission reduction and other variables showed a strong linear relationship between emission reduction and windspeed for the largest particle size ranges evaluated. These analyses also showed that emission rates were directly related to windspeed and inversely related to the moisture content of the pile surface. These relationships held regardless of the particle size fraction considered.

Optimum windscreen design parameters recommended for permanent or semi-permanent installations are porosity = 50 percent, height = 1.0 H,

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*Readers more familiar with metric units are asked to use the conversion factors at the end of this summary.

width = 5.0 D, and distance = 2.0 H for a pile of height H and diameter D.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Air and Energy Engineering Research Laboratory (AEERL) has instituted a coordinated program for the development of a technology for the control of fugitive particulate sources. The AEERL has identified windscreens as a promising control technique for storage piles, a major source of these emissions. Before this technology can be effectively applied, however, application criteria need to be developed.

Together, AEERL and the Environmental Sciences Research Laboratory (ESRL) have completed an in-house study, designed to determine changes in windspeed (not changes in emissions) due to windscreens. The ESRL wind tunnel was used in experiments conducted to determine the optimal windscreen porosity, size, and location for control of fugitive dust emissions from storage piles. Before this information could be applied to the design of windscreens, it was necessary to conduct a field study to validate the wind tunnel studies with respect to windspeed changes and to determine the relationship between changes in windspeed and changes in fugitive dust emissions.

The three objectives of this study were:

(1) To verify that the data collected in the wind tunnel with respect to changes in windspeed are accurate under field conditions.

(2) To determine the relationship between changes in windspeed and changes in particulate emissions by particle size.

(3) To develop windscreen design parameters.

Previous studies have yielded contradictory results concerning the relationship between particle uptake and windspeed. Similar contradictions were found in the two studies performed to investigate reductions in dust concentrations due to the use of windscreens. The inhouse study and the one described here are the first laboratory and field studies that attempt to measure windspeed or particulate reductions at or near a pile surface.

The inhouse study simulated, in a wind tunnel, the effect of a windscreen in reducing windspeed on the surface of a storage pile. The scale-model storage pile used was 4.3 in. high and was covered with gravel having diameters less than 0.2 in. A variety of windscreen parameters were evaluated during the study, and isotachs of windspeed and windspeed reduction were presented for both unscreened and screened piles.

Field Sampling

The current study entailed a field exercise to evaluate the results of the inhouse study under actual field conditions. The basic sampling protocol used was to measure windspeed and particulate concentrations on two identical storage piles simultaneously. One pile was controlled with a windscreen of 50 percent porosity, and one had no windscreen. A critical parameter in such a test protocol is that the piles be identical initially and throughout the test period with respect to dust-emitting characteristics. The piles were constructed out of the same highly erodible material (shredded topsoil) and were shaped identically.

Field Site

The field site was located on a privately owned farm in the Wichita, KS, area. This area had the desirable characteristics of relatively high-speed winds with a persistent direction. The 24-acre field was in a rural area about 7 mi northwest of the Wichita Mid-Continent Airport. This level area was bounded by a paved road on the western edge and an unpaved road on the northern edge (downwind).

The entire field was covered with grass, which grew to a height of 2-6 in. There were no continually active particulate sources in the upwind direction (south) from the field, just additional pastures and fields with mature crops. Nor were there any tall windbreaks within 0.5 mi to the south. Trees that grew along the stream at the south end of the field only extended 10-15 ft above field level and were at least 500 ft from the sampling area.

The identically constructed storage piles consisted of dried, shredded topsoil. The piles were conical, with a height of 8 ft and a base diameter of 25 ft and were located 150 ft apart. A detailed test plot is shown in Figure 1. The instrument trailer was 75 ft downwind of the piles. Screen widths up to 5 pile diameters were accommodated with this layout.

Sampling Equipment and Deployment

Windspeed was monitored with several rotating-cup windspeed sensors with pulsed output. The output was directed through a windspeed translator module that converted the signal to a standardized analog voltage. This signal was translated to a digital signal, through the use of an analog-to-digital converter, which was then processed by a personal computer.

Wind direction was monitored upwind with a wind direction sensor. The signal was input to a translator module and an analog-to-digital converter for computer processing.

Ten windspeed sensors were used, one of which was upwind at a height of 8 ft to correspond with the height of the storage pile. Placement of the sensors was guided by verification of wind tunnel testing: it was desirable to obtain windspeed measurements at the same locations as in the wind tunnel testing. The wind tunnel testing, however, involved 108 windspeed measurement locations, 9 sensors at a time. Pile rotation to 12 positions yielded 108 measurements. Such a protocol was impractical for a field test because of the equipmen required and because wind direction i the field is not fixed as it is in a win tunnel.

Nine windspeed sensors were de ployed downwind of the screen, five o the uncontrolled pile and four on th controlled pile. The sensors were set a a fixed position on the pile, about 6 in above the surface of the pile and per pendicular to the ground. The position were set relative to the prevailing win direction, and they remained fixed ove the 8-week test.

So that identical instruments could b positioned at the same relative loca tions on each pile, a true north point an true south point were determined fo the base of each pile. A string was the run across the peak of the pile to co nect the two points. Vertical distance were measured along the string, an horizontal dimensions were measure perpendicular to the string.

Particulate was measured with a tot particulate exposure profiler head. Th exposure profiler head consisted of high-volume motor with a variable flo rate, a filter holder, and a circular inta

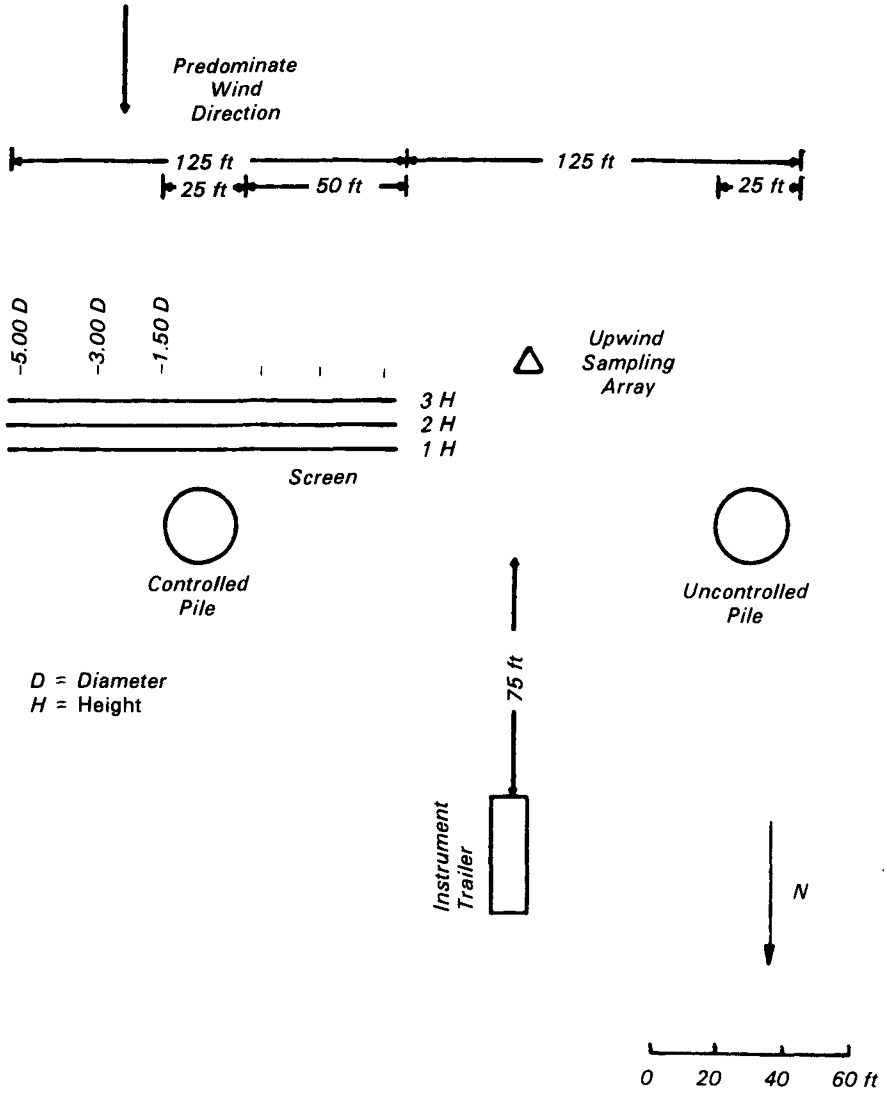

Figure 1. *Test plot layout.*

nozzle that was oriented directly into the wind during testing. The filter was a standard, glass-fiber high-volume filter. Because the sampler collects all ambient particles indiscriminately, the emission data obtained represented total particulate (TP).

The sampling heads were operated approximately isokinetically so as not to skew the particle size distribution of the collected sample. This design was potentially difficult because the wind currents induced by the pile and windscreen would not follow the standard logarithmic profile, and would change with changing wind direction and windscreen height. This problem was overcome by mounting rotating cup anemometers near each profiling head mounted on the profiling tower. The anemometers sent data to an onsite Apple computer for averaging.

Particle size data were obtained from the exposure profiler filters to permit a determination of windscreen control efficiency by particle size. Alternative methods for obtaining the size distribution from the filter were optical microscopy, scanning electron microscopy, and laser diffraction. All methods share the same two weaknesses: material must be removed from the filter, and physical size data must be converted to aerodynamic size data. Laser diffraction with the Microtrak Particle Size Analyzer is the most reliable and cost-efficient method. This device outputs particle size distributions in up to 13 particle size classes over a range of 1-175 μm. Project resources were adequate to use laser diffraction on one filter from each tower per test. Each sample was then subjected to the particle-sizing analysis.

Four exposure profilers were mounted on an 11-ft tower. The tower was 10 ft behind the midline and 2 ft to the side of the top of the conical pile. Profiler head heights were 4, 5, 8, and 11 ft. Two independent variables were monitored: pile surface silt content, and pile surface moisture. Soil samples were taken from the pile by removing the top 0.5 in. of soil in a vertical strip of 1 × 48 in. from the middle of the pile.

A detailed quality assurance report was prepared prior to field sampling and adhered to throughout the study. The principal elements of the quality assurance procedures are in the project report.

Objective 1—Verification of Wind Tunnel Windspeed Data

The first objective of the study was to compare the wind tunnel data with the windspeed data collected in the field. The two major elements of comparison were:

(1) Comparison of the windspeed isotachs on an unscreened pile.
(2) Comparison of the windspeed isotachs on screened piles by screen configuration.

Windspeed Comparisons Between Wind Tunnel and Field Testing for an Unscreened Pile

The wind tunnel windspeed data are presented as a set of contours of normalized windspeed, u/u_r, where u is the windspeed at the pile surface, and u_r is the windspeed at the maximum height of the pile measured in the absence of the pile.

A direct comparison of the field data and wind tunnel data required the following data manipulations of the unscreened pile data:

(1) Preparation of a data base with 5-min average data of windspeeds corresponding to incoming wind direction.
(2) Preparation of u/u_r values for each sampler location.
(3) Summarization of u/u_r values derived from the field for comparison with the wind tunnel data.

A computerized data base was prepared. It consisted of 5-min average windspeed data stratified by incoming wind direction in 10° cohorts.

Composite u/u_r values were calculated for the 10° wind direction cohorts, as shown in Table 1. As the wind direction moves around the pile, the locations of the sensors are effectively shifted to new positions. This same approach was used in the original inhouse wind tunnel study. In the field study, however, the wind direction was varied rather than the pile orientation. Utilization of the entire data base yields 55 data points. Because only 110° of the compass is shown, a substantial portion of the compass is left unresolved. Some of the data points are plotted in Figure 2, over the isotachs from the wind tunnel study.

As shown in Figure 2, the data on the front of the pile match reasonably well for $u/u_r < 0.8$; however, the area where the ratio is >1.0 appears to be larger than that found in the wind tunnel. The field data for the back side of the pile yielded significantly higher u/u_r ratios than the wind tunnel study. In fact, the highest ratios measured during the field testing were on the back of the pile. The testing suggests that the high windspeed flow lines not only extend around to the back of the pile, but are reinforced in some fashion.

The differences noted between this study and the inhouse study can be attributed to a number of factors:

(1) Ambient windspeeds and wind direction measured in the field are much more variable than those observed in the wind tunnel and resulted in higher turbulence.

(2) Actual pile configuration and composition during the field testing may not have been comparable to the idealized scale model pile used in the wind tunnel, possibly a significant factor.

(3) Experimental equipment used in the two studies may not have been comparable. The extent to which the wind sensors correspond to the laboratory thermistors is unknown.

(4) Experimental errors between the two studies may not have been of comparable magnitude.

(5) The presence of reentrained dust from the pile surface may have some effect on the measurements. For example, it may be that the inherent kinetic energy of the entrained particles from the front of the pile can be transferred to the wind sensors behind the pile and result in higher apparent windspeeds.

Table 1. *U/U_r Values for the Unscreened Pile 125° to 234° Wind Directions*

Wind Direction, 10° Cohort	Position 1	Position 2	Position 3	Position 4	Position 5
125-134	0.82	1.08	0.72	1.36	1.05
135-144	0.68	1.08	0.71	1.34	1.08
145-154	0.65	1.13	0.83	1.35	1.14
155-164	0.56	1.07	0.81	1.21	1.06
165-174	0.46	1.09	0.82	1.07	1.00
175-184	0.53	1.09	0.84	0.94	0.95
185-194	0.57	1.11	0.88	0.74	0.82
195-204	0.60	1.08	0.86	0.45	0.64
205-214	0.67	1.11	0.88	0.33	0.49
215-224	0.82	1.16	1.02	0.20	0.39
225-234	0.88	1.25	1.07	0.28	0.38

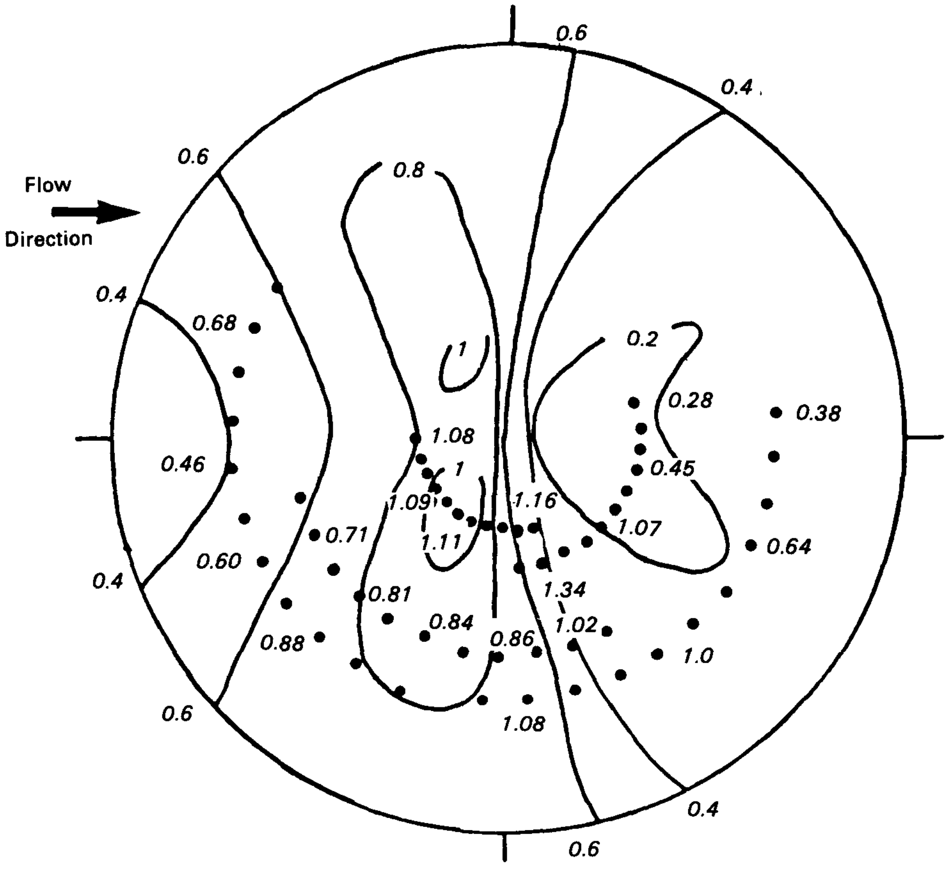

Figure 2. *Composite u/u_r values for an unscreened pile—field testing and wind tunnel data.*

Windspeed Control Effectiveness for Windscreens

The wind tunnel windspeed data for screened piles are presented as a series of isotach lines. The isotach lines are presented in the form of $1 - (u/u_0)$, where u and u_0 are windspeeds with and without a windbreak.

The field data were also manipulate into the $1 - (u/u_0)$ format. Data were als stratified by incoming wind directio and screen configuration. Data coul not be presented as a series of isotac lines as in the wind tunnel report, because only four data points on the pil were obtained (in contrast to 108 dat points in the inhouse study).

A portion of the data were refo matted to indicate the maximum win screen wind reduction by incomin windspeed and screen configuration.

Several conclusions could be drawn from the analysis. Windspeed reduction was greatest for perpendicular screen orientations. A 2.0-pile-height distance, 1.5-pile-diameter width, and a 1.25-pile-height screen were found to be most effective. For nonperpendicular winds, on the other hand, the 3.0-pile-diameter screen width was the most effective. In the lee of the pile, negative control efficiencies were recorded.

Findings of the inhouse study were compared with those of the current study. Both studies found the taller windscreens to be most effective. The inhouse study found a 3.0-pile-height distance to be more effective than a 1.0-pile-height distance. A 2.0-pile-height distance was not evaluated. The current study found a 2.0-pile-height distance to be more effective than either the 1.0 or a 3.0-pile-height distance. Both studies found a 1.5-pile-diameter screen length to be more effective than a 1.0-pile-diameter screen length. Both studies recorded negative screen efficiencies in the lee of the pile, but the field study showed this result to a much greater extent. In general, the wind tunnel efficiencies were higher than those measured in the field.

Objective 2—Comparison of Windspeed Reductions and Particulate Control Efficiencies

The second objective of the study was to compare average windspeed reductions with particulate emission reductions for entire tests as measured by the exposure profilers. There were 42 valid tests in the data set.

All applicable data for windspeed versus particulate (TP) emission reductions are shown in Table 2. A linear regression of windspeed (WS) versus total particulate (TP) reductions yielded a correlation of 0.372, R^2 of 0.138, significance level of 0.015, slope of 0.841, and y-intercept of −0.150. These results indicated a significant relationship between the two variables that was nearly 1 to 1.

Table 2. *Comparison of Windspeed and Total Particulate Reductions*

Test	*Windspeed, ft/min* *Screened*	*Piles Exposed*	*Reduction*	*Total Particulate, lb/3.28 ft* *Screened*	*Piles Exposed*	*Reduction*
1B	1679	1755	0.043	9.82	8.36	−0.175
2	951	1480	0.357	1.45	1.34	−0.082
3	1039	1653	0.371	2.92	2.34	−0.250
4	791	1228	0.356	1.04	0.98	−0.058
5	969	1354	0.284	1.26	2.52	0.499
6	545	1024	0.468	0.54	0.66	0.180
7	598	1026	0.417	0.46	0.49	0.051
9	473	1070	0.558	0.38	0.47	0.197
10	350	524	0.332	0.02	0.04	0.453
11	312	869	0.641	0.02	0.04	0.471
12	257	409	0.372	0.03	0.03	−0.061
13B	198	314	0.369	0.01	0.01	0.371
14	477	1018	0.531	0.04	0.06	0.394
15A	661	1020	0.352	0.03	0.02	−0.188
15B	641	679	0.056	0.03	0.03	0.101
16	493	580	0.150	0.01	0.01	0.029
17	386	508	0.240	0.03	0.08	0.588
19A	256	294	0.129	0.03	0.02	−0.596
19B	350	388	0.098	0.01	0.01	−0.111
20	343	342	−0.003	0.01	0.01	0.180
21A	402	993	0.595	0.04	0.04	0.108
21B	494	985	0.498	0.06	0.34	0.825
22	512	1010	0.493	0.07	0.91	0.928
23A	562	1031	0.455	0.20	2.15	0.908
23B	230	380	0.395	0.02	0.04	0.486
24	426	455	0.064	0.02	0.03	0.192
25A	714	961	0.257	0.29	0.19	−0.509
25B	680	820	0.171	0.15	0.10	−0.555
26	902	986	0.085	0.04	0.03	−0.431
27	577	1009	0.428	0.17	0.12	−0.403
28B	424	721	0.412	0.09	0.13	0.290
29	375	609	0.384	0.01	0.02	0.358
30A	419	680	0.384	0.04	0.03	−0.599
30B	433	620	0.302	0.02	0.03	0.301
31	313	545	0.426	0.01	0.01	0.357
32	305	356	0.143	0.01	0.01	0.063
33	174	289	0.398	0.04	0.03	−0.147
34A	214	275	0.222	0.01	0.01	0.391
34B	198	272	0.272	0.01	0.01	−0.071
35	310	410	0.244	0.01	0.01	0.218
36	256	380	0.326	0	0	0.000
105	408	389	−0.049	0	0	0.000

When the linear regression was forced through zero (no windspeed reduction results in no TP reduction), the correlation improved to 0.417, R^2 was 0.174, the significance level was 0.005, and the slope was 0.466. This relationship was more significant than the one above and indicated TP reductions slightly less than half of the corresponding windspeed reductions.

There were 15 negative TP reductions in the 42 tests. A negative TP reduction means that a higher emission rate was measured on the screened pile than on the exposed pile. Many of these tests in which the screen appeared to increase emissions could be the result of differences that were less than the measurement error for exposure profiling, but several of the differences in emission rates were large enough to indicate the probability that these measurements reflected actual occurrences of increased emissions. This observation agreed with the findings (discussed previously herein and in the inhouse study) that the windscreen actually produced increased windspeeds on the lee side of the pile.

If the negative TP reductions were assumed to be due to measurement errors and set at zero, the correlation was virtually unchanged at 0.404, R^2 was 0.163, the significance level was 0.010, the slope was 0.626, and the y-intercept was 0.175.

It was observed that many of the tests were taken at windspeeds too low to cause wind erosion, and (during other tests) the moisture content of the pile was so high that erosion would not occur even with high windspeeds. Twenty of these tests with negligible emissions were eliminated to see whether the windspeed/emission rate relationship was stronger during tests with wind erosion. The results of this regression analysis were: R = 0.287, R^2 = 0.082, significance level = 0.184, slope = 0.859, and y-intercept = −0.122. According to this analysis, the tests with negligible emissions did not appear to be distorting the first calculated relationship between the two variables.

The above regression analyses indicate that a highly significant relationship exists between windspeed and particulate emission reductions, and that the relationship is approximately linear with a slope less than 1 (1 percent reduction in windspeed results in less than 1 percent reduction in particulate emissions). Also, in some instances windspeed on the front face of the pile appears to be reduced by the windscreen, but emissions from the pile actually increase as a result of higher windspeeds on the back of the pile.

Particle Size Data

The emission rates of particles within several size ranges were determined by selecting a heavily loaded filter from each profiling test and subjecting it to laser diffraction analysis. The resulting percentages of net sample weight by particle size range were then multiplied by the TP emission rate for the test to obtain emission rate by particle size range. The effectiveness of the windscreen in reducing emissions for each size range was then calculated as 1 - ER_{scr}/ER_{exp} for that range.

The particulate reductions by size range were then compared with corresponding windspeed reduction in the same manner as with the TP reduction data; i.e., by regression analysis.

None of the particle size ranges had as significant a relationship with windspeed as TP did, partially because of the smaller data sets available with the particle size data (19 tests instead of 42). Particle size data could not be obtained on many filters because of their light mass loadings. The particle size emission reductions that had the highest correlations with windspeed reduction were 30 - 62 µm and 62 - 176 µm. The two small particle size ranges (<10 µm and 10 - 30 µm) both had poor correlations. Slopes of regression lines for the two particle sizes that were reasonably significant were higher than the slopes for TP, which indicates an emission reduction (in those size ranges) almost equal to windspeed reduction. No explanation was apparent for differences in variation with windspeed for the different particle sizes.

The same frequent negative emission reductions were observed in all particle size ranges, as was the case for TP. This indicates that increased emissions were actually occurring as a result of the screen, rather than as the anomalous result of sampling or laboratory analysis errors.

Factors Other than Windscreen Affecting Emission Rates

Multiple linear regression (MLR) analysis was used to identify external variables affecting emission rates. Only test data from the unscreened pile were utilized because these emission rates were not altered by the presence of the windscreen.

The variables included in the analysis were windspeed, moisture content, and silt content of surface material. Particle size was also a variable in that MLR analyses were run with four different sets of emission rates (<10 µm, <30 µm, <62 µm, and TP) as dependent variables to examine the effects of the external variables on different size ranges of particles.

These regression analyses showed a strong linear relationship between TP emission rate and windspeed and a strong inverse relationship between TP emission rate and moisture content of the pile. Approximately the same relationship was observed between the two variables and emission rates regardless of the size fraction considered.

Objective 3—Development of Windscreen Design Parameters

The final objective of the study was to develop windscreen design parameters. For the three windscreen design parameters that were varied by test, the field test results should provide better information than wind tunnel data for optimizing design values. Conditions such as wind direction variation, surface moisture content, and crusting could be incorporated in field testing, but not in wind tunnel studies.

Stepwise MLR was the statistical test employed. The three windscreen variables—height, length, and distance from pile—were entered along with exogenous variables such as windspeed, surface moisture content, and silt content. None of the exogenous variables had such an overriding effect on relative emission rates with and without the screen that they obscured the impacts of changes in screen parameters. By including these variables in the MLR, the relatively small effects of these variables were taken into account rather than acting as interferences in the direct comparison of test results.

Combining the results of the MLR with graphical analysis led to several design conclusions. Screen lengths of 5.0 D appear to be appropriate for permanent or semipermanent installations. Given the wind direction variations that occur in real situations, the 1.0 to 1.5 D lengths tested in the wind tunnel are probably too short. The 2.0 H screen-to-pile distance was found to be optimum. This distance yielded slightly greater emission reductions than the 1.0 or 3.0 H distance. Both the wind tunnel study and this study showed that the 0.5 H height windscreen was not as effective as screens of 1.0 H. Also, the screen height of 1.0 H is nearly as effective as higher screens. In general, the optimum design parameters appear tc be: porosity = 50 percent; heigh = 1.0 H; width = 5.0 D; and distance = 2.0 H.

Recommendations

The field study has helped to identif several important areas for further in vestigation. Although the wind tunne study and the field study are in genera agreement for the front of the pile, th results are contradictory in one signif cant area. The field study showed tha large portions of the back of the pile ha windspeeds higher than the referenc windspeed. This observation was rein forced by the particulate emission data Negative emission reductions wer noted for the screened pile in a larg number of tests. This basic result is i direct conflict with the bulk of the win tunnel data. Although the inhouse stud found some negative reductions, th field study showed negative reduction as large as 40 percent.

Some ongoing physical process o processes must not have been ade quately investigated. The results to dat raise questions on the applicability o windscreens for reducing emission from storage piles. Before windscreen are recommended as a control me sure, it is imperative that the observe relationship between the use of win screens and the emission rate be inve tigated further.

Metric Equivalents

Readers more familiar with metric units may use the following to convert to that system:

Nonmetric	Times	Yields metric
acre	4047	m^2
ft	0.305	m
in.	2.54	cm
lb	0.454	kg
mi	1.609	km

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***Dale L. Harmon** is the EPA Project Officer (see below).*

The complete report, entitled "Field Evaluation of Windscreens as a Fugitive Dust Control Measure for Material Storage Piles," (Order No. PB 86-231 289/AS; Cost: $16.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

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