Assessment of Soil Moisture and Fixatives Performance in Controlling Wind Erosion of Contaminated Soil at the Hanford Site

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ABSTRACT

During the remediation of burial grounds at the US Department of Energy's (DOE's) Hanford Site in Washington State, the dispersion of contaminated soil particles and dust is an issue that is faced by site workers on a daily basis. This contamination issue is even more of a concern when one takes into account the semi-arid characteristics of the region where the site is located. To mitigate this problem, workers at the site use a variety of engineered methods to minimize the dispersion of contaminated soil and dust particles. Once such methods is the use of water and/or suppression agents (fixatives) that stabilizes the soil prior to soil excavation, segregation, and removal activities. A primary contributor to the dispersion of contaminated soil and dust is wind soil erosion. The erosion process occurs when the wind speed exceeds a certain threshold value (threshold shear velocity), which depends on a number of factors including wind force loading, particle size, surface soil moisture, and the geometry of the soil. Thus under these circumstances the mobility of contaminated soil and generation and dispersion of particulate matter are significantly influenced by these parameters. Wind tunnel experiments were conducted at the Florida International University's Applied Research Center (FIU-ARC) to evaluate the effectiveness of three commercially available fixatives in controlling the mobility of soil particles on soil mounds when exposed to varying wind forces. The fixatives tested included: (1) a calcium chloride solution; (2) a petroleum hydrocarbon emulsion; and 3) a synthetic organic. As an initial step, approximately 500 lbs of uncontaminated soil was obtained from the Hanford Reservation in Washington State. Soil samples were placed in an open-loop, low speed wind tunnel and exposed to wind forces ranging from 10 to 30 miles per hour (mph). Wind erosion controlling capabilities of commercially available fixatives and soil moisture were tested at a laboratory scale. Soil samples with varying moisture (W/W %) content and soil samples treated with fixatives, selected from a wide range of commercially available products, were exposed to a wind speeds ranging from 10 - 30 miles per hour (MPH). During these experiments, amount of soil displaced due to the wind forces, the amount of airborne particulates generated, and the moisture loss were measured to better understand the performance of selected fixatives and soil moisture. Results obtained during the study showed that there is a significant reduction in wind erosion and airborne particles generation by increasing the soil moisture for the velocities tested. Similar trend was observed when the soil samples treated with fixatives were exposed to the same range of velocities (10 - 30 MPH).

1.0 INTRODUCTION

As a result of the past operations, the Hartford Site presently contains over 1,500 identified waste management units, including solid and liquid waste disposal sites, underground storage tanks, unplanned release sites, and contaminated surface structures. Contamination at these sites is widely varied and consists of solid waste, hazardous chemicals, radioactive materials, and mixed contamination. The 618-9 Burial Ground Environmental Restoration Assessment (ERA) document was conducted as a time-critical response action initiated in February 1991. The response action involved the retrieval of organic solvents potentially contaminated with uranium disposed of in 55-gallon drums during the 1950's. Since the solvent had not been detected in the groundwater and there was no significant subsidence on the ground surface, it was felt that at least a portion of the drums were still intact. It was the intent of the ERA to retrieve the solvent before it was released into the environment. The retrieval process consisted of excavating the soil around the intact drums, puncturing the drums with a non-sparking opener, and pumping the material into new containers, which is associated with potential for airborne contamination. The other possible means of contamination is re-suspension of contaminated soil caused by wind forces and escape of radioactive particulates and gases [7]. In the year 2001, Washington State Department of Health oversight program reported the detection of plutonium concentrations just greater than the detection limits [7]; which may be of health and safety concern and appropriate safety methods need to be implemented. To address the hazardous conditions prevailed due to the airborne contamination; DOE authorities used a baseline approach which includes the combination of water and surfactants (fixatives) to suppress airborne contamination. The effectiveness of wind erosion control is dependent on the moisture of the soil, amount of fixative and weather conditions. Another issue that greatly influences the importance of contamination control is the type and quantity of contaminant. Florida International University's Applied Research Center (FIU-ARC) supported the Washington Closure Hanford Field Remediation Project at the Hanford site by analyzing the use of several commercially available fixatives for contamination control of dust and soil particles. The study focused on determining the effects of varying environmental conditions, such as moisture and wind force, on the effectiveness of the selected fixatives.

2.0 MATERIALS AND METHODS

2.1 Fixative Selection

Literature search was conducted through various journals, conference proceedings, and World Wide Web (WWW) for the products and technologies used for stabilization of contamination in soil and dust. Based on the search, a wide range of fixatives and technologies were considered and were short listed by incorporating the pre-collected vendor information from Hanford site personnel and past practices. The extensive list was further reduced based on the substrate considered for this research work (i.e. soil). The fixatives selected for these experiments were RoadMaster™ (calcium chloride), DustBond® (petroleum hydrocarbon emulsion) and DuraSoil® (synthetic organic).

2.2 Experimental Setup

To simulate the wind forces that prevail in the environment, an open-loop low speed wind tunnel was utilized, as shown in Figure 1. Wind tunnel allowed the sample to be exposed to a sustained wind speeds ranging from 10 - 30 mph. The wind tunnel consists of a 12" x 12" x 18" test section that was equipped with a Pitot tube for velocity measurements and sampling cell of 3" x 3" x 1" to place the soil sample and expose it to the various wind speeds. Down stream of the wind tunnel was equipped with a collection box for soil collection. PM10 particulate matter measurements were conducted by using an aerosol analyzer instrument (DustTrack).

Figure 1 Open-Loop, Low Speed Wind Tunnel

3.0 RESULTS AND DISCUSSIONS

Approximately 500 lbs of soil was obtained from an uncontaminated area of the Hanford Reservation in Washington State. The soil sample was split into five smaller specimens for homogenous Bouyoucos sample analysis to determine the particle size distribution [2]. It was determined that the Hanford soil contains an average of 96.2% sand, 3% silt, and 0% clay. It was concluded that soil provided by Hanford was mostly sandy soil [5]. Moisture of the Hanford soil was analyzed using ASTM standard D2216, 50 grams of wet soil specimen was weighted and placed in an oven and heated to 110^{o} C for a period of 24 hours and was found to be 2.7% by weight and was considered as baseline moisture. Two distinct sample matrices were used for the wind tunnel experiments:

1. Hanford soil sample with varying soil moisture by weight (2.7%, 5%, 10%, 15% and 20%)
2. Hanford soil samples having baseline (2.7%) soil moisture treated with selected fixatives (RoadMaster™ (38% calcium chloride), DustBond®, and DuraSoil®).

3.1 Hanford Soil with Varying Percent Soil Moisture by Weight (2.7%, 5%, 10%, 15%, and 20%)

For these experiments, a soil sample weighing 224 grams was used and exposed to wind speeds in the range of 10- 25 mph. Hanford soil with 2.7% moisture by weight was used as a baseline sample and other samples with varying moisture were prepared by adding water to the sample, water need to added were calculated based on the calculations shown in Table 1. Prepared samples were placed in the sampling cell of the wind tunnel's test section and exposed to free-stream winds of 10 - 25 mph (Figure 2). During the experiment, velocity in the test section was recorded at 5 different locations vertically above the soil sample, 0.25", 3", 6", 8", and 10" from the surface of the sample. Sample was exposed to each velocity regime for a period of 10 minutes to be more accurate in assessing the parameters. After each velocity regime, the moisture of the sample was measured to quantify the moisture loss. Experiments were repeated for data consistency and accuracy. After completing each velocity regime, a mass balance was conducted by weighing the soil sample remained in the sampling cell, the amount of soil physically moved downstream and the amount of soil used for moisture analysis.

Table 1 Calculations for obtaining 5% moisture soil sample

Calculations	Results
Weight of the wet sample required	224 grams
Desired final moisture	5.0% by weight
Mass of water present in 5.0% moisture soil	0.05 * 224 = 11.2 grams
Mass of dry soil	0.95 * 224 = 212.8 grams
Moisture of baseline sample	2.7% by weight
Mass of water present in 2.7% moisture soil	0.027 * 224 = 6.05 grams
Mass of 2.7% moisture soil required	212.8 + 6.05 = 218.85 grams
Mass of water to be added	224 – 218.85 = 5.15 grams (ml)

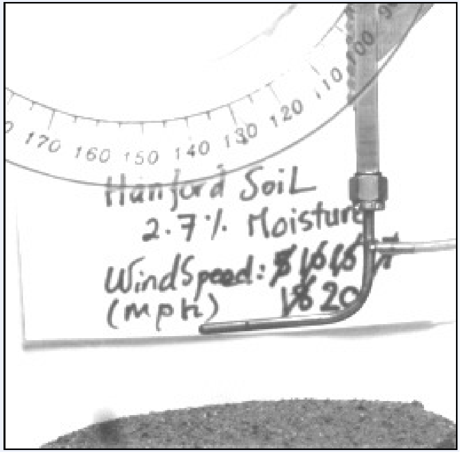

Figure 2 Hanford soil 2.7% moisture at 20 mph

Soil samples with moisture contents ranging from 2.7% to 20% by weight were prepared and used during these experiments. Soils with specific moisture contents were prepared by using Hanford soil, having baseline moisture of 2.7%, and a final weight of 224 grams of wet soil. Since the density of water is 1 g/ml, the amount of water added to 224 grams of soil with 2.7% moisture to attain 224 grams of soil with 5.0% moisture is 5.15 grams or ml (Table 1). The amount of 2.7% moisture soil required/used and the amount of water added to the sample to obtain required soil moistures are summarized in Table 2.

Table 2 Quantities of soil and water used for preparing desired soil samples

Moisture %	Amount of 2.7% moisture soil used (grams)	Amount of water added (ml)
5.0	218.85	5.15
10.0	207.65	16.35
15.0	196.45	27.55
20.0	185.25	38.75

Figure 3 represents the average mass of the sample displaced for each velocity regime during the experiment conducted with 2.7% and 5% moisture soil samples. At the lowest moisture tested (2.7% moisture), a total of 164.5 grams (73% of sample) of sample was collected downstream of the wind tunnel after exposing to the range of velocities (10 - 25 mph). The final average mass remaining in the wind tunnel's sampling cell at the end of the experiments was 32.0 grams (14% of the soil). The soil moisture at the end of the experiment was measured to be 1.9% by weight. The moisture loss was quantified to be 1.8 grams (0.8% of the soil). A total of 11.4 grams (5.0% of the soil) was collected and used for moisture measurements and 12.3 grams (5.5% of the soil) was lost via airborne particulates generated and escaped through the open end of the wind tunnel.

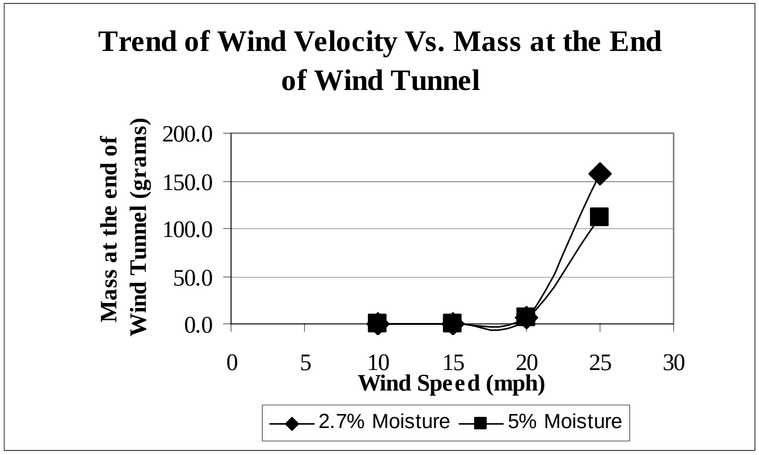

Figure 3 Trend of wind velocity vs. mass collected at wind tunnel's exit for soil with 2.7% and 5% moisture

Figure 4 represents the average mass of the sample displaced for each velocity regime during the experiment conducted with 10%, 15% and 20% moisture soil samples. At the maximum moisture tested (20% moisture), no soil was displaced and the sample appeared to be intact. The amount of soil collected at the back end of the wind tunnel was quantified as 0.0 grams. The final average mass remaining in the wind tunnel's sampling cell at the end of the experiments was 197.5 grams (88.2% of the soil). The soil moisture at the end of the experiment was measured to be 12.1% by weight. The amount of soil loss due to moisture was calculated to be 6.3 grams. Throughout the experiment, a total of 11.3 grams (5.0% of the soil) was collected and used for moisture measurements. Approximately 2.8 grams (1.3% of soil) was believed to be airborne and/or escaped through the open back end of the wind tunnel.

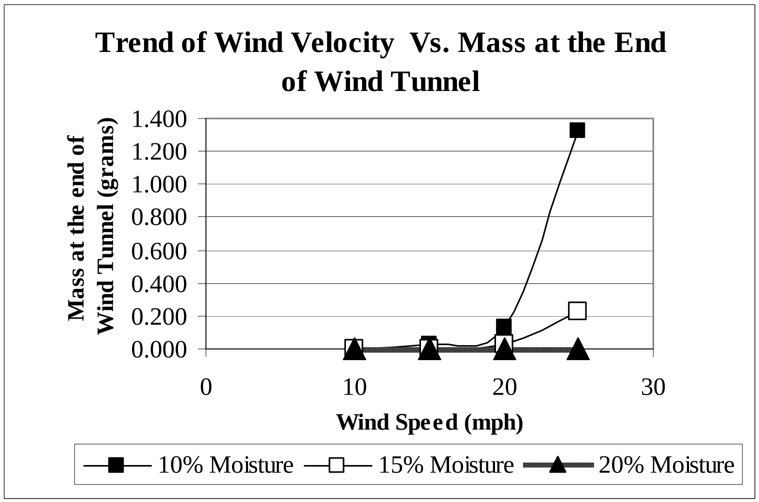

Figure 4 Trend of wind velocity vs. mass collected at wind tunnel's exit for soil with 10%, 15%and 20% moisture

3.2 Hanford Soil Sprayed With Selected Fixatives

Initial phase of these experiments were conducted using manufacture's recommended dilution and/or application rates for the fixatives selected and no soil movement was observed. So new dilution and/or application rates were calculated, the calculations of application and dilution rates are shown in Table 3.

Table 3 Summary of fixatives application and dilution rates

Fixative	Dilution	Volume of Fixative (ml)	Volume of Water (ml)
RoadMaster™	2.50%	0.69	9.84
	5.00%	1.38	9.15
	7.50%	2.07	8.46
	10.00%	2.76	7.77
DustBond®	7 : 1*	4.93	34.49
	1 : 1 *	4.93	4.93
	0.5 : 1*	4.93	2.465
DuraSoil®	100% †	11.8	--
	50% †	5.94	--
	25% †	2.97	--

*Water : Dustbond® Ratio
† Application rate (not dilution)

3.2.1 Results for RoadMaster™ Fixative

Various RoadMaster™ (Calcium Chloride solution) samples were prepared by spraying the amounts of fixative volumes presented in Table 3, by using 224 grams of Hanford soil sample with 2.7% moisture. It was observed that the RoadMaster™ covered 100% of the surface of the soil sample for all application rates. As represented in Figure 5, at a concentration of 2.5% CaCl, a total average of 10.0 grams (4.3% of the soil) was collected downstream of the wind tunnel's test section for the range of velocities tested. The final average mass remaining in the wind tunnel's test section at the end of the experiments was 210.0 grams (91.3% of the soil). An average of approximately 10 grams (4.3%) of soil was airborne and lost due to evaporation effects.

In addition at RoadMaster™ concentrations of 7.5% and 10%, a total average of 2.0 grams (0.8% of the soil) and 0 grams respectively were collected downstream of the wind tunnel's test section for a range in velocities of 10 to 30 mph. The final average mass remaining in the wind tunnel's test section at the end of the experiments was 222.0 grams (96.1% of the soil) and 220 grams respectively (95.2% of the soil) for these two concentrations. An average of approximately 7 grams (3.0% of the soil) and 11 grams (4.8% of the soil), respectively, was airborne and lost due to evaporation effects.

Based on the results from these experiments, it was determined that the RoadMaster™ provided excellent soil suppression when the soil was exposed to the prescribed velocity ranges.

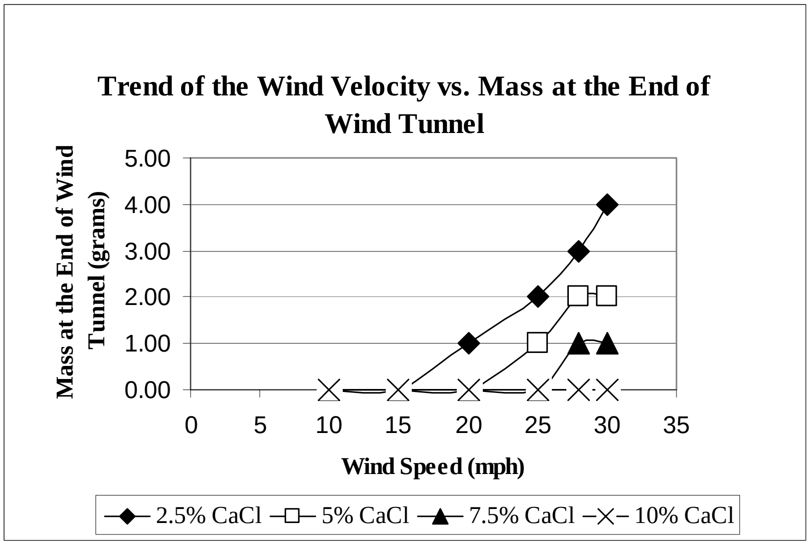

Figure 5 Trend of wind velocity vs. mass collected at the end of the wind tunnel for RoadMaster™

3.2.2 Results for DustBond® Fixative

DustBond® was sprayed on 224 grams of Hanford soil sample containing 2.7% moisture. It was also observed that the DustBond® covered 100% of the surface of the soil sample for all the dilution ratios applied. As presented in Figure 6, at a dilution ratio of 0.5:1 (Water: DustBond®), a total average of 3.0 grams (1.3% of the soil) was collected downstream of the wind tunnel's test section for the range of velocities tested. For this dilution ratio, a total mass of 231 grams of soil was used (224 grams of soil and remaining is the amount of fixative applied). The final average mass of sample remaining in the wind tunnel's test section at the end of the experiments was 223.0 grams (96.5% of the soil). An average of approximately 4.3 grams (1.8% of the soil) of soil was airborne and lost due to evaporation effects.

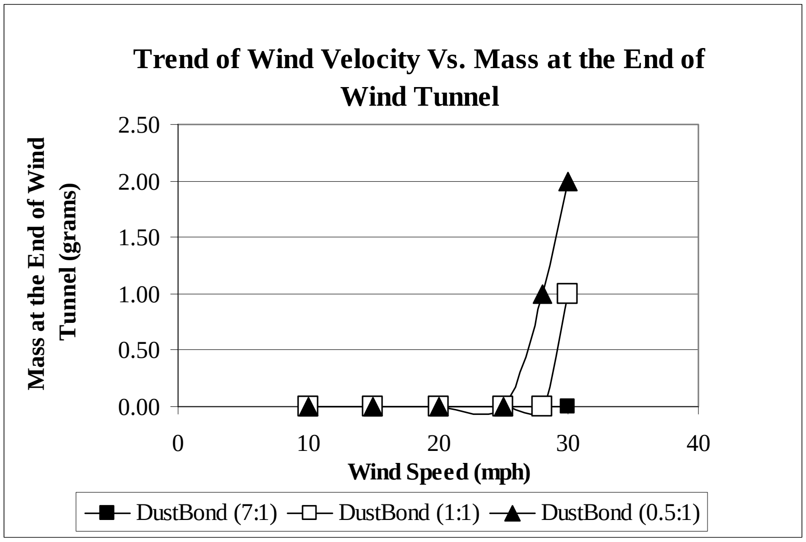

Figure 6 Trend of wind velocity vs. mass collected at the end of the wind tunnel for DustBond®

At a dilution ratio of 7:1 (Water: DustBond®), a total average of 0.0 grams (0% of the soil) was collected downstream of the wind tunnel's test section for a range in velocities tested (10-30 mph). For this dilution ratio, a total mass of 242.5 grams of soil was used (224 grams of soil and remaining is the amount of fixative applied). The final average mass remaining in the wind tunnel's test section at the end of the experiments was 238.5 grams (98.3% of the soil) and an average of approximately 4 grams (1.6% of the soil) was airborne and lost due to evaporation effects. It can be observed from Figure 6 below that there is no soil movement for velocities under 25 mph at dilution ratio of 0.5:1 (Water: DustBond®) and only 1 gram of soil was moved at 30 mph for dilution ratio of 1:1 (Water: DustBond®).

Based on the results from these experiments, it was determined that the DustBond® provided better results than RoadMaster™ in soil suppression when the soil was exposed to the prescribed velocity ranges.

3.2.3 Results for DuraSoil® Fixative

The DuraSoil® fixative was mixed with 231 grams of Hanford soil sample for three application rates (25%, 50%, and 100%) of DuraSoil®. Application was accomplished by pouring the above solutions onto the soil sample. It was observed that the DuraSoil® covered only approximately 80% of the surface of the soil sample. From Figure 7 it is shown that at an application rate of 25% of DuraSoil®, a total average of 5.0 grams (2.1% of the soil) was collected downstream of the wind tunnel's test section for this range in velocities. For these experiments, a total mass of 230 grams of soil was used. The final average mass remaining in the wind tunnel's test section at the end of the experiments was 222.3 grams (96.6% of the soil). An average of approximately 2.6 grams (1.2% of the soil) of soil was airborne and lost due to evaporation effects.

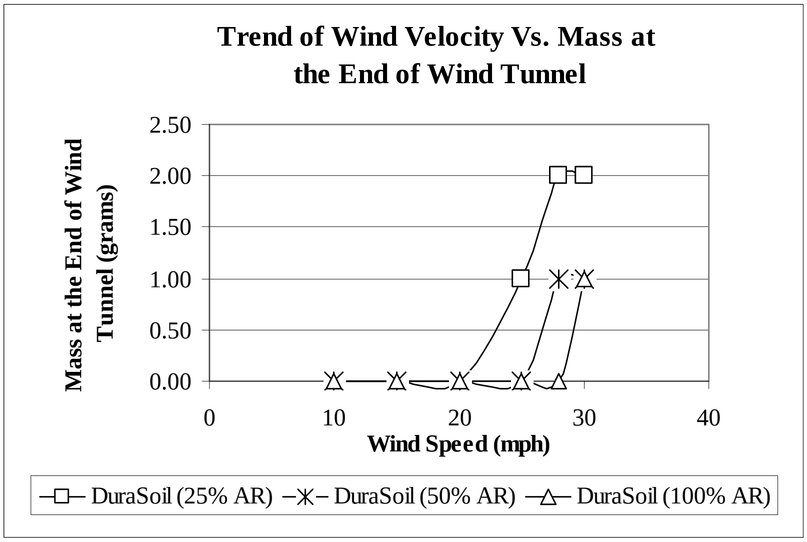

Figure 7 Trend of wind velocity vs. mass collected at the end of the wind tunnel for DuraSoil®

From Figure 7 it is shown that at an application rate of 100% of DuraSoil® (vendor recommended), a total average of 1.0 grams (0.4% of the soil) were collected respectively downstream of the wind tunnel's test section for a range in velocities of 10 to 30 mph. For this test, a total mass of 234.0 grams of soil was used. The final average mass remaining in the wind tunnel's test section at the end of the experiments was 229.7 grams (98.1% of the soil). An average of approximately 3.3 grams (1.4% of the soil) was airborne and lost due to evaporation effects.

3.3 PM10 Particulate Matter Measurements

A real time dust (aerosol) monitor (TSI 8520 Dust Track) was used to record PM10 particulate matter measurements and was placed at approximately 1 inch behind the soil mound in the wind tunnel test section. For the purpose of this study, it was determined that PM10 particle measurements were recorded for a 10-minute time frame would be sufficient to provide an idea of the amount of airborne particles generated by the wind. PM10 particle size measurements were collected for Hanford soil with varying percent moisture (2.7% - 20% by weight) for a velocity range from 10 to 25 mph. Figure 8 and 9 respectively show the amount of airborne particulates concentrations obtained during these experiments. The largest concentration recorded for the Hanford soil with 2.7% moisture and at a velocity of 25 mph was 240 mg/m^3. The amount of airborne particulate generated was increased with the increase of wind velocity. For the same soil moisture (2.7%) but a lower wind velocity (15 mph), an average airborne particulate concentration was only 8.72 mg/m^3. It was also observed that as the soil moisture content was increased, the amount of airborne particulates decreased.

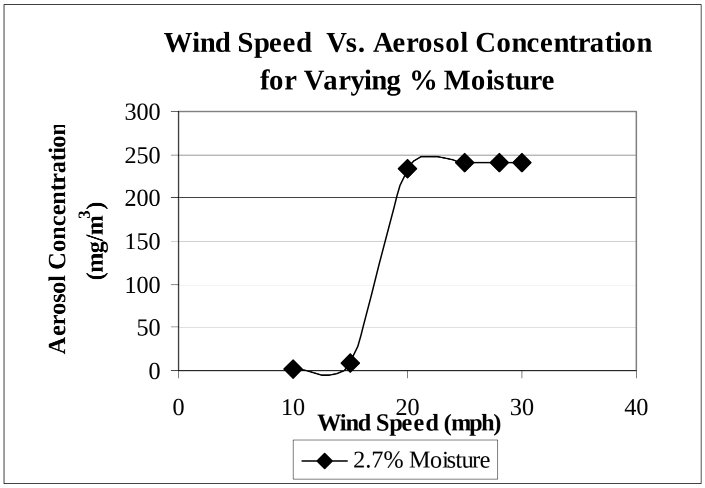

Figure 8 Average airborne particulates concentration for Hanford soil with 2.7% moisture

The DustBond® fixative showed better performance in suppressing the soil when compared with the other two. It can also be seen from the data that the amount of airborne particulate generated increases as the velocity increases; this is true for all the three fixatives (see Table 4). It can also be observed that the fixative performance is comparable with the previous results obtained for Hanford soil with 15% and 20% moisture content. Also, vendor recommended concentrations where used for DustBond® and DuraSoil® fixatives (7.0:1.0 and 100% application rate respectively). A significant difference in the results was observed at these concentrations. For example, at 30 mph, the airborne concentration for DustBond® is 0.400 mg/m^3 as compared to the results obtained for DuraSoil® at the same wind velocity, 1.480 mg/m^3. All things being equal, 73% more airborne concentration was detected when soil was sprayed with DuraSoil® for the same velocity (30 mph).

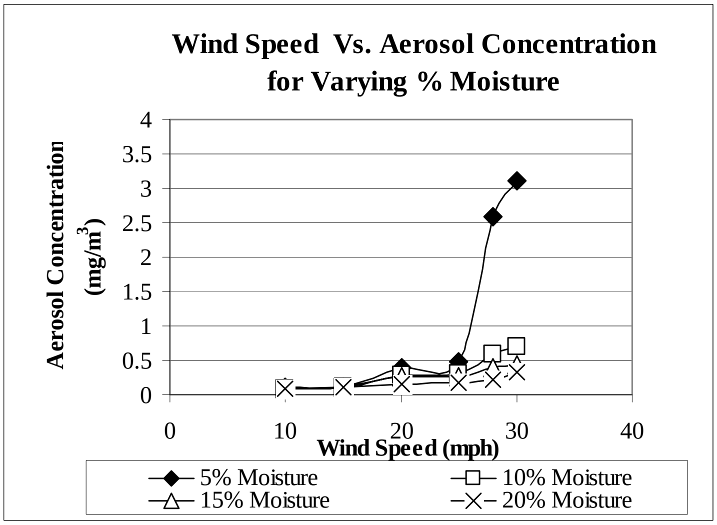

Figure 9 Average airborne particulates concentration for Hanford soil with varying % moisture

Table 4 Average airborne particulate concentration for Hanford soil with selected fixatives (RoadMaster™, DustBond®, and DuraSoil®)

Speed (mph)	**RoadMaster™ (% CaCl)**				**DustBond® (water : DustBond®)**			**DuraSoil® (application rate)**		
	2.5%	**5.0%**	**7.5%**	**10.0%**	**0.5 : 1.0**	**1.0 : 1.0**	**7.0 : 1.0**	**25%**	**50%**	**100%**
10	0.237	0.152	0.137	0.051	0.205	0.136	0.098	0.158	0.140	0.139
15	0.249	0.202	0.211	0.110	0.253	0.211	0.098	0.280	0.250	0.230
20	0.354	0.308	0.298	0.262	0.371	0.260	0.160	0.322	0.305	0.280
25	0.459	0.405	0.395	0.366	0.395	0.360	0.269	0.412	0.405	0.380
28	2.923	0.48	0.469	0.288	0.503	0.469	0.370	0.500	0.502	0.495
30	3.097	2.578	1.503	0.615	0.637	1.503	0.400	2.630	1.520	1.480

4.0 CONCLUSIONS

4.1 Wind and Soil Mobility

Based on the results, it was concluded that an increase in velocity played a major role in the displacement of soil and airborne particulates generation during the wind tunnel experiments. For Hanford soil with 2.7% moisture, there was a 99.7% increase of soil loss as velocity was increased from 15 to 25 mph. Similar patterns were observed for Hanford soil containing 5% moisture by weight. Also a conclusion can be made that moisture content plays a significant role in the ability of the soil to move when exposed to varying wind speeds, as it was also observed from the experiments that there is no soil loss when the moisture content in the soil is 20% by weight; this is true at any velocity between 10 and 25 mph.

In the case of the RoadMaster™ fixative, the highest amount of soil loss was obtained at 30 mph and for the lowest concentration rate applied. Based on the results obtained in the experiments, an average of only 10.0 grams (4.3%) of the soil was lost at a 2.5% dilution rate (0.69 ml of calcium chloride) and 2.0 grams (0.8%) of the soil at 7.5% dilution rate (2.07 ml of calcium chloride) during the entire experiment. The difference between these two concentrations (in terms of ml) is 66.7% more calcium chloride was used to capture an additional 8 grams of soil. When compared to the vendor recommended 10.53 ml (38% calcium chloride) concentration, the difference between these two concentrations (in terms of ml) is 93% more calcium chloride is used to capture only 10 grams of additional soil. It can be concluded that there may be significant cost saving by reducing the dilution ratio of the calcium chloride to 2.5% and/or 5% since there is no significant increase in the amount of soil suppressed by increasing the concentrations of calcium chloride from 2.5% to 38% (vendor recommended).

For DustBond® fixative, an average of 3.0 grams (1.3%) of the soil was lost at the dilution ratio of 0.5:1 (Water: DustBond®), where as at the 7:1 (Water: DustBond®) dilution ratio, no soil loss was observed at any velocity between 10 mph and 30 mph. The amount of water used for 7:1 (Water: DustBond®) and the 0.5:1 (Water: DustBond®) dilution ratios are 34.5 ml and 2.5 ml respectively. The difference in the amount of water for these two dilution ratios is significant

(92.7%), but the improvement in suppression performance is minimal. It can be concluded that cost saving can be achieved in field applications just by reducing the amount of water.

For DuraSoil® fixative experiments at the 25% application rate, only an average of 5.0 grams (2.1%) of the soil was lost, compared to a total average of 1.0 grams (0.4%) of soil loss at an application rate of 100%. The difference in the amount of DuraSoil® used for these two application rates, 25% and 100%, are 2.97 ml and 11.8 ml, respectively. Again, it is believe that cost savings can be achieved by reducing the application rate of the DuraSoil®. Overall, it can be concluded that the selected fixatives performed better then anticipated. The results for the fixatives outperformed the Hanford soil with 2.7% moisture (baseline case).

4.2 Airborne Particulates Measurements

The largest concentration (240 mg/m^3) was recorded for the Hanford soil with 2.7% moisture and at a velocity of 25 mph. It was concluded that, from the experimental data, the amount of airborne particulate generated increased with increasing wind velocity. It was also noticed that as the soil moisture content was increased, the amount of airborne particulates decreased. It was concluded from the experimental data that all of the fixatives tested showed very good performance in suppressing the soil particles and airborne particles for all velocity ranges tested. The DustBond® fixative showed better performance in suppressing the soil when compared with the other two fixatives. It was also observed from the data that the amount of airborne particulate generated increased as the velocity increased; this is true for all three fixatives tested. It can also be observed that the fixatives performance is comparable with the previous results obtained for Hanford soil with 15% and 20% moisture.

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