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Summary Report for Evaluation of Compost Sample Drying Methods

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The U.S. Army Environmental Center (USAEC), formerly the U.S. Army Toxic and Hazardous Materials Agency, has evaluated composting methods for treatment of explosive-contaminated soils and sediments at Army installations. Previous work in support of these efforts developed a compost sample preparation scheme, consisting of air drying followed by milling, to reduce analytical variability in the heterogeneous compost matrix. While this procedure successfully reduced variability, USAEC determined that the time required for air drying results in undesirable delays in analytical results turnaround. The time required to air dry compost samples was typically 3 to 5 days. As a result of this determination, this study on alternative drying methods was conducted.

Three drying methods were examined in this test: (1) air drying as used in previous work, (2) oven drying at 60°C, and (3) convection oven drying at 60°C. The maximum drying temperature of 60°C was based upon the low melting points of the target explosives. Drying methods were compared in terms of time required to achieve specified dryness levels and potential effects on residual explosives levels.

The results of this testing indicate that convection oven drying at 60°C results in rapid and satisfactory drying of compost samples. Required dryness levels (greater than 95% solids) were achieved in approximately 12 hours with this drying method. These tests demonstrate that conventional, commercially available convection ovens can be used for compost sample preparation during field operations.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The U.S. Army Environmental Center (USAEC) has evaluated composting methods for treatment of explosives-contaminated soils and sediments at Army installations. Previous work in support of these efforts developed a compost sample preparation scheme, consisting of air drying followed by milling, to reduce analytical variability in the heterogeneous compost matrix. While this procedure successfully reduced variability, USAEC determined that the time required for air drying results in undesirable delays in analytical results turnaround. As a result of this determination, USAEC conducted this study of alternative drying methods.

Three drying methods were examined in this test: (1) air drying as used in previous work, (2) oven drying at 60°C, and (3) convection oven drying at 60°C. The maximum drying temperature of 60°C was based upon the low melting points of the target explosives. Drying methods were compared in terms of time required to achieve specified dryness levels and potential effects on residual explosives levels.

The results of this testing indicate that a compost solids concentration of at least 91% was required for proper milling. Oven drying required approximately 25 hours to achieve the target dryness levels (>95% solids) while air drying required approximately 212 hours to reach these levels. Convection oven drying at 60°C resulted in rapid and satisfactory drying of compost samples. Target dryness levels were achieved in approximately 12 hours with this drying method. It is expected that conventional, commercially available convection ovens can be used for sample preparation during field operations.

SECTION 1
INTRODUCTION

1.1 BACKGROUND

Roy F. Weston, Inc. (WESTON®) has conducted pilot-scale field studies for the U.S. Army Environmental Center (USAEC) to evaluate seeding and windrow composting for the treatment of explosives-contaminated soils from washout lagoons at the Umatilla Depot Activity (UMDA) in Umatilla, Oregon (1). Monitoring of the composting treatment process requires routine analysis of samples for explosives.

Analytical samples for explosives in compost are prepared by milling the samples in a Thomas-Wiley mill. Drying of the samples (which are moist when drawn from the pile/reactor) is necessary for effective milling. In the past, air drying (at ambient temperatures and environmental conditions) has been employed. The time required for air drying is typically 5 days. This sample preparation scheme was developed by USAEC and USGS (2) and was intended to improve the quality of the analytical data for this highly heterogeneous matrix.

Prior experience indicates that air drying to solids values of 95% or greater is satisfactory from the standpoint of milling machine operation and analytical reproducability. Volatilization or other abiotic loss of explosives during the drying step has not been considered to be a significant problem.

While the basic goals regarding analytical quality have been met, it is necessary to improve the drying step. The principal concern over the current air drying procedure is that air drying introduces substantial delay in analytical turnaround time which will hamper the efficiency of full-scale operations and add additional cost.

USAEC tasked WESTON to conduct a laboratory testing program to examine alternative compost drying methods to address this issue.

1.2 OBJECTIVES

The primary objective of the laboratory tests was to evaluate alternative compost drying methods to identify a method which will reduce the drying time for samples to less than 12 hours. Another important objective of the study was to determine the effect of the drying procedures on explosives concentration (i.e., TNT, RDX, and HMX).

1.3 SCOPE OF WORK

The laboratory study investigated the feasibility of the following two drying methods:

- Oven drying at 60°C.
- Desiccation (convection drying) at 60°C.

The current air drying procedure was also included in the study as a baseline for comparison of the performance of the oven drying methods. The drying temperature for the oven drying methods was set at 60°C to be below the melting temperature and TNT. In addition, this value is at or slightly above the range maintained during the composting operation (typically 50-60°C).

The testing program evaluated the effect of the drying method in terms of the following criteria:

- Degree of dryness achieved as a function of time.
- Degree of dryness required for effective milling and decontamination of the milling equipment.
- Effect of drying procedures on explosives concentration.

Triplicate analyses for solids content and explosives concentrations were conducted for each drying method over a range of solids content values. The results of the study were used to identify a standard of dryness required for homogenization (i.e., milling) of compost samples and provide an assessment of the drying methods in terms of time required to achieve the specified dryness.

The technical approach for the laboratory study was described in WESTON's "USAEC Evaluation of Compost Sample Drying Methods, Test Protocol" (3). The work was authorized under Contract Number DACA31-91-D-0079-0001, Task Order Number 0001, Modification 5, Composting of Explosives, Optimization Study.

SECTION 2
TESTING PROGRAM

2.1 OVERVIEW

The compost sample drying study was conducted at WESTON's Environmental Technology Laboratory (ETL) located in Lionville, Pennsylvania. The various tasks of the study were performed during May 1993. Sample analyses were performed at WESTON's Analytical Laboratory in Lionville, Pennsylvania.

The test program evaluated three alternative drying methods using compost samples from UMDA. The methods consisted of oven drying, convection drying, and air drying. Triplicate analyses were conducted to evaluate the milling properties, solids concentrations, and explosives concentrations in the compost samples. The test program for the compost sample drying study is presented in Table 2-1. The program outlined in Table 2-1 represents a slight modification to the original test protocol. Under the original plan, samples were to be collected at various times over a 96 hour drying period (i.e., the estimated time required for air drying). However, since compost solids concentration was the key variable impacting milling, sample collection during the study was conducted at designated solids contents and the associated drying time was noted.

2.2 COMPOST SOURCE

Compost used in the drying study consisted of finished compost collected from the composting recycle field demonstration test at UMDA (1). The compost was selected from stockpiled finished compost for the seed study (static pile tank reactor) which was known to have measurable explosives concentrations based upon previous analytical data. Approximately 30 gallons of compost was collected during May 1993 and shipped directly to the ETL.

Table 2-1

Test Matrix for Explosives and Solids Content Analyses

Approximate Solids Content, %	Number of Samples				
	Drying Method				Total
	Initial	Air	Oven	Convection	
59	3 (1)	3	3	3	12
70	- -	3	3	3	9
80	- -	3	3	3	9
90	- -	3	3	3	9
95	- -	3	3	3	9
Total	3 (1)	15	15	15	48

(1) Analyzed for solids content only.

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2.3 DRYING METHODS

Air drying, as conducted in past field demonstrations, was used as a baseline for evaluation of the oven drying methods. Air drying consisted of drying compost samples on wire racks located in the ETL's geotechnical testing laboratory at ambient temperature and relative humidity. The ambient temperature ranged from 20°C (68°F) to 22°C (72°F) during the study. The relative humidity ranged from 30% to 80% during the study.

Oven drying was conducted in a Blue-M Model INW 360 non-mechanical convection oven maintained at a constant temperature of 60°C (152°F). The heating elements were located in the side-walls and bottom of the oven. Heat was transferred to the interior space via conduction/radiation forces. No forced or mechanical convection was utilized. The oven had a capacity of eight cubic feet and was vented at the top to expel water vapor. The oven drying method is based on procedures used to assess mixed liquor suspended solids (biomass) concentrations in wastewater treatment operations except that a lower temperature was employed due to the low melting point of TNT.

Convection drying was conducted in a VWR Model 1370F mechanical convection oven maintained at a constant temperature of 60°C (152°F). The heating elements were located in the side-walls of the oven. Heat was transferred to the interior space via mechanical convection. Mechanical convection consisted of using a high capacity fan (turbo) to continuously circulate the interior air across the heating elements and the compost samples. The oven had a capacity of six cubic feet and was vented at the top to expel water vapor. Convection drying was intended to simulate the use of a tray-type food dehydrator.

2.4 TESTING PROCEDURES

The bulk compost sample was mixed and split into 48 test samples. A set of 15 compost samples were placed on the air drying racks and in each of the ovens (regular and convection). Triplicate samples were collected from each of the drying systems at five selected solids content values to provide data covering the total drying period. Total drying period was defined as the total time for the compost to reach at least 95% solids concentration. Prior to the study, the projected total drying period for air drying was 96 hours and for oven and convection drying was 12 hours.

The objective of the sample collection was to obtain test samples from each drying system initially, and after the solids concentrations have reached approximately 70%, 80%, 90% and 95% . The solids concentration was estimated at various times during the total drying period based on the initial solids concentration of the compost, the tare weight of the sample pans, and the gross weight (sample and pan) of each test sample initially and at each of the various times. The initial solids concentration of the compost was determined from the average solids concentration of triplicate "as received" samples collected from the bulk compost sample.

Each test sample was comprised of approximately 200 grams of compost, spread evenly across the bottom of a pre-weighed aluminum baking pan. The pan was approximately 4" wide, 6" long, and 4" deep. The gross weight of each test sample was measured initially and periodically throughout the total drying period to estimate the sample solids concentration and determine if analytical samples should be collected. During periodic weight measurements, test samples were removed from the drying system, immediately weighed without cooling, and then quickly placed back into the drying system until collection. (The approximate dryness levels obtained by these measurements were used to guide the selection of samples used for analysis.) In addition, during each periodic weighing, test samples were rotated to different locations in the drying system to maintain uniform heating rates.

After collection, each test sample was milled using the Thomas-Wiley Laboratory Mill, Standard Model 4 (the same mill that has been used to prepare compost samples during past field demonstrations), placed in a 250 mL amber jar, and submitted to the analytical laboratory for solids content and explosives analyses. Observations during milling were recorded. If the test sample was too wet to be milled, (i.e., the compost clogged the mill), the compost was placed directly into the sample jar without milling and submitted to the laboratory for analysis.

Solids and explosives analyses were conducted on the "as received" test sample submitted to the analytical laboratory. Solids analyses were conducted according to ASTM Method D2216. Explosives analyses for RDX, HMX, and TNT were conducted according to SW846 Method 8330. For the explosives analyses, no additional drying occurred after sample submittal. This was to ensure that any results regarding changes in explosives levels reflected only the sample drying methods being evaluated. All explosives results were reported on a dry weight basis (using the results of separate solids content analyses). The maximum sample quantity was used for analysis to increase the sensitivity of each test. In the previous composting field demonstration (1), sample volumes for explosives analysis were increased to 10 g of soil (from the method-specified 2 g samples) due to the relatively heterogeneous compost matrix. For this study, all explosives analyses were conducted using 15 g of "as received" sample and 40 mL of solvent for extraction (the method requires 2 g of dry sample and 10 mL of solvent). The additional sample volume was intended to account for the moisture in the "as received" samples. Typical detection limits for the explosives analyses during this study were 1 to 2 mg/kg. Explosives analyses were confirmed by analysis on a second column.

SECTION 3
RESULTS

3.1 RESULTS SUMMARY

Replicate and average test results for the compost drying study are summarized in Tables 3-1 and 3-2, respectively. The relationship between average compost solids concentration and drying time for each drying method is illustrated in Figure 3-1. The relationship between average compost explosives concentration and solids concentration for each drying method is illustrated in Figure 3-2.

The study results for total drying time indicate that convection drying was the fastest drying method, drying 200 gram compost samples from 59% solids to 95% solids in approximately 12 hours. Oven drying was the second fastest drying method, drying compost samples to 95% solids in approximately 20 hours. Air drying was the slowest drying method, drying compost samples to 95% solids in approximately 166 hours. Note that for air drying, approximately half the total drying time was required to increase the compost solids concentration from 90% to 97%.

Milling observations indicated that the compost could not be processed through the mill at solids concentrations at or below 90%, but could be processed through the mill at solids concentrations above 91%. Therefore, a minimum solids concentration of approximately 91% in the compost was required for proper milling. Compost at solids concentrations less than 91% caused clogging of the mill and difficulties in decontamination of the unit between samples.

The time required for each drying method to dry 200 gram compost samples to the minimum solids content for milling (91%) can be interpolated from Figure 3-1, which illustrates compost solids concentration versus time. The drying time required to reach 91%

Table 3-1

Compost Drying Study - Replicate Test Results

Parameter	Drying Method	Target Solids (%)														
		59			70			80			90			95		
Drying Time (hours)	Air	0	0	0	51	51	51	101	101	101	149	149	149	212	212	212
	Oven	0	0	0	11	11	11	20	20	20	22	22	22	25	25	25
	Convection	0	0	0	2.5	2.5	2.5	7	7	7	11	11	11	12	12	12
Millable (Y/N)	Air	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
	Oven	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Convection	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
Solids Conc. (%)	Air	57.2	61.2	54.0	76.2	74.3	74.2	91.0	89.8	90.1	94.6	94.2	93.8	97.6	96.7	97.5
	Oven	56.5	60.7	57.9	75.2	77.9	77.4	90.7	89.5	93.6	99.7	99.1	97.2	99.4	98.5	99.8
	Convection	59.8	59.9	61.3	68.0	75.3	66.7	86.0	85.8	91.0	92.6	92.2	97.4	95.3	92.2	96.4
RDX Conc. (mg/kg)	Air	1,100	860	840	820	910	970	820	720	690	870	840	800	830	800	860
	Oven	900	850	880	930	970	1,000	1,200	1,100	1,200	630	740	700	580	650	650
	Convection	950	900	920	760	1,000	1,000	920	910	940	910	1,100	810	890	1,100	850
HMX Conc. (mg/kg)	Air	490	390	400	430	430	450	370	330	320	370	370	370	340	330	360
	Oven	430	410	420	440	460	480	540	550	540	300	340	310	280	300	300
	Convection	430	430	440	350	490	490	420	430	430	410	430	320	360	480	320
TNT Conc. (mg/kg)	Air	7.5	12.0	10.0	11.0	17.0	11.0	23.0	16.0	34.0	59.0	13.0	13.0	11.0	23.1	51.0
	Oven	16.0	5.6	11.0	7.8	6.0	5.9	27.0	24.0	17.0	8.8	22.0	31.0	18.0	12.0	38.0
	Convection	8.9	7.9	22.0	15.0	17.0	78.0	7.5	6.4	23.0	20.0	13.0	27.0	11.0	21.0	38.0

RESULTS1.XLS

Table 3-2

Compost Drying Study - Average Test Results (1)

Parameter	Drying Method	Target Solids (%)				
		59	70	80	90	95
Drying Time (hours)	Air	0	51	101	149	212
	Oven	0	11	20	22	25
	Convection	0	2.5	7	11	12
Millable (Y/N)	Air	N	N	N	Y	Y
	Oven	N	N	Y	Y	Y
	Convection	N	N	N	Y	Y
Solids Conc. (%)	Air	58.7	74.9	90.3	94.2	97.3
	Oven		76.8	91.3	98.7	99.2
	Convection		70.0	87.6	94.1	94.6
RDX Conc. (mg/kg)	Air	911	900	743	837	830
	Oven		967	1167	690	627
	Convection		920	923	940	947
HMX Conc. (mg/kg)	Air	427	437	340	370	343
	Oven		460	543	317	293
	Convection		443	427	387	387
TNT Conc. (mg/kg)	Air	11.2	13.0	24.3	28.3	28.4
	Oven		6.6	22.7	20.6	22.7
	Convection		36.7	12.3	20.0	23.3

(1) Averages are based on triplicate analyses except for the initial test results, which are based on nine replicate analyses.

RESULTS1.XLS

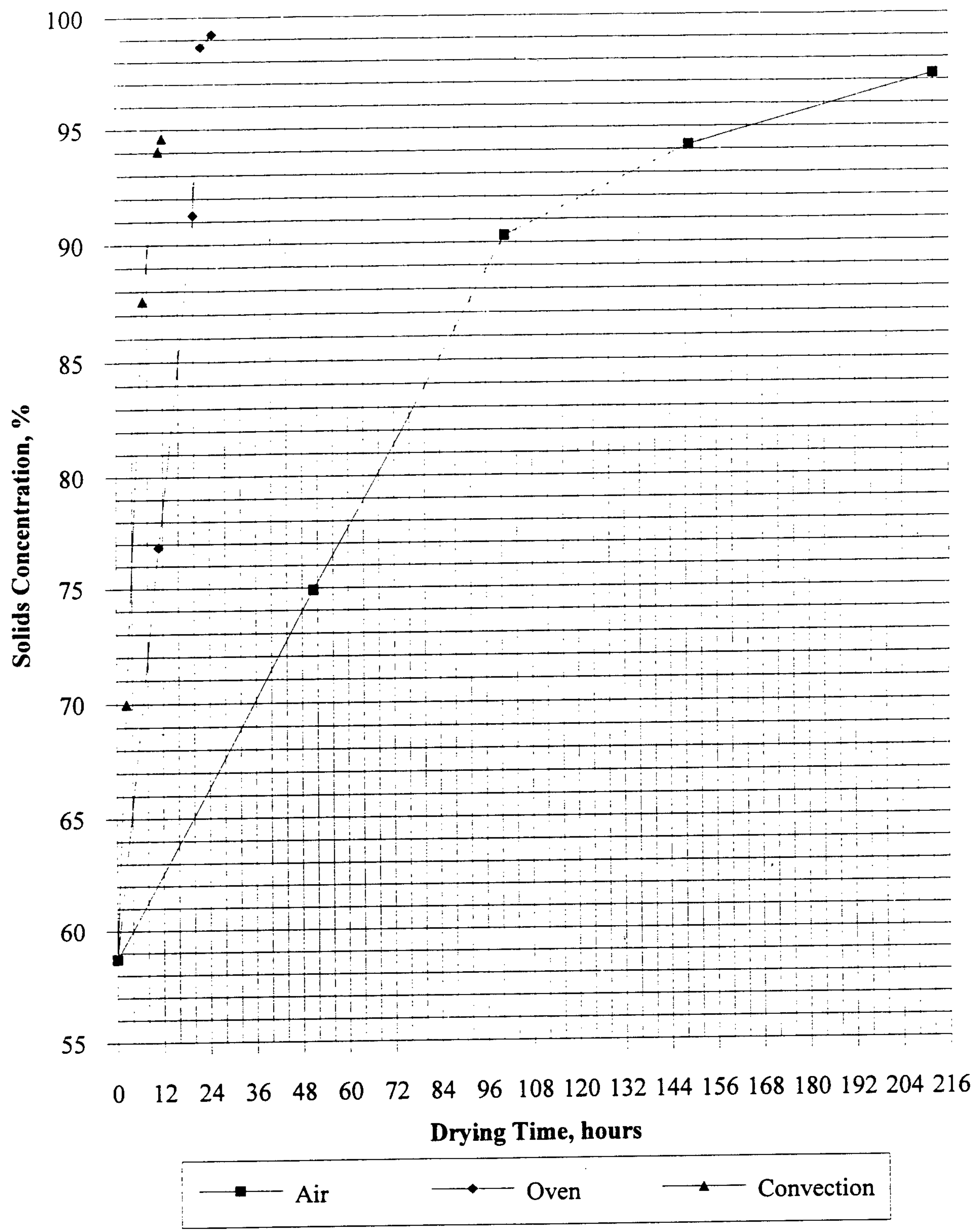

Figure 3-1 : Compost Average Solids Concentration versus Drying Time.

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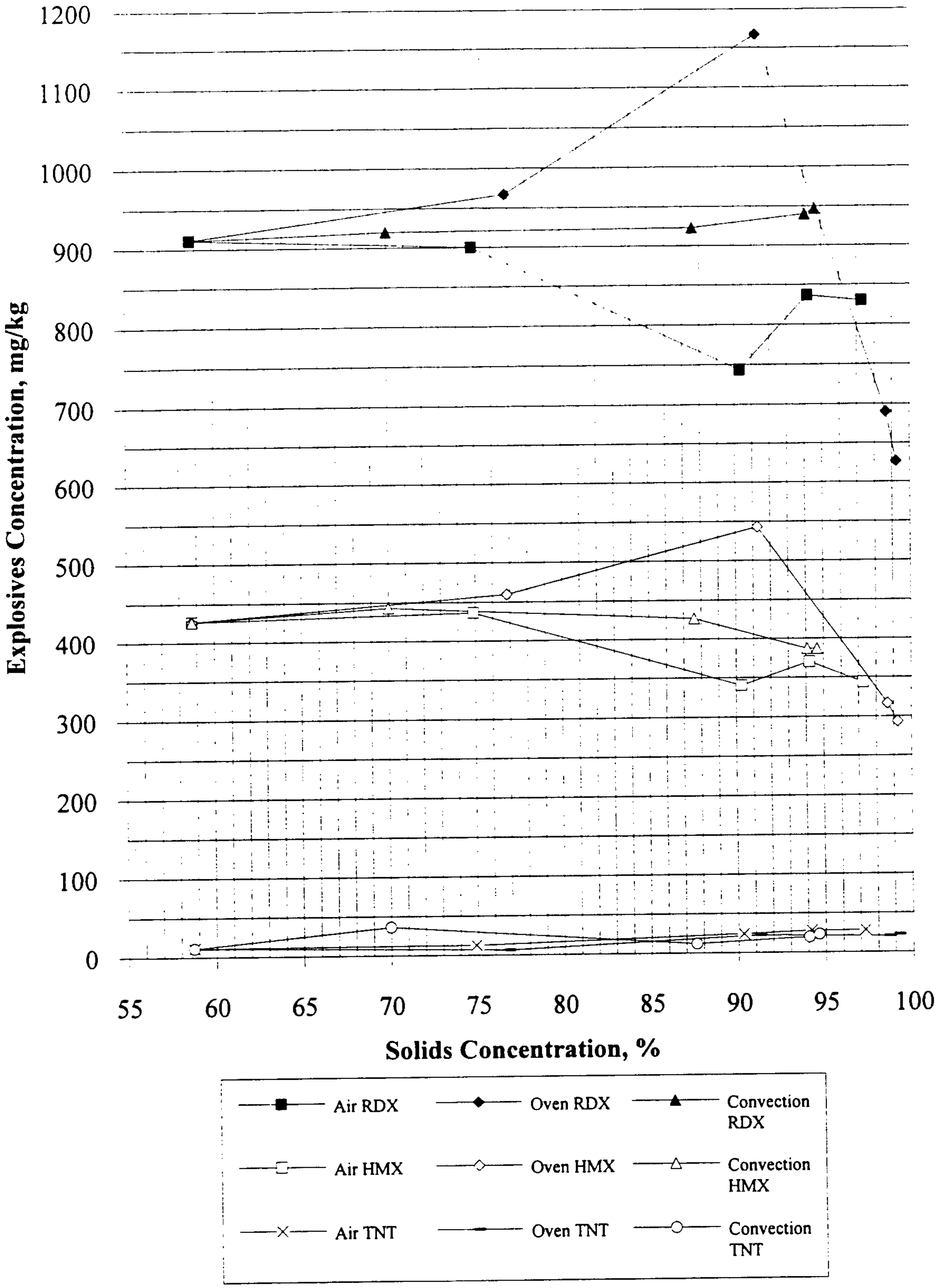

Figure 3-2 : Compost Average Explosives Concentration versus Solids Concentration.

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solids was approximately 9 hours for convection drying, 20 hours for oven drying, and 110 hours for air drying.

Explosives analyses were conducted on nine replicate compost samples representing the triplicate samples collected initially, prior to drying and milling, for each of the three drying methods. Table 3-2 shows that the average explosives concentrations of the nine replicate compost samples were 911 mg/kg RDX, 427 mg/kg HMX, and 11.2 mg/kg TNT. These initial explosives concentrations are the average "as received" concentrations unaffected by the drying or milling operations (All explosives data, however, are corrected to a dry weight basis using separate solids analyses). As a comparison to these data, explosives concentrations for Day 40 compost samples (air dried and milled) collected during the field demonstration seeding studies at UMDA ranged from 130 to 1,030 mg/kg for RDX (466 mg/kg average), 168 to 302 mg/kg for HMX (234 mg/kg average), and 6.5 to 25.1 mg/kg for TNT (13.5 mg/kg average) (1).

The average explosives concentrations of triplicate compost samples collected after complete convection drying and milling were 947 mg/kg RDX, 387 mg/kg HMX, and 23.3 mg/kg TNT. Over the 12 hour drying period, average RDX concentrations increased 4%, average HMX concentrations decreased 9%, and average TNT concentrations increased 108% compared to the average "as received" explosives concentrations. Figure 3-2 shows that, in general, average explosives concentrations remained relatively constant during convection drying.

The average explosives concentrations of triplicate compost samples collected after complete oven drying and milling were 627 mg/kg RDX, 293 mg/kg HMX, and 22.7 mg/kg TNT. Over the 25 hour drying period, average RDX concentrations decreased 31%, average HMX concentrations decreased 31%, and average TNT concentrations increased 102% compared to the average "as received" explosives concentrations. Figure 3-2 shows that, in general, average explosives concentrations varied considerably during oven drying, especially after the compost reached solids concentrations where milling was conducted.

The average explosives concentrations of triplicate compost samples collected after complete air drying and milling were 830 mg/kg RDX, 343 mg/kg HMX, and 28.4 mg/kg TNT. Over the 212 hour drying period, average RDX concentrations decreased 9%, average HMX concentrations decreased 20%, and average TNT concentrations increased 153% compared to the average "as received" explosives concentrations. Figure 3-2 shows that, in general, average explosives concentrations varied considerably during air drying, especially after the compost reached solids concentrations where milling was conducted.

3.2 STATISTICAL ANALYSIS

A statistical analysis of the replicate explosives measurements on the compost was also conducted to identify if significant changes and variation in explosives concentrations occurred during the drying and milling processes. The relative standard deviations of replicate explosives analyses on compost samples collected during the study are presented in Table 3-3.

Relative standard deviation is a measure of the variability of individual data points about the average value and is defined as the standard deviation of replicate measurements expressed as a percentage of the average of the same set of measurements.

A comparison between average explosive concentrations measured on replicate compost samples collected initially, after drying to a solids content just below where milling was possible, and at the end of the drying period (after milling) is presented in Table 3-4. Table 3-5 presents a comparison between the relative standard deviations (variability) of these same replicate explosives measurements. The relationship between the relative standard deviation of replicate explosives measurements on the compost and solids content for each drying method is illustrated in Figure 3-3.

The relative standard deviations of explosives concentrations measured on the nine replicate compost samples collected prior to drying and milling were 9% for RDX, 7% for HMX, and

Table 3-3

Compost Drying Study - Relative Standard Deviation of Replicate Test Results (1)

Parameter	Drying Method	Target Solids (%)				
		59	70	80	90	95
Drying Time (hours)	Air	0	51	101	149	212
	Oven	0	11	20	22	25
	Convection	0	2.5	7	11	12
Millable (Y/N)	Air	N	N	N	Y	Y
	Oven	N	N	Y	Y	Y
	Convection	N	N	N	Y	Y
Total Solids (%)	Air	4.2	1.5	0.7	0.4	0.5
	Oven		1.9	2.3	1.3	0.7
	Convection		6.6	3.4	3.1	2.3
RDX Deviation (%)	Air	8.7	8.4	9.2	4.2	3.6
	Oven		3.6	4.9	8.1	6.4
	Convection		15	1.7	16	14
HMX Deviation (%)	Air	6.7	2.6	7.8	0.0	4.4
	Oven		4.3	1.1	6.6	3.9
	Convection		18	1.4	15	22
TNT Deviation (%)	Air	45	27	37	94	72
	Oven		16	23	54	60
	Convection		98	75	35	59

(1) Relative standard deviations are based on triplicate analyses except for the initial test results, which are based on nine replicate analyses.

RESULTS1.XLS

Table 3-4

Change in Explosives Concentrations Measured in Compost
Before & After Milling and Drying

Drying Method	Parameter	Concentration, mg/kg (1)			% Change	
		Initial	Before Milling	Final	Before Milling	Final
Convection	RDX	911	923	947	1	4
	HMX	427	427	387	0	-9
	TNT	11.2	12.3	23.3	10	108
Oven	RDX	911	967	627	6	-31
	HMX	427	460	293	8	-31
	TNT	11.2	6.6	22.7	-41	102
Air	RDX	911	743	830	-18	-9
	HMX	427	340	343	-20	-20
	TNT	11.2	24.3	28.4	117	153

(1) Averages are based on triplicate analyses except for the initial test results, which are based on nine replicate analyses.

Table 3-5

Change in Relative Standard Deviations of Explosives Concentrations Measured in Compost
Before & After Milling and Drying

Drying Method	Parameter	Relative Standard Deviation, % (1)			% Change	
		Initial	Before Milling	Final	Before Milling	Final
Convection	RDX	8.7	1.7	14	-81	64
	HMX	6.7	1.4	22	-80	220
	TNT	45	75	59	68	30
Oven	RDX	8.7	3.6	6.4	-58	-26
	HMX	6.7	4.3	3.9	-35	-42
	TNT	45	16	60	-64	34
Air	RDX	8.7	9.2	3.6	6	-58
	HMX	6.7	7.8	4.4	16	-34
	TNT	45	37	72	-17	61

(1) Relative standard deviations are based on triplicate analyses except for the initial test results, which are based on nine replicate analyses.

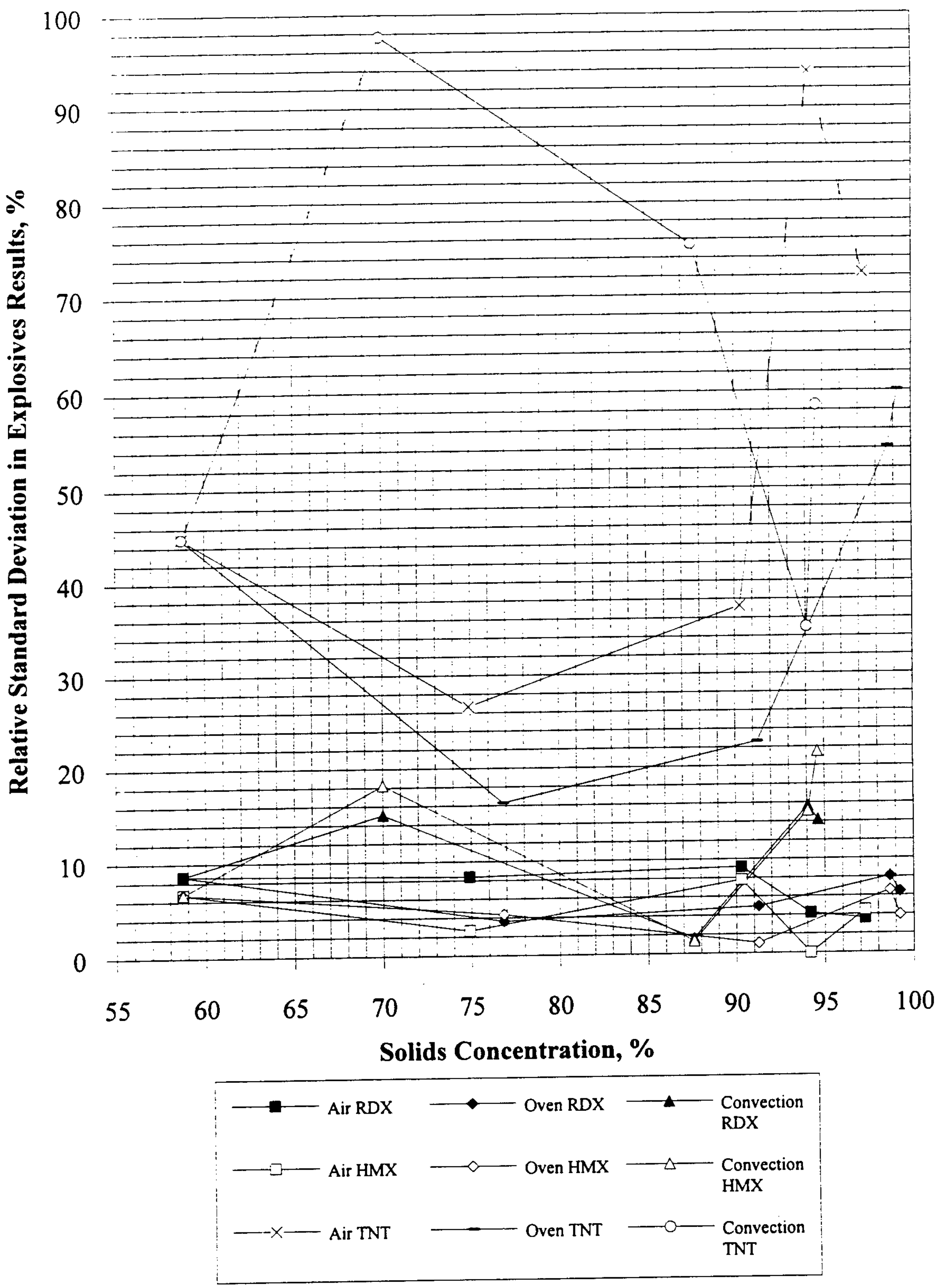

Figure 3-3 : Relative Standard Deviation in Compost Explosives Results versus Solids Concentration.

EXPRDTS2.XLC

45% for TNT. The relative standard deviations of explosives concentrations measured on triplicate compost samples collected after complete convection drying and milling were 14% for RDX, 22% for HMX, and 59% for TNT. The relative standard deviations of explosives concentrations measured on triplicate compost samples collected after complete oven drying and milling were 6% for RDX, 4% for HMX, and 60% for TNT. The relative standard deviations of explosives concentrations measured on triplicate compost samples collected after complete air drying and milling were 4% for RDX, 4% for HMX, and 72% for TNT.

Note that large deviations in replicate TNT measurements compared to the relative standard deviations of RDX and HMX were observed. The large deviation in TNT measurements maybe due to the fact that the concentration values are relatively low and variations in values are, therefore, proportionally higher. Figure 3-3 suggests that relative standard deviations of replicate explosives measurements of the compost increased as explosives concentrations decreased. For example, average RDX concentrations in the compost ranged from 627 mg/kg to 1,167 mg/kg with relative standard deviations ranging from 2% to 16%, as compared to the average TNT concentrations which ranged from 6.6 mg/kg to 36.7 mg/kg with relative standard deviations ranging from 16% to 98%.

Table 3-4 shows that oven drying and milling caused the greatest change in the average explosives concentrations (excluding TNT) and convection drying and milling caused the least change in average explosives concentrations (excluding TNT). The change in average explosives concentration (excluding TNT) for air drying and milling fell in between the two oven methods. The study results indicate that explosives concentrations after complete drying in an oven followed by milling exhibit a greater change than exhibited by air drying and milling, while the explosives concentrations after complete drying in a convection oven followed by milling fall within the range found for air drying and milling.

Analyses of explosives concentrations during the course of the drying study were intended to determine whether the drying steps resulted in a loss of explosives through melting or volatilization. If the sample preparation step caused such losses, analytical results might underestimate the actual explosives levels and, therefore not be fully reliable for verifying the achievement of cleanup criteria during remediation. While the data from the study did indicate some changes in explosives levels during drying, some of the changes were increases, while others were decreases. It is not known whether these results reflect changes in the compost or simply the inherent variability in this heterogeneous matrix.

Table 3-4 also shows that, regardless of the drying method used, the change in average explosives concentrations was typically less for compost samples dried to a solids content just below where milling was possible, as compared to the change in explosives concentrations for compost samples dried and milled at the end of the drying period. This indicates that milling may have greater effects on the compost explosives concentrations than the drying method used or drying time.

Table 3-5 shows that, for convection drying, the change in relative standard deviations of explosives concentrations were typically less for compost samples dried to a solids content just below where milling was possible, as compared to the change in relative standard deviations of explosives concentrations for compost dried and milled at the end of drying period. Replicate explosives results, therefore, became more variable after milling than before milling for convection dried compost. The same increase in variability of replicate explosives results was also measured for the oven dried compost. However, for the air dried compost, replicate explosives results became less variable after milling than before milling.

SECTION 4
CONCLUSIONS

The following conclusions summarize the results and key findings of the compost drying study:

1. A compost solids concentration of at least 91% was required for proper milling.

2. The approximate drying time required to reach 91% solids was 9 hours for convection drying, 20 hours for oven drying, and 110 hours for air drying. The convection drying method met the established objective for a drying time of 12 hours while the oven drying method did not.

3. Convection drying was the fastest drying method and had the least effect on explosives concentrations in the compost. Over the 12 hour drying period, average RDX concentrations increased 4%, average HMX concentrations decreased 9%, and average TNT concentrations increased 108%. The changes in concentration were less than those observed for air drying.

4. Oven drying was the second fastest drying method but had the greatest effect on explosives concentrations in the compost. Over the 25 hour drying period, average RDX concentrations decreased 31%, average HMX concentrations decreased 31%, and average TNT concentrations increased 102%.

5. Air drying was the slowest drying method and had the second least effect on explosives concentrations in the compost. Over the 212 hour drying period, average RDX concentrations decreased 9%, average HMX concentrations decreased 20%, and average TNT concentrations increased 153%.

6. The average explosives concentrations of nine replicate compost samples collected prior to drying and milling were 911 mg/kg RDX, 427 mg/kg HMX, and 11.2 mg/kg TNT. The relative standard deviations for these results were 9% for RDX, 7% for HMX, and 45% for TNT.

7. The average explosives concentrations of triplicate compost samples collected after convection drying and milling were 947 mg/kg RDX, 387 mg/kg HMX, and 23.3 mg/kg TNT. The relative standard deviations for these results were 14% for RDX, 22% for HMX, and 59% for TNT.

8. The average explosives concentrations of triplicate compost samples collected after oven drying and milling were 627 mg/kg RDX, 293 mg/kg HMX, and 22.7 mg/kg TNT. The relative standard deviations for these results were 6% for RDX, 4% for HMX, and 60% for TNT.

9. The average explosives concentrations of triplicate compost samples collected after air drying and milling were 830 mg/kg RDX, 343 mg/kg HMX, and 28.4 mg/kg TNT. The relative standard deviation for these results were 4% for RDX, 4% for HMX, and 72% for TNT.

10. Relative standard deviations of replicate explosives measurements of the compost increased as explosives concentrations decreased. For example, average RDX concentrations in the compost ranged from 627 mg/kg to 1,167 mg/kg with relative standard deviations ranging from 2% to 16%, as compared to the average TNT concentrations which ranged from 6.6 mg/kg to 36.7 mg/kg with relative standard deviations ranging from 16% to 98%.

11. Regardless of the drying method used, the variability in average explosives concentrations were significantly less for compost samples dried to a solids content just below where milling was possible, as compared to the variability in explosives concentrations for compost samples dried and milled at the end of the drying period.

12. Replicate explosives results became more variable after milling than before milling for convection dried compost. The same increase in variability of replicate explosives results was also measured for the oven dried compost. However, for the air dried compost, replicate explosives results became less variable after milling than before milling.