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Project Summary

Pilot Field Studies of FGD Waste Disposal at Louisville Gas and Electric

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Properly prepared landfill from FGD sludge/fly ash mixtures can prevent trace element contamination of underlying groundwater. Analyses of leachates from the series of landfill impoundments in this study show that trace elements on the RCRA list of contaminants were found in concentrations below those proposed to characterize hazardous or toxic wastes.

Decreasing concentrations, with time, of trace contaminants were observed in both leachate and runoff samples obtained from the stabilized sludge mixtures. Small, synthetically lined, above-ground impoundments provided higher concentrations of trace contaminants than the subsurface impoundments since no attenuation by local soil was provided and vegetation that might minimize runoff was not established on these sites.

Most sites developed compressive strengths significantly greater than the minimum required for recreational or light structural landfill. Water samples from beneath larger subsurface impoundments indicated that the filtering action of soil aids in decreasing the concentration of contaminants reaching the ground water supply. Certain mixtures have undergone a fixation reaction, reducing the permeability and minimizing the release of moisture and/or contaminants to the surrounding soil.

This Project Summary was developed by EPA's Industrial Environmental 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 most extensive commercial experience in flue gas desulfurization (FGD) to date has been with lime/limestone wet scrubbers. It is anticipated that these systems will account for most sulfur or SO_2 removal at electric power stations for the next 10 to 15 years. A major challenge associated with the commercial development of these systems is the disposal of large amounts of by-product sludge within the constraints of land and water quality regulations. It has been estimated that, by 1985, air quality control regulations will require the installation of FGD systems on plants representing 60 million kW of electric generating capacity per year. If this estimate is realized, over 27.2 Mg (30 million tons) of ash-free by-product sludge (50 percent solids) will be produced per year.[1]

Over the past 11 years, more than 50 different procedures for direct disposal or process utilization of this sludge have been evaluated.[2,3] Most investigators have concluded that utilization will not be able to provide viable alternatives to proper disposal of the sludge any more than utilization of fly ash (10 to 15 percent of annual production) has solved the problem of fly ash disposal. Consequently, most waste by-products from FGD will be disposed of in ponds or used as landfill. The choice of disposal methods and amount of treatment required will depend on the geographical location, legal and environmental requirements, economic considerations, and the preferences of the operating company.

Prior laboratory work has indicated the environmental advantages of the disposal of stabilized FGD by-product sludges over untreated FGD sludges. Haas and Ladd[4] showed that waste solids from a limestone scrubbing system could be stabilized by dewatering and subsequent mixing with clay soil or a western type fly ash having a high alkali content. Further studies[5,6] showed that the addition of fly ash and/or lime to FGD sludge solids resulted in the formation of a number of mineral compounds of high strength and low permeability.

These initial studies focused primarily on treatment of FGD sludges to enhance structural properties. However, in addition to being physically unstable, FGD sludges contain varying concentrations of trace elements and dissolved salts which have the potential to contaminate surface and groundwater. Although some soils will absorb many of the trace elements in FGD sludge, major ions (such as calcium, sulfate, and chloride) may not be readily absorbed. Therefore, the disposal of sludge must also address procedures to minimize runoff and to control or prevent seepage. Consequently, leachate analyses were added to the unconfined compressive strength and permeability tests that were already a part of sludge-landfill stabilization studies.

The work described in this report is a major laboratory/field demonstration of landfill disposal of FGD by-product sludges by Louisville Gas and Electric with Combustion Engineering, Inc. and the University of Louisville, performed under contract with the Industrial Environmental Research Laboratory of EPA at Research Triangle Park, North Carolina.

This project was designed to demonstrate the feasibility of landfill disposal of by-product FGD sludge treated with various mixtures of fly ash and stabilizing additives.

Prior to the start of this demonstration, two criteria were established to define an acceptable landfill material: (1) landfill material must have sufficient structural integrity to meet minimum standards of: compressive strength >0.1 MPa (1 ton/ft^2) and permeability $<5 \times 10^{-5}$ cm/s [7]; and (2) landfill material must not contaminate groundwater by leachate or surface water by runoff or erosion. The standards used for leachate evaluation were the levels which had been proposed for defining leachates from hazardous wastes under the Resource Conservation and Recovery Act (Section 261.24)[8] and the U. S. Public Health Service Drinking Water Standards. Both of these standards are shown in Table 1.

Project Objectives

This project was designed to demonstrate the feasibility of environmentally acceptable landfill disposal of mixtures of FGD by-product sludge a fly ash. The FGD by-products used this demonstration were obtained frc the wet scrubbing of flue gas frc combustion of 3 percent sulfur We Kentucky coal at the 65 MW stati generator (No. 6) at the Paddy's Ri Station of Louisville Gas and Elect Co., Louisville, Kentucky. Fly ash w obtained from the electrostatic precip tator hoppers of the No. 6 stea generator during the test period.

The project was part of an over program which covered scrubber testir as well as waste disposal. The was disposal project consisted of two phase each using a different absorbent remove SO_2 from the flue gas during th scrubbing operation.

Since the FGD system at Paddy's Ru was placed in operation in 197 carbide lime, a locally available b

Table 1. *Criteria for Evaluation of Leachate Environmental Impact*

Characteristics	*U. S. Public Health Service Drinking Water Standards*: *Suggested Limit That Should Not Be Exceeded*	*Cause for Rejection*	*Proposed Toxicity Criteria for Hazardous Waste under RCRA*
Physical			
Color, units	*15*		
Taste	*Unobjectionable*		
Threshold odor number	*3*		
Turbidity, units	*5*		
Chemical	*mg/l*	*mg/l*	*mg/l*
Alkyl benzene sulfonate	*0.5*		
Arsenic	*0.01*	*0.05*	*5.0*
Barium		*1.0*	*100*
Cadmium		*0.01*	*1.0*
Chloride	*250*		
Chromium (hexavalent)		*0.05*	*5.0*
Copper	*1*		
Carbon chloroform extract[a]	*0.2*		
Cyanide	*0.01*	*0.2*	
Fluoride[b]	*0.7-1.2*	*1.4-2.4*	
Iron	*0.3*		
Lead		*0.05*	*5.0*
Nitrate	*45*		
Phenols	*0.001*		
Selenium		*0.01*	*1.0*
Silver		*0.05*	*5.0*
Sulfate	*250*		
Zinc	*5*		
Mercury			*0.2*
Total dissolved solids	*500*		

[a] *Organic contaminants.*
[b] *Concentration may be between 0.6 and 1.7 mg/l, depending on the listed annual average maximum daily air temperature.*

product from acetylene manufacture, consisting primarily of $Ca(OH)_2$, has been used as the absorbent. Phase I of the waste disposal project was designed to provide a demonstration of impoundment of mixtures of fly ash and chemically treated sludge from carbide lime scrubbing.

From the standpoint of general usage, commercial lime is more likely to be utilized as the SO_2 absorbent. Phase II was conducted, therefore, using sludge obtained from scrubber operation with commercial lime absorbent.

Conclusions

1. FGD waste sludges can be stabilized to give compressive strengths greater than the minimum required for acceptable landfill disposal. In this study, stabilized sludge samples developed compressive strengths ranging from 0.29 to 2.39 MPa (3.0 to 25 tons/ft^2) when cured and tested under controlled laboratory conditions. Subsequent field testing of selected stabilized sludge mixtures showed strength from 0.01 to 0.50 MPa (0.13 to 5.4 tons/ft^2), measured on core samples removed from the field sites and tested in the laboratory.
2. The correlation between strengths measured on laboratory samples and on core samples from field testing of a particular sludge was poor. It was felt this was due primarily to the unavoidable disturbance of the core samples during collection. The use of a concentric drill/Shelby tubes (Dennison sampler) should prove more satisfactory for this application. *In-situ* plate load tests on several field sites showed strengths developed in stabilized sludges which were significantly higher than indicated by core sample measurements.
3. Stabilization reduces the permeability of sludges, thus minimizing leachate generation. In this study, both laboratory and core samples from field test sites showed an inverse relationship between strength and permeability.
4. Properly prepared landfill from FGD sludge/fly ash mixtures can prevent trace element contamination of the underlying groundwater. All leachates collected from stabilized sludges in this study contained trace elements in concentrations below those proposed to define a hazardous waste under RCRA (Table 1).
5. Process II mixtures (containing rotary drum vacuum filter cake, fly ash, and fixative) had the optimum combination of compressive strength and permeability for landfilling both carbide lime and commercial lime sludges. Process I, utilizing thickener underflow, had low bearing capacity and relatively high permeability. Process III, which compounded mixtures with filter press high solids cake, was too brittle. Process I and III mixtures gained little compressive strength with time and thus are considered unacceptable.

Project Description

The project was divided into two phases: laboratory testing and field demonstration. The laboratory tests provided baseline values for the strength, permeability, and leachate quality of each mixture evaluated. The field demonstration provided similar information on the behavior of stabilized materials under natural environmental conditions including precipitation and freeze/thaw. Included in the field phase was evaluation of the handling, transportation, and placement of the various sludge mixtures.

In this project, the stabilization of sludge from three dewatering processes was evaluated in the laboratory and under field conditions. Process I involved mixing fly ash and a fixative (stabilizing additive) with thickener underflow to form a pumpable mixture that was self-hardening upon standing. Process II consisted of mixing fly ash, partially dewatered sludge, and a fixative to form a compactable stable landfill. Process III used a maximum dewatered sludge, fixative, and/or fly ash to form a compactable stable landfill.

The laboratory tests screened a large number of stabilized sludge/fly ash mixtures for consideration in the field demonstration phase. The sludges were mixed with fly ash in ratios ranging from 0:1 to 1.5:1 parts by weight fly ash to dry scrubber solids. Varying percentages of fixative (lime, hydrated lime, carbide lime, or Portland cement) were added to determine the quantity necessary to achieve optimum results.

To predict the landfill behavior of stabilized sludges, the following tests were performed.

1. Unconfined compressive strength.
2. Permeability.
3. Leachate analysis.

The results of the laboratory testing are discussed in depth.

Briefly, on the basis of the laboratory test results, 10 mixtures were chosen for field evaluation. The mixtures were chosen to allow comparison between sludges with different degrees of dewatering and/or fixation additives.[9]

A quantity of each mixture was prepared in the field with a process train designed for this purpose. The sludge/flyash/treated mixtures were impounded in specially prepared sites to facilitate collection of leachate. Ten commercial above-ground swimming pools and five larger subsurface impoundments were used as monitored disposal sites for the mixtures.[9,10]

Laboratory Testing

The laboratory testing phase served as a screening effort in which many stabilized sludge mixtures could be evaluated. The data provided the basis for selecting a smaller group of mixtures for further field evaluation.

Sixty mixtures were prepared for the initial laboratory screening. Sludges from two FGD scrubbing processes were used in this study. One sludge was generated at LG&E's Paddy's Run Unit No. 6 using carbide lime as the scrubber absorbent. This carbide lime sludge contains mainly calcium sulfite (Table 2). Less than 10 percent of the sulfur products are oxidized to calcium sulfate. Because of the high sulfite content, the carbide lime sludge is very difficult to dewater. Previous field observations had indicated that the thickener underflows contained 18 to 24 percent solids and the vacuum filter cake contained 35 to 40 percent solids. Tests at vendor laboratories had shown that 50 to 55 percent solids could be obtained with a filter press operating at 1035 KPa (150 psig). The other sludge evaluated in the laboratory program resulted from the operation of Combustion Engineering's 12.340 Nm^3/hr (12,000 scfm) prototype scrubber using commercial lime as the scrubber absorbent. The commercial lime sludge contains a greater amount of calcium sulfate, with 10 to 20 percent of the sulfur products oxidized to the sulfate form (Table 2). As a result, the material dewatered considerably better than the carbide lime sludge. Thickener underflow was expected to contain 26 to 30 percent solids which field vacuum filtration had been shown to dewater the material to 50 percent solids.

Table 2. Carbide and Commercial Lime Typical Analysis (in % by weight unless noted otherwise)

Analysis	*Commercial Lime Sludge*			*Carbide Lime Sludge*	*Fly Ash*
	As Rec'd		*Mg Added*		
CaO	40.53		38.07	30.10	1.71
SO_2[b]	8.63		5.26	5.43	0.78[a]
SO_3[c]	36.42		39.20	38.13	—
MgO	0.17		1.87	0.19	0.56
Al_2O_3		0.87		3.48	14.8
Fe_2O_3		1.74		4.03	35.8
SiO_2		4.17		10.8	43.0
Na_2O		0.12		0.19	0.33
K_2O		0.05		0.38	1.16
TiO_2		0.01		0.10	0.62
CO_2		7.3		9.0	0.12
Cl^-		0.22		0.19	0.19
Cu (ppm)		10		130	70
Pb (ppm)		40		80	100
Cd (ppm)	2			3	6
Hg (ppm)	<0.03			<0.03	0.06
As (ppm)	10			3	34
Se (ppm)	1			1	1

[a]*Total sulfur, calculated as SO_3.*
[b]*Total sulfur less sulfite sulfur, calculated as SO_3.*
[c]*Sulfite sulfur, calculated as SO_2.*

Laboratory studies indicated that 65 percent solids could be obtained by using a filter press to dewater commercial lime sludge.

The ability to stabilize a FGD sludge is greatly affected by its water content. As the solids content of the sludge is increased, the void ratio decreases producing material with a higher dry density. Smaller quantities of fixative are required to harden sludges with low void ratios because the individual particles are closer and can thus react more readily with each other and the hardening agent. The optimum moisture content for maximum compaction of FGD sludges solids is 30-40 percent.

Based on previous experience, as well as typical ratios of sulfur to ash in coal, the sludges were mixed with fly ash in ratios ranging from 0:1 to 1.5:1 parts by weight fly ash to dry scrubber solids. Varying percentages of fixative were added to aid the cementing reaction. Four stabilizing agents (lime, hydrated lime, carbide lime and Portland cement) were evaluated as "fixatives."

The following tests were performed during the laboratory screening phase to determine the landfill behavior of stabilized sludge mixtures.

1. Unconfined compressive strength.
2. Permeability.
3. Leachate analysis.

Complete data from the laboratory tests are appended to the report.

Unconfined Compressive Strength

The unconfined compressive strength (UCC) test is a standard soil mechanics test which measures the compressive strength of a cylinder of stabilized sludge mixtures which had been cured in a humid environment for 60 days. The shear strength (half the unconfined compressive strength) indicates the bearing capacity of the landfilled sludge after an initial cure period. Table 3 lists UCC strengths measured for the sludge mixtures tested. Generally, a mixture having an unconfined compressive strength greater than 0.1 MPa (1.0 tons/ft^2) would be capable of providing a stable landfill which could be reclaimed for recreational use. The higher strength mixtures would be capable of supporting more intensive uses, such as structural loads.

As seen in Table 3, most laboratory samples met the strength criteria of 0.1 MPa (1.0 tons/ft^2). Therefore, the 25 mixtures selected for permeability testing were chosen to provide a broad evaluation of different fixatives, fly a: ratios, and moisture contents.

Permeability

The permeabilities of the sludg mixtures were measured using a fallir head permeameter. Sludge mixture were cured under saturated conditior for 30 days before permeability testin Table 3 lists the permeability coefficien measured in the laboratory tests. Fc comparison, typical coefficients are: 0. cm/sec for a uniform coarse sand, 10 cm/sec for silty sand, and 10^{-7} cm/se for clay. Most of the stabilized sludg mixtures tested were relatively impe vious, with coefficients of permeabilit ranging from 10^{-4} to 10^{-7} cm/sec. A shown in Figure 1, permeability appeare to vary inversely with the UCC strengt in the laboratory samples.

Leachate Analyses

During permeability testing, th leachates from the sludge sample were collected for chemical analysis The first and second pore volumes wer combined, as were the fifth and sixth, t obtain sufficient sample for the numbe of analyses desired. These two sample were analyzed for the major and trac elements listed in Table 4. The trac elements marked with an asterisk ar those which appear in the Resourc Conservation and Recovery Act list o contaminants which will be used t

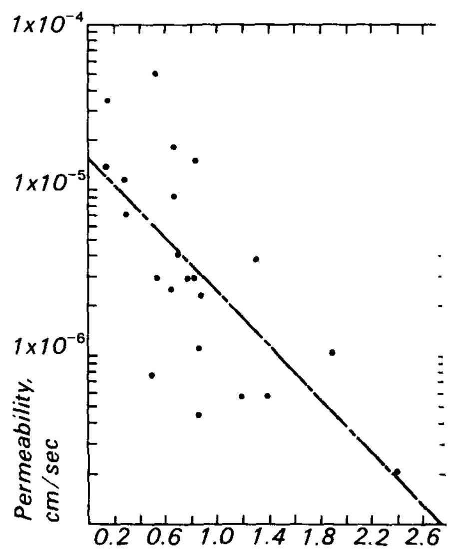

Figure 1. Permeability vs unconfined compressive (UCC) strength (laboratory tests).

define toxicity. These substances are also regulated under EPA's National Primary Drinking Water Standards (Table 1).

Leachate analyses for all laboratory samples are appended to the report. The fixation reaction minimizes the release of contaminants to the leachate as can be seen by comparing the stabilized sludge leachate analysis to a sludge and sludge/fly ash mixture containing no fixative (Table 5). In addition, the quality of the leachates improved with time in the stabilized mixtures, indicating that the fixation reaction continues for some period after initial placement. Several mixtures had very low permeabilities, and the necessary pore volumes were never collected.

Based on the laboratory tests, 12 mixtures were chosen for further evaluation under field conditions. The field mixtures were chosen from laboratory samples which developed strengths greater than 0.1 MPa (1 ton/ft^2) and had low permeabilities. Field mixtures are identified by number in Table 3.

Field Demonstration

Scrubber and Pilot Waste Handling System

Process Configurations

The FGD system at Paddy's Run Unit No. 6 consists of two scrubber modules which operate in parallel at full load. Figure 2 shows the overall arrangement of the scrubbing system during the collection of the by-product used during this study. Inlet SO_2 concentrations were about 2000 ppm at a gas flow rate of 180,000 Nm^3/hr (175,000 acfm) with the boiler at half load. A liquid/gas ratio (L/G) of 7.5 l/Nm^3 (28 gal./1000 cfm) was maintained during the test program.

For Phase I (carbide lime), SO_2 removal ranged between 75 and 83 percent. A slurry inlet pH of 8 was controlled over the 6-week period required to collect and process sufficient by-product to fill six impoundments.

During Phase II (commercial lime), about 2000 ppm magnesium was added to allow assessment of its effect on system operation. The slurry inlet pH of 8 was maintained and SO_2 removal exceeded 90 percent. The sludge by-product was processed and all 10 remaining impoundments were filled within a month.

A schematic flow diagram of the waste material handling system used to process the sludge during the field demonstration phase is shown in Figure 3.

The entire thickener underflow was pumped around a 244 m (800 ft) circulation loop. A slip stream taken

Table 3. *Laboratory Program Sludge Test Sample Identification*

Field Mix	*Sample No.*	*Sludge Composition*	*Fly Ash Sludge Ratio*	*Fixative*	*Permeability cm/s*	*60-Day Unconfined Compressive Strength MPa*	*t/ft^2*
1	P1	24% C.L.	1:1	5% C.L.[a]	7.6 x 10^{-5}	[b]	
	P2	24% C.L.	1:1	25% C.L.	8.5 x 10^{-5}	[b]	
2	P3	42% C.L.	1:1	5% C.L.	2.9 x 10^{-6}	0.78	8.2
	P4	42% C.L.	1:1	15% C.L.	7.7 x 10^{-7}	0.50	5.2
3	P5	42% C.L.	1:1	% CaO[c]	1.1 x 10^{-6}	0.86	9.0
5	P6	55% C.L.	1:1	None	5.7 x 10^{-7}	1.40	14.6
6	P7	55% C.L.	1:1	3% C.L.	2.1 x 10^{-7}	2.40	25.1
	P8	55% C.L.	0:1	None	3.9 x 10^{-6}	Not Tested	
4	P9	55% C.L.	0:1	5% CaO	4.5 x 10^{-7}	0.88	9.2
7	P10	65% CaO	1:1	None	7.0 x 10^{-6}	0.29	3.0
	P11	50% CaO	0.5:1	3% P.C.[d]	1.4 x 10^{-5}	0.14	1.5
	P12	50% CaO	0.5:1	10% P.C.	2.9 x 10^{-6}	0.56	5.9
	P13	50% CaO	1.5:1	3% P.C.	2.5 x 10^{-6}	0.64	6.7
8	P14	50% CaO	0.5:1	3% CaO	4.1 x 10^{-6}	0.70	7.3
	P15	50% CaO	0.5:1	10% CaO	2.3 x 10^{-6}	0.87	9.1
9	P16	50% CaO	1.5:1	3% CaO	5.7 x 10^{-7}	1.20	12.5
	P17	50% CaO	0.5:1	5% P.C.	3.5 x 10^{-5}	0.15	1.6
10	P18	50% CaO	1:1	3% P.C.	5 x 10^{-5}	0.52	5.4
	P19	50% CaO	1:1	5% P.C.	1.14 x 10^{-5}	0.27	2.8
	P20	50% CaO	0.5:1	5% CaO	1.5 x 10^{-5}	0.82	8.6
11	P21	50% CaO	1:1	3% CaO	2.94 x 10^{-6}	0.81	8.5
12	P22	50% CaO	1:1	3% $Ca(OH)_2$[e]	9.2 x 10^{-6}	0.68	7.1
	P23	50% CaO	1:1	5% CaO	1.05 x 10^{-6}	1.90	19.8
	P24	50% CaO	0.5:1	10% $Ca(OH)_2$	1.8 x 10^{-5}	0.66	6.9
	P25	50% CaO	1.5:1	3% $Ca(OH)_2$	3.8 x 10^{-6}	1.31	13.7

[a]*Carbide lime.*
[b]*Too weak (soft) to test.*
[c]*Commercial lime.*
[d]*Portland cement.*
[e]*Commercial quicklime.*

Table 4. *Leachate Analyses - Limits and Methods*

(Determined on Both Laboratory and Field Samples

		Detection Limit ppm	Method of Test
Calcium	Ca	0.05	Atomic Absorb.
Magnesium	Mg	0.01	Atomic Absorb.
Carbonate	CO_2	1.0	CO_2 Absorption Train
Sulfite	SO_3	1.0	Iodine-Iodate Titration
Sulfate	SO_4	1.0	Barium Perchlorate Titration
Chloride	Cl	0.05	Mercuric Nitrate Titration
Copper	Cu	0.02	AA (flame)
*Lead	Pb	0.001	AA (furnace)
*Cadmium	Cd	0.01	AA (flame)
*Mercury	Hg	0.001	AA (flameless)
*Arsenic	As	0.001	AA (furnace)
*Selenium	Se	0.001	AA (furnace)
	(Determined on Field Samples Only)		
Iron	Fe	0.03	AA (flame)
Zinc	Zn	0.004	AA (flame)
*Chromium	Cr	0.01	AA (flame)
Aluminum	Al	0.1	AA (flame)
Manganese	Mn	0.01	AA (flame)
Sodium	Na	0.002	Emission
Nickel	Ni	0.04	AA (flame)
*Barium	Ba	0.1	AA (flame)
*Silver	Ag	0.01	AA (flame)
Fluoride	F	0.01	Spec. Ion Elec.
Boron	B	0.1	Carminic Acid Colorimetric
Beryllium	Be	0.01	AA (flame)
Vanadium	V	1.0	AA (flame)
Nitrate	NO_3	1.0	Brucine Sulfate Colorimetric

*In RCRA list of contaminants.

from the loop was used to fill a 25.4 (10-in.) dia. x 3 m (10 ft) high slı surge tank. The remaining slurry \ then returned to the vacuum fi which is normally used to dewater bulk solids prior to disposal. Th processes were used to prepare mixtures for disposal.

For Process I, the slurry was pum from the surge tank through a 3.8- (1.5-in.) magnetic flowmeter directl the mixer into which additive and fly a were being metered.

In Process II, the sludge was watered in the filter press to produc filter cake of the same solids content the filter cake from the commerc rotary vacuum filter. When remov from the filter press, the filter cake into a surge bin from which it w metered into the mixer by a 15.2-cm (in.) variable speed screw (VSS) convey Fly ash and additive were simultaneous metered into the mixer.

Process III was used to evaluate t use of a filter press operating at hi pressure to dewater the sludge. T filter press provides a means of obtaini a much drier cake than can be obtain with a vacuum filter.

The filter cake was stabilized with ash. All mixtures were discharged in trucks, transported 11.2 km (7 mi.) to t Cane Run Plant, and placed in the te impoundments.

Table 5. *Laboratory Leachate Analyses*

	Sludge Only 55% Carbide Lime 0:1 Fly Ash to Sludge No Fixative		Mix 7 65% Comm. Lime 1:1 Fly Ash to Sludge 3% P. C.		Mix 10 50% Comm. Lime 1:1 Fly Ash to Sludge No Fixative		Mix 9 50% Comm. Lime 1:1 Fly Ash to Sludge 3% CaO	
Pore Volume #	1 & 2	5 & 6	1 & 2	5 & 6	1 & 2	5 & 6	1 & 2	5 & 6*
Cont.								
µmhos/cm	6850	2500	2850	2000	2550	575	1800	
pH	7.8	7.5	7.8	7.7	9.2	8.0	9.3	
TDS (ppm)	4100	1500	1700	1200	1400	345	1100	
Cl^- (ppm)	345	<5	10	15	20	<5	15	
$SO_3^=$ (ppm)	30	—	40	—	30	20	230	
Cd (ppm)	0.02	<0.01	0.02	<0.01	0.01	0.01	<0.01	
Cu (ppm)	0.06	0.02	0.02	0.02	<0.02	<0.02	<0.02	
Pb (ppm)	0.2	0.1	0.1	0.1	—	—	<0.1	
Hg (ppm)	0.001	0.002	0.018	0.001	0.002	0.002	0.001	
As (ppm)	0.05	0.01	0.03	0.03	0.007	0.003	0.01	
$SO_4^=$ (ppm)	5390	1960	1580	1470	1320	218	440	
Ca (ppm)	260	300	320	300	650	110	6.7	
Se (ppm)	0.023	0.002	—	0.003	0.010	<0.001	0.008	
Mg (ppm)	—	—	0.18	0.16	0.10	0.04	0.02	

(*)Due to low permeability of samples, pore volumes 5 & 6 were not available for 60 days of collection.

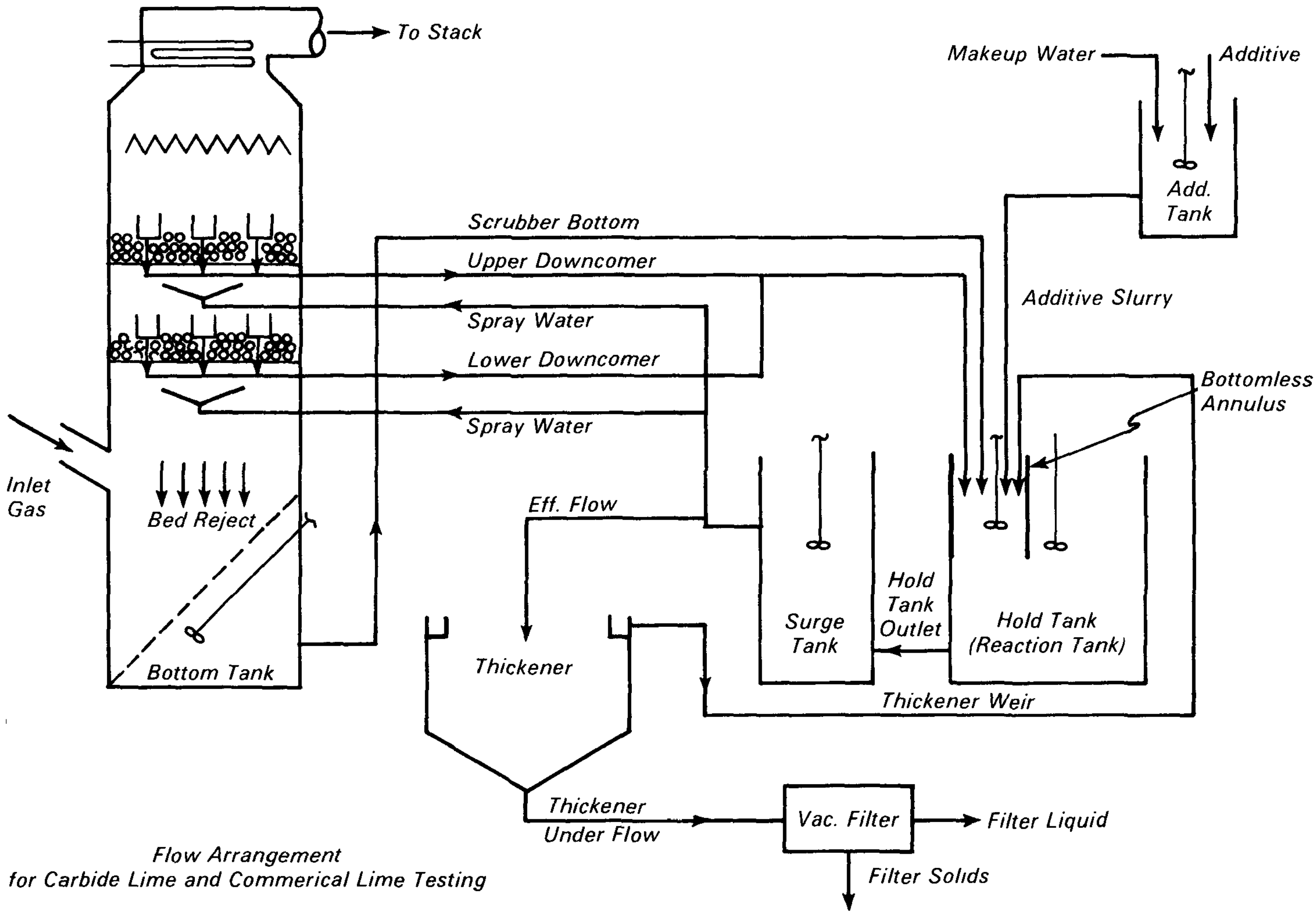

Figure 2. *Flow arrangement FGD system.*

Field Impoundments

General Description

Two general criteria characterize acceptable landfill disposal practice. The landfill must (1) not cause contamination of groundwater by leaching, or surface water by runoff or erosion, and (2) must provide a material with minimum structural integrity.

Ten commercial above-ground swimming pools and five large impoundments (Figure 4) were used as monitored disposal sites for sludge/fly ash mixtures.

Leachate samples were collected for analysis 1 week after filling each impoundment. Thereafter, leachate was collected at 2- or 3-month intervals. The leachate collection containers were emptied and cleaned after each sampling period. These leachates were analyzed for dissolved ions including major and trace constituents. In some instances, either no leachate sample was produced or insufficient sample was available to allow complete analysis. In the latter case, an analytical priority was established to provide maximum information from the available sample.

Using National Weather Service precipitation data, the maximum water which was available to percolate through the test sites was calculated. This amount of liquid available was translated into pore volumes for each test impoundment. Analysis of the rainfall data indicates that the large impoundments were exposed to 2.0 to 2.3 pore volumes of precipitation, while the small impoundments had seen 3.0 to 3.7 pore volumes, after 600 days. Thus, the laboratory leachate data previously discussed would represent 4 to 6 years of comparable field impoundment leachate analysis. (Of course, in many instances, runoff and surface evaporation at the field sites reduced the quantity of liquid prior to its passage through the sludge; therefore, the pore volume estimates for the field are high.)

Small Scale Impoundments

One type of disposal site consisted of small scale impoundments (Figure 5). The primary purpose of these test sites was to provide a means of determining the quality of the leachate and runoff from the test mixtures under field conditions. The small scale impoundments were 10 lined above-ground swimming pools with a capacity of about 19 m^3 (24 yd^3). Four of these were used for sludge mixtures from a scrubbing system using carbide lime as an absorbent and six for sludge from a system using commercial lime.

The bottom 15.2 cm (6 in.) of each pool contained non-reactive graded gravel to facilitate collection of the leachate. The leachate drained by gravity to a collection tank.

Runoff was collected from the surface of the small scale impoundments through a gravel filter held in place by a coarse screen. This procedure ensured drainage regardless of the level to which the sludge consolidated. The runoff was analyzed for dissolved species at the same intervals as indicated for the leachate.

Large Scale Impoundments

The small scale impoundments provided a convenient means of determining maximum leaching rates and leachate quality without any interference from local surroundings. In the actual field site, the landfill will either absorb or release moisture to the surrounding soil. The large scale impoundment areas provided a means of assessing the impact of the disposal material in terms of its effect on local soil moisture and the quality (dissolved ions) of the moisture in the soil and of the water in the aquifer beneath the disposal sites.

Five large scale impoundment areas were excavated, each with a capacity of about 38 m^3 (50 yd^3). The disposal sites, located in natural soil, are of two styles: approximately 4.9 x 4.9 x 2.4 m (16 x 16 x 8 ft) tapers and 9.1 x 2.4 x 1.2 m (30 x 8 x 4 ft) pits (Figure 6). Two contained carbide sludge mixtures while the remainder contained mixtures of commercial lime sludge (Figure 4). Soil moisture was monitored by suction lysimeters located 15.2, 61.0, and 182.8 cm (6, 24, and 72 in.) beneath the bottom of the test site.

Field Test Results

Strength

Table 6 lists the maximum compressive strengths measured in the laboratory and field mixtures. Of the carbide lime sludge mixtures, only Mix 2 (vacuum filtered sludge, fly ash, and fixative) developed a compressive strength ≥0.10 MPa (1.0 tons/ft^2) at all depths to provide an acceptable landfill material. Mix 1 (thickener underflow, fly ash, and fixative) developed a hard surface crust, but the underlying mixture could not support any significant load. Mix 4 (sludge and fixative, but no fly ash) did not develop sufficient strength to provide an acceptable landfill; in fact, the initial strength of this mixture, 0.15 MPa (1.5 tons/ft^2), was significantly reduced during the test program, probably due to freeze/thaw effects.

All but Mix 7 of the commercial lime sludge mixtures developed compressive strengths greater than the 0.28 MPa (3 tons/ft^2) capacity of the *in-situ* vane shear device. After less than 6 weeks of placement, Mix 7, the only commercial lime-sludge/fly-ash mixture which did not contain a fixative, exhibited little tendency toward cementitious properties. The core samples collected for laboratory strength tests on this mix were extremely sensitive to disturbance and the samples were very friable and brittle. Although core samples collected from the other commercial lime mixtures all showed some degree of disturbance due to sampling, the compressive strength tests in the University of Louisville laboratory indicated that cementitious reactions had occurred to some extent in all the commercial lime-sludge/f ash/fixative mixtures (Mixes 8-12). T highest strengths measured on cc samples were from Mix 10 which us Portland cement as the fixative. Tt mixture formed a hard surface crust aı appeared to be very resistant weathering.

Because of the large degree disturbance which occurred in the co samples from the high strength mixture additional *in-situ* plate load streng tests were run on two commercial lin mixtures (11 and 12), to better defir actual in-place strength. In the test c Mix 12, in large impoundment 4, a tot load of 1.34 MPa (14 tons/ft^2) caused settlement of 3 cm (1.2 in.), indicatir that this material would be capable bearing significant foundation load Mix 11, in large impoundment 5, als showed significant load bearing capacit Several cycles of loading were applie with loads up to 1.32 MPa (13. tons/ft^2); the net settlement after th loads were removed was 2.8 cm (1. in.). The behavior of Mix 11 under th plate load tests indicated that thi material would be able to bear very hig foundation loads.

Mix 6, in small impoundment 4, wa transported to the field site in a cemer

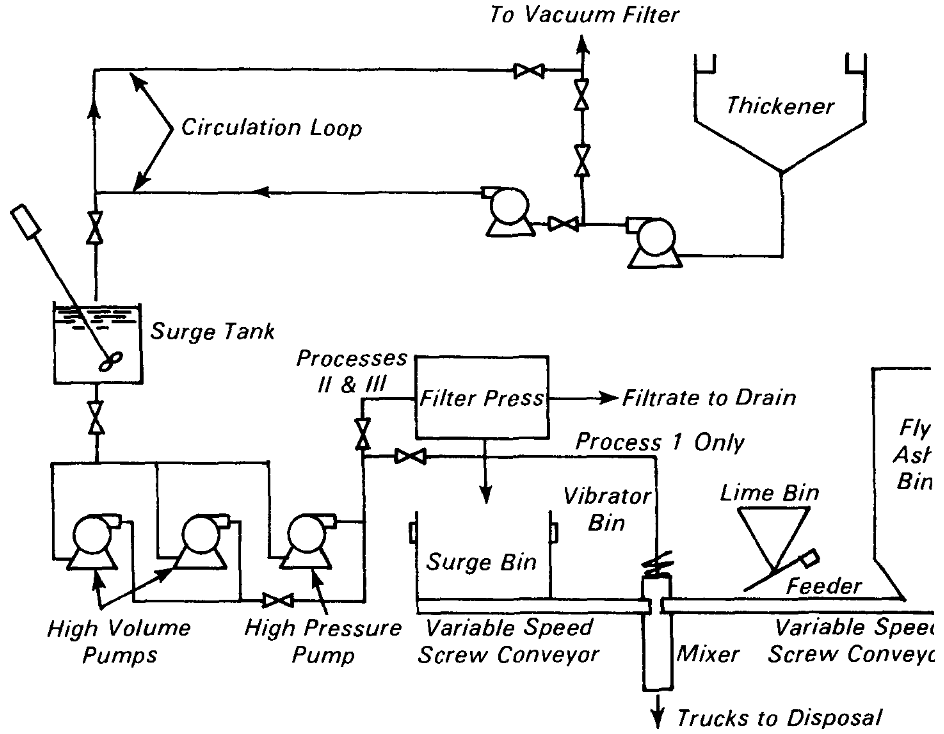

Figure 3. Waste material handling system.

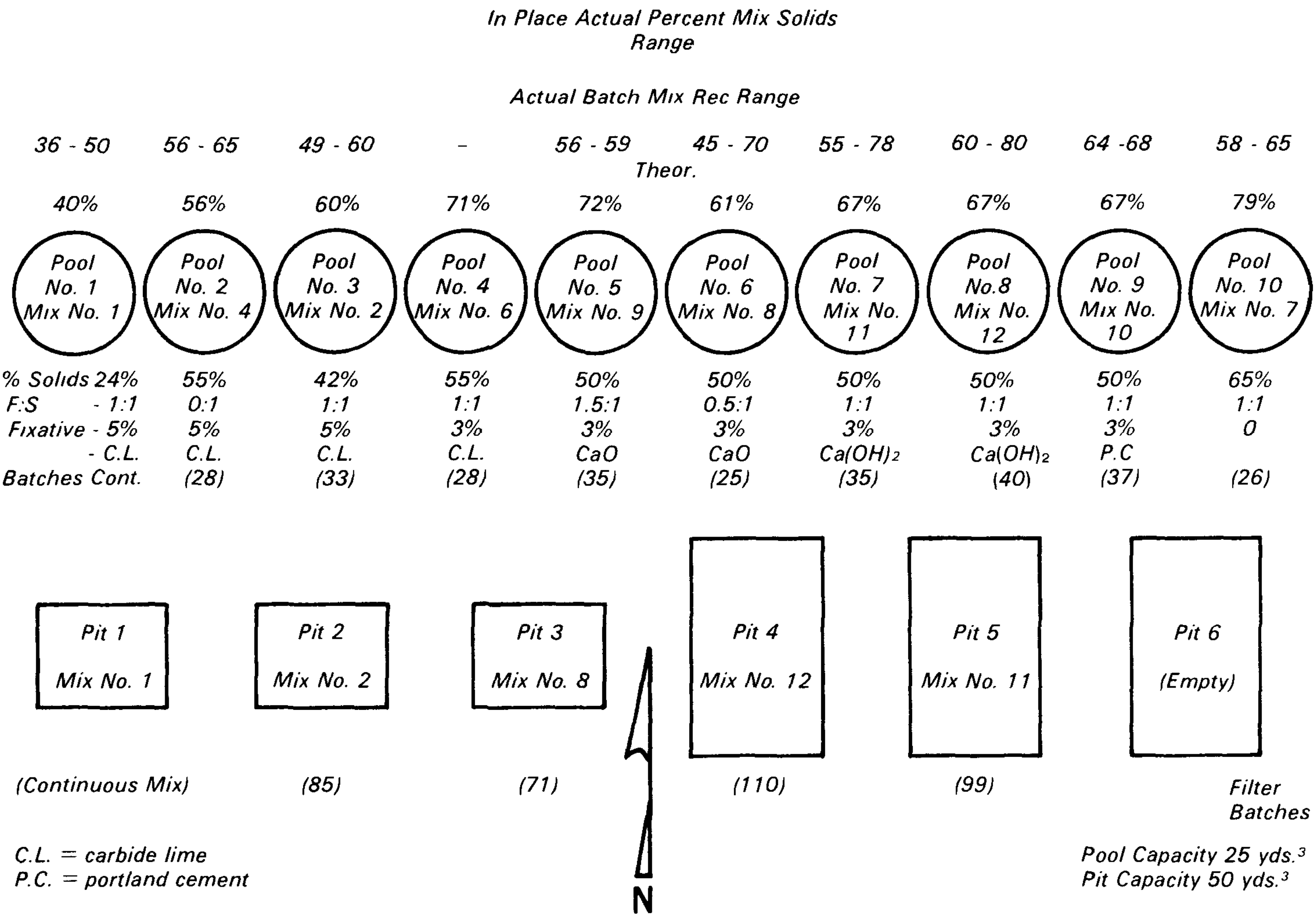

Figure 4. *Sludge impoundment sites.*

mix truck. This experiment was unsuccessful, resulting in the need to add large quantities of fly ash in order for the sludge material to discharge from the truck. The resulting large "snowballs" froze and disintegrated upon thawing. Consequently, physical tests were not performed on Mix 6.

In summary, Process II mixtures (containing rotary drum vacuum filter cake, fly ash, and fixative) provided the optimum combination of maximum compressive strength and low permeability for the environmentally safe impoundment of both carbide lime and commercial lime sludges as landfill. On the other hand, Process I, utilizing thickener sludge at 24 percent solids, was too soft for acceptable landfill. In addition, mixtures compounded with filter press (high solids) sludge (Process III) were brittle, gained little in compressive strength with time, and thus

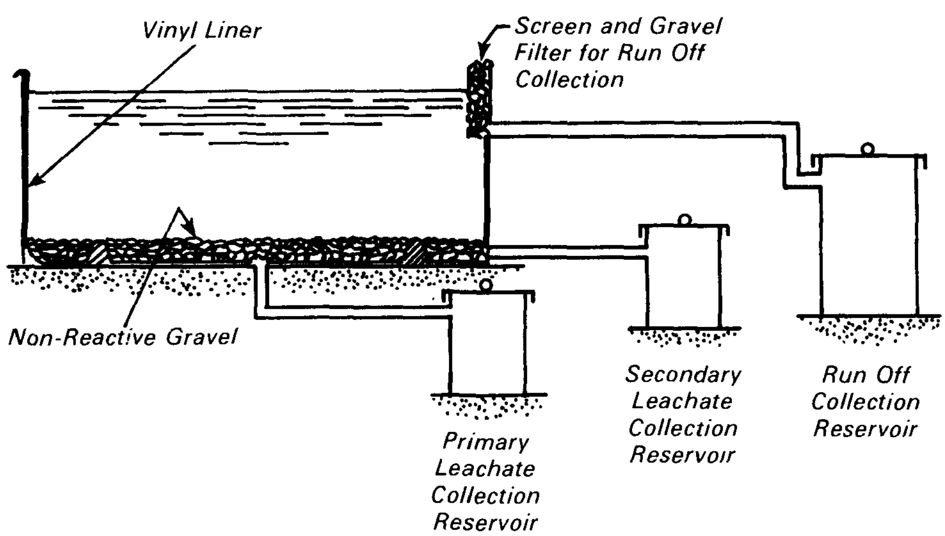

Figure 5. *Small scale impoundments (pools).*

are not considered acceptable as landfill.

Permeability

The severe disturbance which occurred in the core samples made it difficult to obtain a valid sample for permeability testing from the field mixtures. However, for the core samples tested, it appears that the permeability of the field mixtures is within an order of magnitude of that measured on corresponding mixtures during the laboratory phase. Proper compaction during placement of the field mixtures is a strong factor in the reduction of permeability. In some mixtures (particularly those in the above-ground pools) where compaction was not adequate, the *in-situ* mass permeability may be higher than measured on the core samples. In an actual full scale landfill operation, conventional compaction equipment would be used to ensure that a specified density is obtained.

As with the laboratory test samples, an inverse relationship between permeability and unconfined compressive strength was noted for the core samples (Figure 7).

Leachate Analysis

Major Constituents—

Mix 1 (consisting of carbide lir sludge thickener underflow, fly ash, a lime— Process I mixture) produced t poorest quality leachates throughc the field study. This mixture was plac at ≈35-50 percent solids. The leachat collected from the small above-groui impoundments contained 1000-50(ppm dissolved solids, with an average approximately 3000 ppm. The s(moisture samples collected beneath tl large in-ground impoundments coı taining Mix 1 showed that son contaminants were leaching from tl sludge mixture into the underlying so Initial soil moisture samples collecte 15.2 cm (6 in.) below the large impoun(ment contained approximately 40C ppm of dissolved solids, similar to th leachates from the small impoundmen A gradual decrease in dissolved solic concentration occurred in the so moisture samples with time and deptl indicating that some attentuation (contaminant impact on groundwate was provided by the underlying soil.

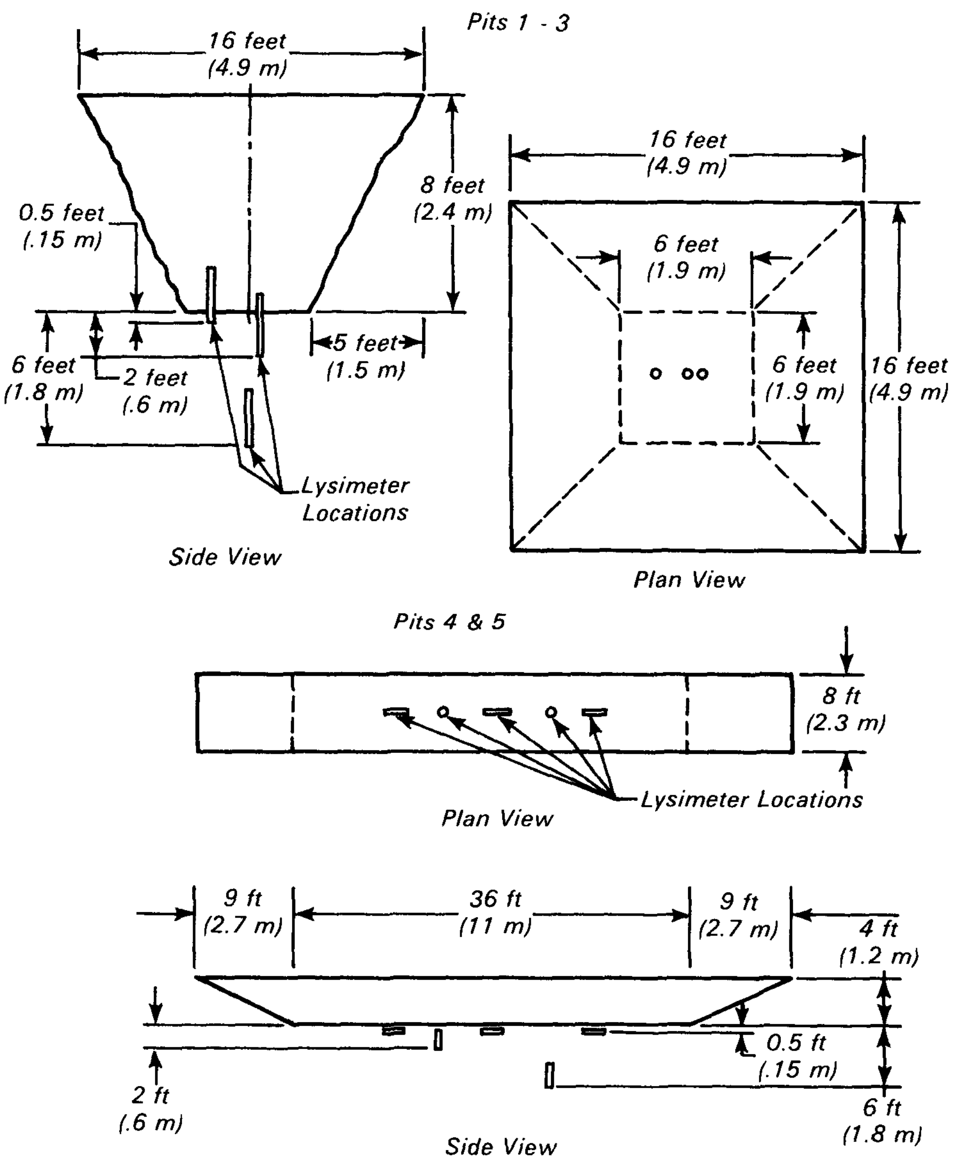

Figure 6. *Schematic-large scale impoundments (pits).*

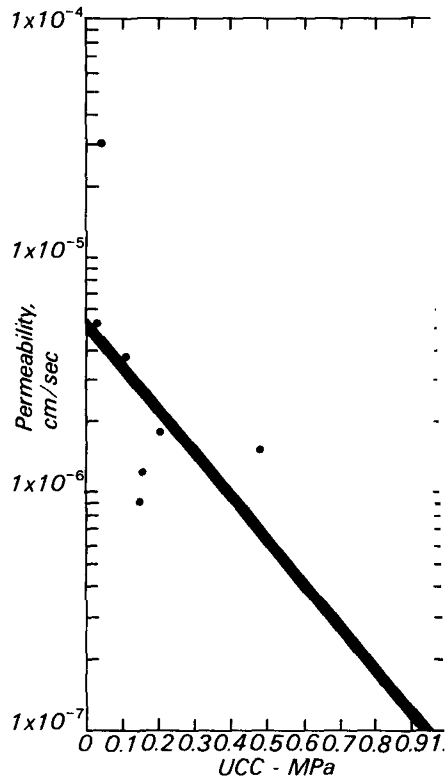

Figure 7. *Permeability vs unconfined compressive strength.*

Table 6. Comparison of Field and Laboratory Results of Physical Testing

Process	Sample Identification / Location	Maximum Compressive Strength MPa (tons/ft²): Lab 60 days	Field (In-Situ) Initial	Field (In-Situ) Final	Field (Core) Initial	Field (Core) Final	Minimum Permeability cm/s: Lab 60 days	Field (Core)
I	Mix 1	too soft	<0.01	0.15	too soft	0.04	$7.6x10^{-5}$	$3x10^{-5}$ (724 days)
	Pit 1	(too soft)	<(0.1)	(1.6)	(too soft)	(0.4)		
II	Mix 2	0.78	0.07	>0.28	0.02	0.10	$2.9x10^{-6}$	$3.8x10^{-6}$(661 days)
	Pit 2	(8.2)	(0.7)	(>3.0)	(0.2)	(1.1)		
III	Mix 4	0.88	0.06	0.12	0.01	0.03	$4.5x10^{-7}$	$5.2x10^{-6}$ (664 days)
	Pool 2	(9.2)	(0.6)	(1.2)	(0.1)	(0.3)		
III	Mix 6	2.4	[a]	[a]	[a]	[a]	$2.1x10^{-7}$	[a]
	Pool 4	(25.1)	[a]	[a]	[a]	[a]		
III	Mix 7	0.29	0.12	0.27	0.01	0.07	$7.0x10^{-6}$	too brittle
	Pool 10	(3.0)	(1.2)	(2.8)	(0.1)	(0.8) (Brittle)		
II	Mix 8	0.69	0.24[c]	>0.28[b]	0.09	0.14	$4.1x10^{-6}$	$0.9x10^{-6}$ (464 days)
	Pit 3	(7.2)	(2.2)	(>3.0)	(0.9)			
II	Mix 9	1.10	0.06	>0.28[b]	0.03	0.26	$5.7x10^{-7}$	$4.5x10^{-6}$ (59 days)
	Pool 5	(11.6)	(0.6)	(>3.0)	(0.3)	(2.8)		
II	Mix 10	0.52	>0.28[b]	>0.28[b]	0.31	0.48	$5x10^{-5}$	$1.5x10^{-6}$ (417 days)
	Pool 9	(5.5)	(3.2)[c]	(>3.0)	(3.3)	(5.0)		
II	Mix 11	0.81	0.22[c]	>0.28[b]	0.10	0.15	$2.9x10^{-6}$	$1.2x10^{-6}$ (466 days)
	Pit 5	(8.5)	(2.0)	(>3.0)	(1.1)	(1.6)		
II	Mix 12	0.68	0.26	>0.28[b]	0.10	0.20	$9.2x10^{-6}$	$1.8x10^{-6}$ (452 days)
	Pit 4	(7.1)	(2.7)	(>3.0)	(1.1)	(2.1)		

[a] Not tested in field-spheres from "cement mixing" truck at start.
[b] Strength exceeded capacity of vane shear test device.
[c] No initial test (Measured at 48 days).

Process II mixtures consisted of a sludge dewatered to a solids content obtainable by rotary drum vacuum filtration with fly ash and fixative in various proportions. Due to the superior filtration properties of commercial lime sludges, these mixtures were placed at higher solids contents than the Process II carbide-lime/sludge mixture. Commercial-lime/sludge mixtures varied from 58 to 70 percent solids, depending on fly ash addition, while the single carbide-lime/sludge Process II mixture was placed at approximately 54 percent solids. Solids content at placement had a strong impact on the ability to compact the mixtures; and subsequently, on the permeability of the test site.

The quantity of leachate collected from the small impoundments containing Process II mixtures was significantly lower than from the Process I mix. In general, no leachate samples were available from the small above-ground impoundments containing Process II mixtures until 2 - 3 months after placement; and, in several cases, no leachate was produced during the test period.

Leachate quality varied among the Process II mixtures due to the ratio of fly ash: sludge, type of fixative, and the degree of compaction achieved during initial placement. In many cases, it is difficult to differentiate these effects. However, a comparison between Mixes 8, 9, and 11 indicates the trend. All three mixtures were made with commercial lime sludge, fly ash, and lime as a fixative: Mix 8 contained a fly ash/sludge ratio of 0.5:1.0; Mix 11, 1.0:1.0; and Mix 9, 1.5:1.0. The additional fly ash in Mix 11 allowed greater compaction than Mix 8, enhanced fixation, and resulted in a mixture with lower quantities of leachate generation. In Mix 9, however, concentrations of dissolved solids and other contaminants were higher than those measured in either Mix 8 or 11. Thus, there appears to be an optimum proportion of fly ash (1:1 fly ash/sludge in this case) beyond which leachate quality begins to degrade.

Process II carbide-lime/sludge mixture 2 contained vacuum filter sludge cake, fly ash, and carbide lime fixative. Leachates were available from the small above-ground impoundment 180 days after placement. The initial leachate samples contained ≈5000 ppm dissolved solids; subsequent leachate samples contained less than 1000 ppm. Soil moisture samples from beneath the in-ground impoundment containing Mix 2 showed a release of dissolved solids to the groundwater slightly lower than from Process I carbide-lime/sludge Mix 1.

Two Process III mixtures were prepared with carbide-lime/sludge and one with commercial-lime/sludge. Unfortunately, problems with the sampling equipment prevented the collection of leachate from the commercial lime sludge Process III mixture.

Trace Elements—

Trends in trace element concentrations between various sludge mixtures were more difficult to discern than those of major constituents due to the lower accuracy inherent in the analysis of these elements in the parts per billion range. In many cases, trace element concentrations were below detectable limits or below background levels (as determined by rainwater and groundwater analysis).

Mix 1, the Process I carbide-lime/sludge mixture, produced the leachates with the highest levels of trace contaminants during the study. For example, Figure 8 compares the concentration of one trace metal, arsenic, in leachates from Mix 1 and two Process II mixtures, Mixes 8 and 11. However, it is important to note that the concentration of trace elements in all leachates and soil moisture samples collected in this study was below that established under RCRA for defining hazardous wastes. Thus, on the basis of toxicity, all of the sludge mixtures tested would be designated non-hazardous.

Summary of Leachate Analysis Results—

Based on an evaluation of both major and trace contaminants measured in the leachate tests, the following results were evident:

1. Leachate generation decreased with time for those mixtures which were designated—Proceses II and III. Leachate quality improved with increasing dryness up to an optimum mixture dryness at placement, beyond which the material became brittle, permeability increased, and (thus) leachate generation increased.
2. The quantity of leachate from the low-solids Process I mixture decreased initially, then remained fairly constant during the test period. This mixture produced the poorest quality leachates of the field study.
3. Soil moisture quality beneath the large impoundments containing Process II mixtures increased with time, indicating a reduction in leachate generation. Also, quality increased with depth below the impoundment, indicating some physical filtering or chemical ion exchange reaction with the surrounding soil.
4. The concentration of trace elements found in the collected leachate and soil moisture samples was below RCRA limits throughout the testing.

The complete data base of all leachate samples collected from the field test sites is appended to the report.

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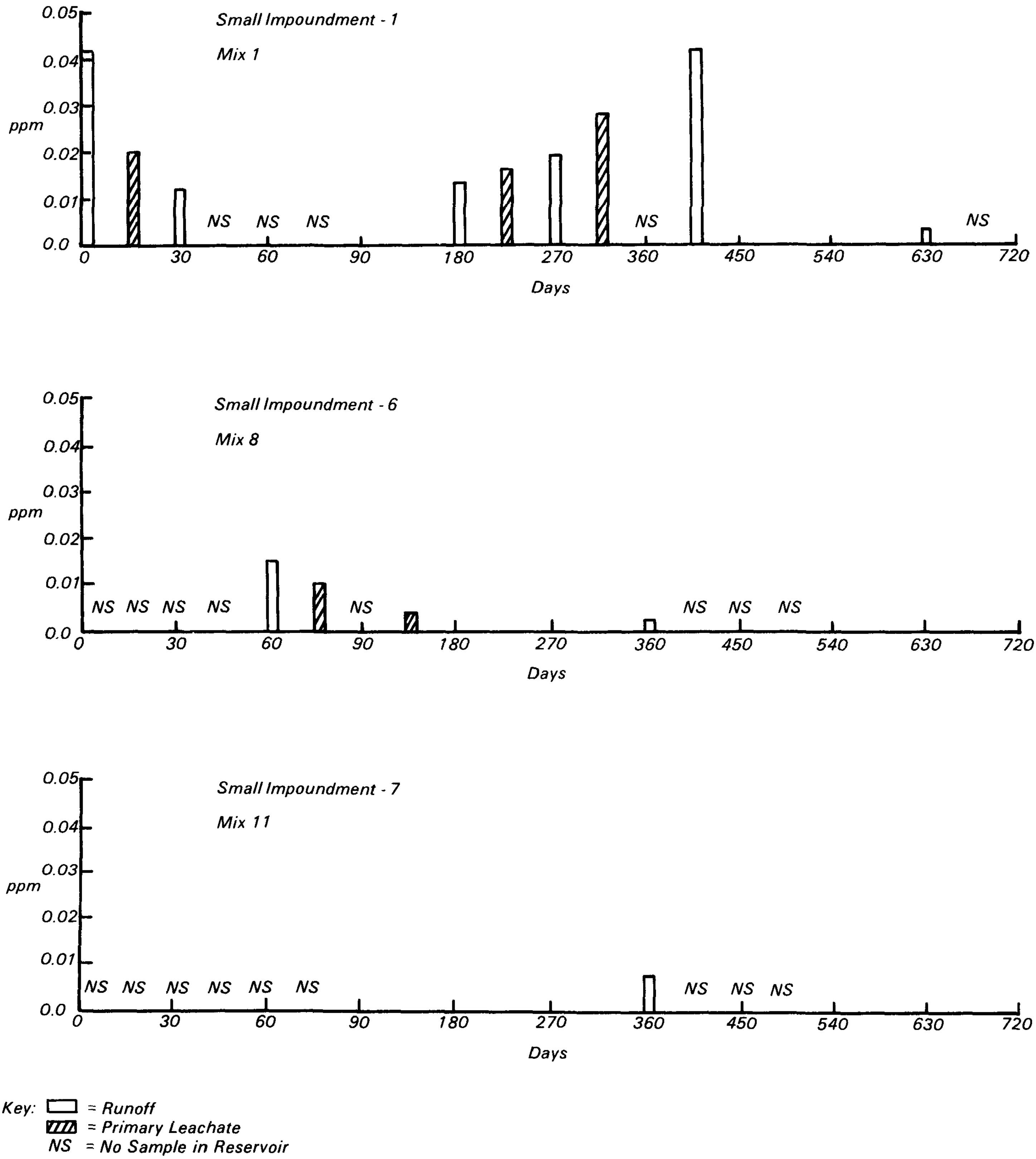

Figure 8. Leachate and runoff samples - Mix 1, 8, & 11, arsenic (RCRA limit 50 ppm).

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The complete report, entitled "Pilot Field Studies of FGD Waste Disposal at Louisville Gas and Electric," (Order No. PB 82-105 479; Cost: $23.00, subject to change) will be available only from:
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