Acoustically Enhanced Remediation of Contaminated Soils and Ground Water

Volume II

Topical Report

October 1995

RECEIVED
APR 24 1997
OSTI

Work Performed Under Contract No.: DE-AR21-94MC30360

For

U.S. Department of Energy
Office of Environmental Management
Office of Technology Development
1000 Independence Avenue
Washington, DC 20585

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

MASTER

By
Weiss Associates
5500 Shellmound Street
Emeryville, California 94608-2411

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED **HR**

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

APPENDIX A

ANALYTICAL REPORTS

ANALYTICAL REPORTS

This report contains the following analytical reports:

1. Hydraulic conductivity and Atterberg limits of Porcelain clay (Earth Tech, 9/15/94).
2. Laser particle size analyses of Oklahoma sand, Custer feldspar, porecelain clay and Ajax sand (Core Petrophysics, 10/22/94 and 4/17/95).
3. X-ray diffraction analyses of Custer feldspar and porcelain clay (Sandia National Laboratory, 11/21/94).
4. Density and viscosity of canol oil (Core Laboratories, 4/18/95).
5. Residual oil saturation analyses of Oklahoma sand samples with canola oil (PTS Laboratories, 6/26/95).
6. Residual oil saturation analyses of Oklahoma sand samples wiht Soltrol 220 (PTS Laboratories, 7/17/95).

September 15, 1994

Weiss Associates
5500 Shellmound Street
Emeryville, CA 94608-2411

Attention: Mr. Jim Spencer
Subject: Report/Laboratory Testing Results
Project Name: Porcelain Clay
Project No.: 40-0223-5A JWS
Earth Tech Project No.: 95-370-18301

Dear Mr. Spencer:

Enclosed please find laboratory testing results for the sample from the Porcelain Clay project. The analyses performed on the samples from the above project were conducted in general accordance with the ASTM standard testing procedures listed below.

Telephone

714.842.7011

Facsimile

714.842.3735

TYPE OF TEST

Hydraulic Conductivity
Atterberg Limits

TEST PROCEDURE

ASTM D 5048
ASTM D 4318

Test results are presented in the Table 1 and Data Sheets attached.

ASTM: American Society for Testing and Materials, Annual Book of ASTM Standard, Section 4, Volume 04.08 & 04.09 Soil and Rock (I & II), Geosynthetics, 1994.

Thank you for selecting Earth Tech (The Earth Technology Corporation) to provide laboratory testing services to Weiss Associates. Please feel free to contact us if you should have any questions concerning these results.

Very truly yours,

EARTH TECH
Laboratory Testing Services

Somsak Poolperm

Somsak Poolperm
Staff Engineer II

Lester Fruth

Lester Fruth, Ph.D.
Manager, Geomechanics Laboratories

Enclosures

CC: Weiss Associates
C/O SARA
15262 Pipeline Lane
Huntington Beach, CA 92649

18411 Gothard Street, Unit F, Huntington Beach, CA 92648

(714) 842-7011 Fax (714) 842-3735

PROJECT NAME: Porcelain Clay

EARTH TECH NO.: 95-370-18301

PROJECT NO.: 40-0223-5A JWS

SUMMARIZED BY: S. Poolperm

CLIENT: Weiss Associates

DATE: 09/13/94

TABLE 1

SUMMARY OF LABORATORY TEST RESULTS

Sample	Atterberg Limits ASTM D 4318 LL,PL,PI'	Saturated Hydraulic Conductivity ASTM D 5084		Soil Identification ASTM D 2488 (Group Symbol)
		Effective Confining Pressure (psi)	Hydraulic Conductivity k ₂₀ (cm/sec)	
Porcelain Clay	34,16,18	4.8	1.9E-08	CL

LL,PL,PI' = Liquid Limit, Plastic Limit, Plasticity Index

Testing Program Results

The hydraulic conductivity test specimen was prepared from a block using the following equipment: lathe, wire saw, spatula, knife, split mold and straight edge. The test specimen was trimmed to a diameter of 2.5 inches and a height of 3.0 inches. The moisture content was 25.9% by dry weight after drying $\geq$ 16 hours in an oven at 110°C and dry density was 96.6 pcf. Atterberg Limits testing followed ASTM D 4318 procedures obtaining Liquid Limit, Plastic Limit, and Plasticity Index Values of 34, 16, 18 respectively. According to Weiss Associates the percentage of fines (passing # 200 sieve) is close to 100. The sample is, therefore, classified as a Lean Clay (CL). The specimen was homogeneous, firm, wet and workable to sticky.

The saturated Hydraulic Conductivity Test followed ASTM D 5084 procedures. Tap water was used as a permeant. The test specimen was set up in a permeability cell with a saturated filter paper disc, a porous stone and a platen at each end. A rubber membrane was installed over the sample assembly and sealed to the end platens. The perm cell was then connected to a perm board. The porous stones and pressure lines were thoroughly flushed to minimize the amount of air present in the system. Backpressure saturation was continued until evaluation of the B value indicated a degree of saturation of 0.95 or greater. An effective stress of 5 psi was used to consolidate the saturated test specimen. This minimum effective stress was selected as a worst case scenario and to minimize required permeation time so as to stay within the seven (7) day limit specified by Weiss Associates. The sample was anticipated to have a low hydraulic conductivity. The cell pressure was adjusted to 100 psi as requested by Weiss Associates and the backpressure was 95 psi. The height and volume change of the specimen versus time were monitored during consolidation. After volume change measurement indicated the end of primary consolidation, the falling head permeability was started. A pressure gradient of 2 psi was applied across the sample to obtain fluid movement between the inflow and outflow burettes. In this case Weiss Associates requested seven (7) days or less for the permeation phase. During the permeation, inflow, outflow, time and temperature were periodically monitored and recorded while pressures were regulated constant. For the first 24 hours the values of hydraulic conductivity were steady (within $\pm$ 25% of the mean k value) but the ratios of inflow to outflow were not between 0.75 and 1.25. The permeation continued until the two ASTM criteria were accomplished at a mean k_{20} of $1.9\text{E-}08$ cm/sec.

After completion of the conductivity test the sample was removed from the cell assembly and the diameter and height were measured. It was then weighed and oven dried. These measurements were then used to obtain the Final Conditions presented on the cover data sheet.

SATURATED HYDRAULIC CONDUCTIVITY

(TRIAXIAL CELL)

TEST PROCEDURE NO. ASTM D 5084/EPA 9100

FALLING HEAD METHOD

Project Name: Porcelain Clay

Sample Description: Light Gray, Lean Clay (CL)

Project No: 40-0223-5A JWS

Tested by: RA

Date: 09/08/94

Boring No.: n/a

Input Checked by: RA

Date: 09/13/94

Depth(ft): n/a

Reviewed by: *Sp*

Date: 09/14/94

Sample No.: n/a

Sample Type: Block (trimmed)

		INITIAL CONDITION	FINAL CONDITION
Diameter (in)	1.	2.497	2.495
	2.	2.500	2.485
	3.	2.500	2.493
	Average	2.499	2.491
Height (in)	1.	3.001	2.985
	2.	3.000	3.005
	3.	3.004	3.007
	Average	3.002	2.999
Moisture Content (%)		25.86	25.97
Wt. Wet Sample + Container (gms)		179.23	542.78
Wt. Dry Sample + Container (gms)		149.96	446.54
Wt. Container (gms)		36.76	75.96
Density and Saturation			
Wt. Wet Sample + Container (gms)		469.71	542.78
Wt. Container (gms)		0.00	75.96
Wet Density (pcf)		121.5	121.7
Dry Density (pcf)		96.6	96.6
% Saturation		93.8	94.2

Assumed GS= 2.7

Back Pressure Saturation

B Value (%) = 96

Height After Back Pressure Saturation (in.)= 3.0031

Consolidation

Cell Pressure (psi) = 100.5

Burette Area (sq. in.)= 0.036

Back Pressure(psi) = 95.7

Initial Burette Ht.(cm)= 4.9

Effective Pressure (psi) = 4.8

Final Burette Ht.(cm)= 12.5

Initial Vertical Reading (in)= 0.1570

Change in Height

Final Vertical Reading (in)= 0.1658

After Consol (in.)= 0.0088

SATURATED HYDRAULIC CONDUCTIVITY

(TRIAxIAL CELL)

TEST PROCEDURE NO. ASTM D 5084/EPA 9100
FALLING HEAD METHOD

Project Name:	Porcelain Clay	Cell Pressure:	100.5 psi	Initial Sample Height:	3.0017 in
Project No:	40-0223-5A JWS	Bottom Pressure (Pb):	97.8 psi	Initial Area of Sample:	4.9048 sq. in.
Boring No.:	n/a	Top Pressure (Pt):	95.7 psi	Final Sample Ht. * (L):	2.9943 in
Depth(ft):	n/a	Consolidation Pressure:	4.8 psi	Final Sample Area (A)*	4.8808 sq. in.
Sample No.:	n/a	Burette Area (influent) (Ai):	0.036 sq. in.	Tested by:	RA Date: 09/08/94
Sample Type:	Block (trimmed)	Burette Area (effluent) (Ao):	0.036 sq. in.	Input Checked by:	RA Date: 09/13/94
Sample Description:	Light Gray, Lean Clay (CL)	Vol. Change During Consol.:	0.108 cu. in.	Reviewed by:	<i>SP</i> Date: 09/14/94

* After Consolidation

Date	Time	Incremental Elapsed Time (t) (min)	Temp. ° C	Water Height Influent Burette (hi) (cm)	Water Height Effluent Burette (ho) (cm)	Uncorrected Hydraulic Conductivity(k) (cm/sec)	Corrected Conductivity at 20 C (cm/sec)	Inflow Rate/ Outflow Rate	Remarks
08-Sep-94	11:33 AM	0		27.4	2.7				Initial Reading
08-Sep-94	01:15 PM	102	23.0	27.2	3.1	1.9E-08	1.7E-08	0.50	
08-Sep-94	02:55 PM	100	22.9	26.9	3.4	1.9E-08	1.8E-08	1.00	
08-Sep-94	04:12 PM	77	22.8	26.7	3.6	1.7E-08	1.6E-08	1.00	
09-Sep-94	08:12 AM	960	22.2	23.9	6.1	1.8E-08	1.7E-08	1.12	
09-Sep-94	09:26 AM	74	22.1	23.7	6.2	1.6E-08	1.5E-08	2.50	
09-Sep-94	10:21 AM	55	22.1	23.4	6.3	2.1E-08	2.0E-08	2.50	
09-Sep-94	11:22 AM	61	22.1	23.2	6.5	2.2E-08	2.1E-08	1.00	
09-Sep-94	01:55 PM	153	22.6	22.6	7.0	2.4E-08	2.3E-08	1.20	
09-Sep-94	04:38 PM	163	22.0	22.0	7.5	2.3E-08	2.2E-08	1.20	
10-Sep-94	05:58 PM	1520	22.0	17.1	12.0	2.2E-08	2.1E-08	1.09	
11-Sep-94	04:41 PM	1363	21.8	13.1	15.7	2.1E-08	2.0E-08	1.08	

SATURATED HYDRAULIC CONDUCTIVITY

(TRIAxIAL CELL)

TEST PROCEDURE NO. ASTM D 5084/EPA 9100

FALLING HEAD METHOD

Project Name:	Porcelain Clay	Cell Pressure:	100.5 psi	Initial Sample Height:	3.0017 in
Project No:	40-0223-5A JWS	Bottom Pressure (Pb):	97.8 psi	Initial Area of Sample:	4.9048 sq. in.
Boring No.:	n/a	Top Pressure (Pt):	95.7 psi	Final Sample Ht. * (L):	2.9943 in
Depth(ft):	n/a	Consolidation Pressure:	4.8 psi	Final Sample Area (A)*	4.8808 sq. in.
Sample No.:	n/a	Burette Area (influent) (Ai):	0.036 sq. in.	Tested by:	RA Date: 09/08/94
Sample Type:	Block (trimmed)	Burette Area (effluent) (Ao):	0.036 sq. in.	Input Checked by:	RA Date: 09/13/94
Sample Description:	Light Gray, Lean Clay (CL)	Vol. Change During Consol.:	0.108 cu. in.	Reviewed by:	<i>SP</i> Date: 09/14/94

* After Consolidation

Date	Time	Incremental Elapsed Time (t) (min)	Temp. ° C	Water Height Influent Burette (hi) (cm)	Water Height Effluent Burette (ho) (cm)	Uncorrected Hydraulic Conductivity(k) (cm/sec)	Corrected Conductivity at 20 °C (cm/sec)	Inflow Rate/ Outflow Rate	Remarks
12-Sep-94	08:10 AM	929	21.6	10.6	18.0	2.0E-08	2.0E-08	1.06	Average Last 4 rdgs= 1.9E-08
12-Sep-94	09:35 AM	85	21.8	10.4	18.2	1.9E-08	1.8E-08	0.98	Upper Limit= 2.4E-08
12-Sep-94	12:55 PM	200	21.8	9.9	18.7	2.0E-08	2.0E-08	0.98	Lower Limit= 1.4E-08
12-Sep-94	03:06 PM	131	21.9	9.6	19.0	1.9E-08	1.8E-08	0.98	

$$k = \frac{A_i \cdot A_o \cdot L \cdot \ln(h_1/h_2)}{A \cdot t \cdot (A_i + A_o)}$$

where $h_1, h_2 = ((P_b - P_t)/Y - \text{change in } h_i - \text{change in } h_o) \text{ at } t_1 \text{ and } t_2$

$Y = \text{Water Density}$

ATTERBERG LIMITS

Test Procedure No. 160 ASTM D4318-93

Project Name: Weiss Associates
 Project No.: 40-0223-5A JWS
 Boring No.: N/A
 Sample No.: Porcelain Clay
 Visual Sample Description: Light Gray lean Clay (CL)

Tested By: kiat Date: 9/6/94
 Data Input By: kiat Date: 9/7/94
 Checked By: sp Date: 9/9/94
 Depth (ft.): N/A

TEST NO.	PLASTIC LIMIT		LIQUID LIMIT			
	1	2	1	2	3	4
Number of Blows [N]			30	25	20	15
Container No.	BM1	95	MG	B-21	98	UV
Wet Wt. of Soil + Cont. (gm.)	12.45	12.81	8.70	8.49	8.22	9.76
Dry Wt. of Soil + Cont. (gm.)	10.81	11.14	6.75	6.57	6.34	7.38
Wt. of Container (gm.)	0.94	0.91	0.90	0.92	0.89	0.91
Moisture Content (%) [Wn]	16.62	16.32	33.33	33.98	34.50	36.79

LIQUID LIMIT
 PLASTIC LIMIT
 PLASTICITY INDEX

34

16

18

Classification of fine-grained
 & fine-grained fraction of soils
 CL

$$PI \text{ at "A" - Line} = 0.73(LL-20) = 10.2$$

One - Point Liquid Limit Calculation

$$LL = W_n(N/25)^{0.121}$$

PROCEDURES USED

- ☒ Wet Preparation
 Multipoint Wet Preparation
- ☐ Dry Preparation
 Multipoint Dry Preparation
- ☒ Procedure A
 Multipoint Test
- ☐ Procedure B
 One-point Test

WEISS ASSOCIATES
JOB # 40-0223-3-3.2

DATE : October 22, 1994
FILE NO : 2-941022-1
SAMPLE : SARA 1 Oklahoma sand

LASER PARTSIZ DISTRIBUTION

DEPTH :				SORTING PARAMETERS		
PERCENTILES	DIAMETER			PARAMETER	TRASK*	FOLK**
	(mm)	(inches)	(phi)			MOMENT**
5	0.2734	0.0108	1.8709	MEAN	0.1753	2.5436
10	0.2455	0.0097	2.0263	MEDIAN	0.1737	2.5256
16	0.2291	0.0090	2.1262	SORTING	1.1993	0.4149
25	0.2068	0.0081	2.2737	SKEWNESS	0.9858	0.3560
50	0.1737	0.0068	2.5256	KURTOSIS	0.2448	3.1875
75	0.1438	0.0057	2.7981	SURFACE AREA (m ² /cc)		
84	0.1293	0.0051	2.9508			0.0367
90	0.1167	0.0046	3.0987	STD DEVIATION (mm)	0.0476	*COMPUTED USING MILLIMETER VALUES
95	0.1032	0.0041	3.2768	STD DEVIATION (inches)	0.0019	

*COMPUTED USING MILLIMETER VALUES
**COMPUTED USING PHI VALUES

WEISS ASSOCIATES
JOB # 40-0223-3-3.2

SAMPLE: SARA 1
DEPTH :

LASER PARTSIZ™ DISTRIBUTION

PARTICLE SIZE DISTRIBUTION								SORTING PARAMETERS			
	DIAMETER				WEIGHT %			PARAMETER	TRASK*	FOLK**	MOMENT**
	MESH	PHI	IN	MM	SEP	SEP	CUM				
CRS SAND	35	1.00	0.0197	0.5000	0.0	0.0	0.0	MEAN	0.1753	2.5342	2.5436
	40	1.25	0.0165	0.4200	0.0		0.0	MEDIAN	0.1737	2.5256	2.5256
	45	1.50	0.0138	0.3500	0.0		0.0	SORTING	1.1993	0.4192	0.4149
	50	1.75	0.0117	0.2970	1.8		1.8	SKEWNESS	0.9858	0.0500	0.3560
MED SAND	60	2.00	0.0098	0.2500	6.6	8.4	8.4	KURTOSIS	0.2448	1.0987	3.1875
	70	2.25	0.0083	0.2100	15.0		23.5				
	80	2.50	0.0070	0.1770	24.6		48.0				
	100	2.75	0.0056	0.1490	23.9		71.9				
FINE SAND	120	3.00	0.0049	0.1250	15.1	78.6	87.0	SURFACE AREA (m ^ 2/cc)		0.0367	
	140	3.25	0.0041	0.1050	7.7		94.7	STD DEVIATION (mm)		0.0476	
	170	3.50	0.0035	0.0880	3.3		97.9	STD DEVIATION (inches)		0.0019	
VERY	200	3.75	0.0029	0.0740	1.6		99.5				
FINE SAND	230	4.00	0.0024	0.0620	0.5	13.0	100.0				
	270	4.25	0.0021	0.0530	0.0		100.0				
	325	4.50	0.0017	0.0440	0.0		100.0				
	400	4.75	0.0015	0.0370	0.0		100.0				
CRS SILT	500	5.00	0.0014	0.0310	0.0	0.0	100.0	PERCENTILES	(mm)	(inches)	(phi)
		5.25	0.0010	0.0260	0.0		100.0	5	0.2734	0.0108	1.8709
		5.50	0.0009	0.0220	0.0		100.0	10	0.2455	0.0097	2.0263
		5.75	0.0007	0.0190	0.0		100.0	16	0.2291	0.0090	2.1262
MED SILT		6.00	0.0006	0.0160	0.0	0.0	100.0	25	0.2068	0.0081	2.2737
		6.25	0.0005	0.0130	0.0		100.0	50	0.1737	0.0068	2.5256
		6.50	0.0004	0.0110	0.0		100.0	75	0.1438	0.0057	2.7981
		6.75	0.0003	0.0093	0.0		100.0	84	0.1293	0.0051	2.9508
FINE SILT		7.00	0.0003	0.0078	0.0	0.0	100.0	90	0.1167	0.0046	3.0987
		7.25	0.0002	0.0065	0.0		100.0	95	0.1032	0.0041	3.2768
		7.50	0.0002	0.0055	0.0		100.0				
		7.75	0.0002	0.0046	0.0		100.0				
VERY		8.00	0.0001	0.0039	0.0	0.0	100.0				
FINE SILT		8.25	0.0001	0.0033	0.0		100.0				
		8.50	0.0001	0.0028	0.0		100.0				
		8.75	0.0001	0.0023	0.0		100.0				
		9.00	0.0000	0.0019	0.0		100.0				
		9.25	0.0000	0.0016	0.0		100.0				
		9.50	0.0000	0.0014	0.0		100.0				
		9.75	0.0000	0.0012	0.0		100.0				
CLAY		10.00	0.0000	0.0010	0.0	0.0	100.0				

OTHER DATA

BED THICKNESS (inches)
POSITION (top,middle,bottom)
DISTANCE FROM TOP (in.)
FLU (1=yes, 0=no)

*COMPUTED USING MILLIMETER VALUES

**COMPUTED USING PHI VALUES

WEISS ASSOCIATES
JOB # 40-0223-3-3.2

DATE : October 22, 1994
FILE NO : 2-941022-1
SAMPLE : SARA 2 Custer feldspar

LASER PARTSIZ DISTRIBUTION

DEPTH :

SORTING PARAMETERS

PERCENTILES	DIAMETER			PARAMETER	TRASK*	FOLK**	MOMENT**
	(mm)	(inches)	(ϕ)				
5	0.0732	0.0029	3.7715	MEAN	0.0226	6.2463	6.1092
10	0.0585	0.0023	4.0963	MEDIAN	0.0172	5.8585	5.8585
16	0.0488	0.0019	4.3555	SORTING	2.5802	1.8267	1.7073
25	0.0393	0.0015	4.6680	SKEWNESS	0.7825	0.2364	0.3215
50	0.0172	0.0007	5.8585	KURTOSIS	0.2975	0.7758	1.9180
75	0.0059	0.0002	7.4029	SURFACE AREA (m^2/cc)		0.8277	
84	0.0027	0.0001	8.5249				
90	0.0023	0.0001	8.7731	STD DEVIATION (mm)		0.0229	*COMPUTED USING MILLIMETER VALUES
95	0.0020	0.0001	8.9484	STD DEVIATION (inches)		0.0009	**COMPUTED USING PHI VALUES

WEISS ASSOCIATES
JOB # 40-0223-3-3.2

SAMPLE: SARA 2
DEPTH :

LASER PARTSIZ™ DISTRIBUTION

PARTICLE SIZE DISTRIBUTION								SORTING PARAMETERS			
	DIAMETER				WEIGHT %			PARAMETER	TRASK*	FOLK**	MOMENT**
	MESH	PHI	IN	MM	SEP	SEP	CUM				
CRS SAND	35	1.00	0.0197	0.5000	0.0	0.0	0.0	MEAN	0.0226	6.2463	6.1092
	40	1.25	0.0165	0.4200	0.0		0.0	MEDIAN	0.0172	5.8585	5.8585
	45	1.50	0.0138	0.3500	0.0		0.0	SORTING	2.5802	1.8267	1.7073
	50	1.75	0.0117	0.2970	0.0		0.0	SKEWNESS	0.7825	0.2364	0.3215
MED SAND	60	2.00	0.0098	0.2500	0.0	0.0	0.0	KURTOSIS	0.2975	0.7758	1.9180
	70	2.25	0.0083	0.2100	0.0		0.0				
	80	2.50	0.0070	0.1770	0.0		0.0				
	100	2.75	0.0056	0.1490	0.0		0.0				
FINE SAND	120	3.00	0.0049	0.1250	0.4	0.4	0.4	SURFACE AREA (m^2/cc)		0.8277	
	140	3.25	0.0041	0.1050	0.8		1.1	STD DEVIATION (mm)		0.0229	
	170	3.50	0.0035	0.0880	1.4		2.6	STD DEVIATION (inches)		0.0009	
VERY	200	3.75	0.0029	0.0740	2.2		4.7				
FINE SAND	230	4.00	0.0024	0.0620	3.4	7.7	8.1				
	270	4.25	0.0021	0.0530	5.0		13.1				
	325	4.50	0.0017	0.0440	7.0		20.0				
	400	4.75	0.0015	0.0370	7.6		27.6				
CRS SILT	500	5.00	0.0014	0.0310	6.6	26.2	34.3	PERCENTILES			
		5.25	0.0010	0.0260	5.0		39.2	(mm)			
		5.50	0.0009	0.0220	4.2		43.4	(inches)			
		5.75	0.0007	0.0190	4.5		47.9	(phi)			
MED SILT		6.00	0.0006	0.0160	5.1	18.8	53.1	5	0.0732	0.0029	3.7715
		6.25	0.0005	0.0130	5.0		58.1	10	0.0585	0.0023	4.0963
		6.50	0.0004	0.0110	3.8		61.9	16	0.0488	0.0019	4.3555
		6.75	0.0003	0.0093	3.2		65.1	25	0.0393	0.0015	4.6680
FINE SILT		7.00	0.0003	0.0078	3.4	15.4	68.5	50	0.0172	0.0007	5.8585
		7.25	0.0002	0.0065	4.1		72.6	75	0.0059	0.0002	7.4029
		7.50	0.0002	0.0055	3.9		76.5	84	0.0027	0.0001	8.5249
VERY		7.75	0.0002	0.0046	2.2		78.7	90	0.0023	0.0001	8.7731
FINE SILT		8.00	0.0001	0.0039	1.2	11.4	79.9	95	0.0020	0.0001	8.9484
		8.25	0.0001	0.0033	1.2		81.1				
		8.50	0.0001	0.0028	2.4		83.4				
		8.75	0.0001	0.0023	5.9		89.3				
		9.00	0.0000	0.0019	7.1		96.5				
		9.25	0.0000	0.0016	2.9		99.4				
		9.50	0.0000	0.0014	0.6		100.0				
		9.75	0.0000	0.0012	0.0		100.0				
CLAY		10.00	0.0000	0.0010	0.0	20.1	100.0				

OTHER DATA

BED THICKNESS (inches)
POSITION (top,middle,bottom)
DISTANCE FROM TOP (in.)
FLU (1=yes, 0=no)

*COMPUTED USING MILLIMETER VALUES

**COMPUTED USING PHI VALUES

WEISS ASSOCIATES
JOB # 40-0223-3-3.2

DATE : October 22, 1994
FILE NO : 2-941022-1
SAMPLE : SARA3 Porcelain clay

LASER PARTSIZ DISTRIBUTION

DEPTH :				SORTING PARAMETERS		
PERCENTILES	DIAMETER			PARAMETER	TRASK*	FOLK**
	(mm)	(inches)	(phi)			MOMENT**
5	0.0412	0.0016	4.6004	MEAN	0.0091	7.1155
10	0.0333	0.0013	4.9095	MEDIAN	0.0071	7.1322
16	0.0252	0.0010	5.3119	SORTING	2.5071	1.5532
25	0.0158	0.0006	5.9880	SKEWNESS	0.7772	-0.0429
50	0.0071	0.0003	7.1322	KURTOSIS	0.2107	0.7301
75	0.0025	0.0001	8.6401	SURFACE AREA (m ² /cc)		
84	0.0021	0.0001	8.9023			1.4287
90	0.0018	0.0001	9.0935	STD DEVIATION (mm)	0.0115	
95	0.0016	0.0001	9.3250	STD DEVIATION (inches)	0.0005	

*COMPUTED USING MILLIMETER VALUES

**COMPUTED USING PHI VALUES

WEISS ASSOCIATES
JOB # 40-0223-3-3.2

SAMPLE: SARA 3
DEPTH :

LASER PARTSIZ™ DISTRIBUTION

PARTICLE SIZE DISTRIBUTION								SORTING PARAMETERS			
	DIAMETER				WEIGHT %			PARAMETER	TRASK*	FOLK**	MOMENT**
	MESH	PHI	IN	MM	SEP	SEP	CUM				
CRS SAND	35	1.00	0.0197	0.5000	0.0	0.0	0.0	MEAN	0.0091	7.1155	7.1675
	40	1.25	0.0165	0.4200	0.0		0.0	MEDIAN	0.0071	7.1322	7.1322
	45	1.50	0.0138	0.3500	0.0		0.0	SORTING	2.5071	1.6134	1.5532
	50	1.75	0.0117	0.2970	0.0		0.0	SKEWNESS	0.7772	-0.0429	-0.1603
MED SAND	60	2.00	0.0098	0.2500	0.0	0.0	0.0	KURTOSIS	0.2107	0.7301	1.8514
	70	2.25	0.0083	0.2100	0.0		0.0				
	80	2.50	0.0070	0.1770	0.0		0.0				
	100	2.75	0.0056	0.1490	0.0		0.0				
FINE SAND	120	3.00	0.0049	0.1250	0.0	0.0	0.0	SURFACE AREA (m^2/cc)		1.4287	
	140	3.25	0.0041	0.1050	0.0		0.0	STD DEVIATION (mm)		0.0115	
	170	3.50	0.0035	0.0880	0.0		0.0	STD DEVIATION (inches)		0.0005	
VERY	200	3.75	0.0029	0.0740	0.0		0.0				
FINE SAND	230	4.00	0.0024	0.0620	0.0	0.0	0.0				
	270	4.25	0.0021	0.0530	1.1		1.1				
	325	4.50	0.0017	0.0440	2.4		3.5				
	400	4.75	0.0015	0.0370	3.8		7.3				
CRS SILT	500	5.00	0.0014	0.0310	4.3	11.6	11.6				
		5.25	0.0010	0.0260	3.7		15.3				
		5.50	0.0009	0.0220	3.0		18.3				
		5.75	0.0007	0.0190	3.0		21.4				
MED SILT		6.00	0.0006	0.0160	3.9	13.7	25.3				
		6.25	0.0005	0.0130	5.3		30.6				
		6.50	0.0004	0.0110	6.0		36.6				
		6.75	0.0003	0.0093	5.8		42.4				
FINE SILT		7.00	0.0003	0.0078	5.2	22.3	47.6				
		7.25	0.0002	0.0065	4.6		52.2				
		7.50	0.0002	0.0055	4.0		56.3				
VERY		7.75	0.0002	0.0046	3.3		59.6				
FINE SILT		8.00	0.0001	0.0039	2.9	14.9	62.5				
		8.25	0.0001	0.0033	3.3		65.8				
		8.50	0.0001	0.0028	4.9		70.7				
		8.75	0.0001	0.0023	7.8		78.5				
		9.00	0.0000	0.0019	9.1		87.6				
		9.25	0.0000	0.0016	6.6		94.1				
		9.50	0.0000	0.0014	3.0		97.1				
		9.75	0.0000	0.0012	1.7		98.8				
CLAY		10.00	0.0000	0.0010	1.2	37.5	100.0				

PERCENTILES	DIAMETER		
	(mm)	(inches)	(phi)
5	0.0412	0.0016	4.6004
10	0.0333	0.0013	4.9095
16	0.0252	0.0010	5.3119
25	0.0158	0.0006	5.9880
50	0.0071	0.0003	7.1322
75	0.0025	0.0001	8.6401
84	0.0021	0.0001	8.9023
90	0.0018	0.0001	9.0935
95	0.0016	0.0001	9.3250

OTHER DATA

BED THICKNESS (inches)
POSITION (top,middle,bottom)
DISTANCE FROM TOP (in.)
FLU (1=yes, 0=no)

*COMPUTED USING MILLIMETER VALUES

**COMPUTED USING PHI VALUES

WEISS ASSOCIATES

AJAX SAND
PO 40-02234-JWS

LASER PARTSIZ DISTRIBUTION^{SM} (Extended Range Analysis)

PARTICLE DIAMETER

CORE PETROPHYSICS, INC.
HOUSTON, TEXAS
FILE NUMBER 2-950417-1

WEISS ASSOCIATES
PO #40-0223-4-JWS

SAMPLE: AJAX SAND

LASER PARTSIZ^{TM} DISTRIBUTION

PARTICLE SIZE DISTRIBUTION								SORTING PARAMETERS			
	DIAMETER				WEIGHT %			PARAMETER	TRASK*	FOLK**	MOMENT**
	MESH	PHI	IN	MM	SEP	SEP	CUM				
PEBBLE	5 -	2.00	0.157	4.0000	0.0	0.0	0.0	MEAN	0.2819	1.9692	
GRANULE	10 -	1.00	0.079	2.0000	0.0	0.0	0.0	MEDIAN	0.2655	1.9133	1.9133
V CRS SAND	18	0.00	0.039	1.0000	2.0	2.0	2.0	SORTING		1.4089	
CRS SAND	30	0.75	0.0234	0.6000	14.1		16.1	SKEWNESS			
	35	1.00	0.0197	0.5000	4.0	18.1	20.0	KURTOSIS			
	40	1.25	0.0165	0.4200	6.0		26.0				
	45	1.50	0.0138	0.3500	8.6		34.6				
MED SAND	50	1.75	0.0117	0.2970	9.8		44.4				
	60	2.00	0.0098	0.2500	9.2	33.6	53.7				
	70	2.25	0.0083	0.2100	8.4		62.0				
	80	2.50	0.0070	0.1770	7.4		69.4				
FINE SAND	100	2.75	0.0056	0.1490	6.4		75.8				
	120	3.00	0.0049	0.1250	5.1	27.2	80.9				
	140	3.25	0.0041	0.1050	3.9		84.7				
	170	3.50	0.0035	0.0880	2.8		87.5				
VERY FINE SAND	200	3.75	0.0029	0.0740	2.0		89.5				
	230	4.00	0.0024	0.0620	1.5	10.1	91.0				
	270	4.25	0.0021	0.0530	1.2		92.1				
	325	4.50	0.0017	0.0440	0.9		93.1				
CRS SILT	400	4.75	0.0015	0.0370	0.7		93.8				
	500	5.00	0.0014	0.0310	0.6	3.4	94.4				
		5.25	0.0010	0.0260	0.5		94.9				
		5.50	0.0009	0.0220	0.5		95.4				
MED SILT		5.75	0.0007	0.0190	0.4		95.8				
		6.00	0.0006	0.0160	0.4	1.8	96.2				
		6.25	0.0005	0.0130	0.4		96.7				
		6.50	0.0004	0.0110	0.4		97.1				
FINE SILT		6.75	0.0003	0.0093	0.4		97.4				
		7.00	0.0003	0.0078	0.3	1.5	97.8				
		7.25	0.0002	0.0065	0.3		98.1				
		7.50	0.0002	0.0055	0.3		98.4				
VERY FINE SILT		7.75	0.0002	0.0046	0.3		98.7				
		8.00	0.0001	0.0039	0.3	1.2	99.0				
		8.25	0.0001	0.0033	0.3		99.3				
		8.50	0.0001	0.0028	0.3		99.6				
CLAY		8.75	0.0001	0.0023	0.3		99.9				
		9.00	0.0000	0.0019	0.0		99.9				
		9.25	0.0000	0.0016	0.0		99.9				
		9.50	0.0000	0.0014	0.0		99.9				
		9.75	0.0000	0.0012	0.0		99.9				
		10.00	0.0000	0.0010	0.0	0.9	99.9				

poorly sorted sand

$1.0 < (\phi_{84} - \phi_{16})/4 + < 2.0$

$(\phi_{95} - \phi_5)/6$

PERCENTILES	DIAMETER		
	(mm)	(inches)	(phi)
5	0.8977	0.0353	0.1558
10	0.7574	0.0298	0.4008
16	0.6011	0.0237	0.7344
25	0.4106	0.0162	1.2841
50	0.2655	0.0105	1.9133
75	0.1532	0.0060	2.7068
84	0.1044	0.0041	3.2599
90	0.0699	0.0028	3.8387
95	0.0256	0.0010	5.2904

OTHER DATA

BED THICKNESS (inches)

POSITION (top,middle,bottom)

DISTANCE FROM TOP (in.)

FLU (1=yes, 0=no)

* COMPUTED USING MILLIMETER VALUES

** COMPUTED USING PHI VALUES

JWSSARA2
JWSSARA2

<- 5.000

45.000 ->

6/1/94

Data From: JWSSARA2 Cluster feldspar = Microcline w/ trace illite
 Comments: JWSSARA2 K-spar
 Date: 6/1/94

	Angle	D-Spacing	Height	Intensity	Net Area	Intensity	
1.	8.77	10.068	illite(h)	144	5.9	0	0.0
2.	13.57	6.517	84	3.4	0	0.0	
3.	13.82	6.400	83	3.4	0	0.0	
4.	17.73	5.000	101	4.1	0	0.0	
5.	20.77	4.272	281	11.4	0	0.0	
6.	21.80	4.073	59	2.4	0	0.0	
7.	22.00	4.037	88	3.6	0	0.0	
8.	22.25	3.992	74	3.0	0	0.0	
9.	23.13	3.843	326	13.2	} Kspar	0	0.0
10.	23.48	3.786	287	11.7		0	0.0
11.	23.92	3.716	216	8.8	0	0.0	
12.	24.23	3.671	83	3.4	0	0.0	
13.	25.52	3.487	175	7.1	0	0.0	
14.	26.55	3.354	829	33.7	0	0.0	
15.	26.98	3.302	61	2.5	0	0.0	
16.	27.38	3.255	} Kspar	2461	100.0	0	0.0
17.	27.88	3.198		1198	48.7	0	0.0
18.	29.38	3.038	161	6.5	0	0.0	
19.	30.08	2.969	237	9.6	0	0.0	
20.	30.45	2.933	143	5.8	0	0.0	
21.	30.75	2.905	133	5.4	0	0.0	
22.	31.15	2.869	31	1.3	0	0.0	
23.	32.30	2.769	108	4.4	0	0.0	
24.	34.13	2.625	141	5.7	0	0.0	
25.	34.95	2.565	98	4.0	0	0.0	
26.	35.47	2.528	92	3.7	0	0.0	
27.	35.85	2.503	30	1.2	0	0.0	
28.	36.47	2.461	169	6.9	0	0.0	
29.	36.92	2.432	163	6.6	0	0.0	
30.	38.53	2.335	74	3.0	0	0.0	

JWSSARA3
JWSSARA3

<- 5.000

45.000 ->

6/1/94

Data From: JWSSARA3

Comments: JWSSARA3

Date: 6/1/94

Aardvark porcelain clay = kaolinite + quartz + microcline
K-spar

	Angle	D-Spacing	Height	Intensity	Net Area	Intensity
1.	12.32	7.175	297	6.6	0	0.0
2.	19.88	4.463	48	1.1	0	0.0
3.	20.83	4.262	Quartz 788	17.6	0	0.0
4.	23.23	3.827	90	2.0	0	0.0
5.	24.85	3.580	Kaol 658	14.7	0	0.0
6.	25.52	3.487	-331	-7.4	0	0.0
7.	26.63	3.345	Quartz 4478	100.0	0	0.0
8.	27.42	3.249	745	16.6	0	0.0
9.	27.90	3.195	K-spar 483	10.8	0	0.0
10.	29.40	3.035	56	1.3	0	0.0
11.	30.45	2.933	57	1.3	0	0.0
12.	30.70	2.910	112	2.5	0	0.0
13.	34.95	2.565	84	1.9	0	0.0
14.	35.90	2.499	13	0.3	0	0.0
15.	36.53	2.458	379	8.5	0	0.0
16.	37.70	2.384	110	2.5	0	0.0
17.	38.50	2.336	71	1.6	0	0.0
18.	39.45	2.282	224	5.0	0	0.0
19.	40.22	2.240	175	3.9	0	0.0
20.	41.78	2.160	75	1.7	0	0.0
21.	42.42	2.129	346	7.7	0	0.0

CORE LABORATORIES

LABORATORY TESTS RESULTS 04/20/95

JOB NUMBER: 950878

CUSTOMER: Weiss Associates

ATTN: James W. Spencer

CLIENT I.D.: Canola Oil

DATE SAMPLED: / /

TIME SAMPLED: :

WORK DESCRIPTION: Canola Oil

LABORATORY I.D.: 950878-0001

DATE RECEIVED: 04/18/95

TIME RECEIVED: :

REMARKS: 250 ml jar

TEST DESCRIPTION	FINAL RESULT	LIMITS/*DILUTION	UNITS OF MEASURE	TEST METHOD	DATE	TECHN
Density	0.9190	0.0001	g/ml	D-4052 @ 65 Deg F	04/19/95	PCW
Density	0.9182	0.0001	g/ml	D-4052 @ 70 Deg F	04/19/95	PCW
Density	0.9170	0.0001	g/ml	D-4052 @ 75 Deg F	04/19/95	PCW
Viscosity @ 65 Deg F	72.71	0.01	cP	ASTM D-445	04/19/95	PCW
Viscosity @ 70 Deg F	65.12	0.01	cP	ASTM D-445	04/19/95	PCW
Viscosity @ 75 Deg F	57.00	0.01	cP	ASTM D-445	04/19/95	PCW
<u>per Proctor & Gamble</u> <u>.9182 g/cm³ @ 68°F</u> <u>68 cP at 68°F</u>						

3700 Cherry Avenue
Long Beach, CA 90807
(310) 595-8401

CORE LABORATORIES

QUALITY ASSURANCE REPORT 04/20/95

JOB NUMBER: 950878

CUSTOMER: Weiss Associates

ATTN: James W. Spencer

ANALYSIS			DUPLICATES			REFERENCE STANDARDS		MATRIX SPIKES		
ANALYSIS TYPE	ANALYSIS SUB-TYPE	ANALYSIS I.D.	ANALYZED VALUE (A)	DUPLICATE VALUE (B)	RPD or (A-B)	TRUE VALUE	PERCENT RECOVERY	ORIGINAL VALUE	SPIKE ADDED	PERCENT RECOVERY
PARAMETER: Viscosity @ 65 Deg F			DATE/TIME ANALYZED: 04/19/95 13:00			QC BATCH NUMBER: 946315				
REPORTING LIMIT/DF: 0.01 UNITS: cst			METHOD REFERENCE : ASTM D-445			TECHNICIAN: PCW				
DUPLICATE	Analytical	950878-1	72.71	72.71	0					
PARAMETER: Viscosity @ 70 Deg F			DATE/TIME ANALYZED: 04/19/95 13:00			QC BATCH NUMBER: 946316				
REPORTING LIMIT/DF: 0.01 UNITS: cst			METHOD REFERENCE : ASTM D-445			TECHNICIAN: PCW				
DUPLICATE	Analytical	950878-1	65.12	65.10	0					
PARAMETER: Viscosity @ 75 Deg F			DATE/TIME ANALYZED: 04/19/95 13:00			QC BATCH NUMBER: 946317				
REPORTING LIMIT/DF: 0.01 UNITS: cst			METHOD REFERENCE : ASTM D-445			TECHNICIAN: PCW				
DUPLICATE	Analytical	950878-1	57.00	56.98	0					

3700 Cherry Avenue
Long Beach, CA 90807
(310) 595-8401

PTS Laboratories, Inc.

Geotechnical Services

8100 Secura Way • Santa Fe Springs • CA 90670
Phone (310) 907-3607 • Fax (310) 907-3610

June 26, 1995

James Spencer
Weiss Associates
15262 Pipeline Lane
Huntington Beach, CA 92647

Re: Project No: 40-0223-4-JWS
PTS File: 25069

Dear Mr. Spencer:

Enclosed are final data for analysis conducted on samples submitted from your Project No: 40-0223-4-JWS project. I have included the previous data for your convenience. All analyses were performed by applicable ASTM, EPA or API methodology. Samples will be retained for 30 days before disposal unless prior arrangements are made.

We appreciate the opportunity to be of service and trust these data will prove beneficial in the development of this project. Please feel free to call either myself or Fred Adame, Supervisor, should you have any questions or require additional information.

Sincerely,

PTS Laboratories, Inc.

Larry Kunkel
District Manager

LAK:lg
encl.

PTS Laboratories, Inc.

Client: Weiss Associates

File No: 25069
Date: May 1995

EXTRACTION DATA

(Methodology: API RP40)

Sample ID	Thimble Wt, gm	Sample Wet Wt. w/ Thimble gm	Sample Dry Wt. w/ Thimble gm	Sample Wet Wt, gm	Sample Dry Wt., gm	Fluids Removed gm	Extracted Water raw, ml	Sidearm No.	Sidearm Correction ml	Corrected Water, ml	Extracted Oil Wt, gm	Corrected Oil Wt, gm	Saturation percent initial weight	
													Water	Oil
May 25, 1995														
OK4245W/O	6.53	208.64	175.30	202.11	168.77	33.34	23.80	A1	0.08	23.88	9.54	9.46	11.82	4.68
OK4255W/O	6.51	176.60	151.71	170.09	145.20	24.89	21.05	A1	0.07	21.12	3.84	3.77	12.42	2.22
OK4265W/O	14.05	202.24	175.19	188.19	161.14	27.05	23.05	A1	0.08	23.13	4.00	3.92	12.29	2.08
OK4285W/O	14.32	200.60	173.81	186.28	159.49	26.79	22.33	A2	0.07	22.40	4.46	4.39	12.02	2.36
OK5015W/O	6.93	197.95	170.54	191.02	163.61	27.41	22.75	A2	0.07	22.82	4.66	4.59	11.95	2.40
OK5025W/O	6.62	191.03	163.02	184.41	156.40	28.01	22.35	A3	-0.12	22.23	5.66	5.78	12.05	3.13
OK4245918	7.21	184.32	158.74	177.11	151.53	25.58	21.13	A3	-0.11	21.02	4.45	4.56	11.87	2.57
OK4255914	15.03	195.42	169.08	180.39	154.05	26.34	21.92	A3	-0.12	21.80	4.42	4.54	12.08	2.52
OK50251112	6.83	199.88	172.87	193.05	166.04	27.01	22.40	A3	-0.12	22.28	4.61	4.73	11.54	2.45
OK50351110	15.89	210.03	182.81	194.14	166.92	27.22	22.82	A2	0.07	22.89	4.40	4.33	11.79	2.23
OK50351122	13.05	205.18	178.07	192.13	165.02	27.11	22.57	A1	0.08	22.65	4.54	4.46	11.79	2.32
OK50451102	13.40	205.55	178.02	192.15	164.62	27.53	23.03	A3	-0.12	22.91	4.50	4.62	11.92	2.40
OK50451128	7.53	204.43	175.95	196.90	168.42	28.48	23.50	A1	0.08	23.58	4.98	4.90	11.98	2.49
OK50551100	7.47	204.35	175.42	196.88	167.95	28.93	24.04	A2	0.07	24.11	4.89	4.82	12.25	2.45
June 23, 1995														
OK6075 W/O	15.78	226.02	194.97	210.24	179.19	31.05	26.45	A1	0.08	26.53	4.60	4.52	12.62	2.15
OK6125 W/O	13.24	225.65	194.81	212.41	181.57	30.84	26.10	A2	0.07	26.17	4.74	4.67	12.32	2.20
OK6135 W/O	14.67	224.57	193.05	209.90	178.38	31.52	26.59	A1	0.08	26.67	4.93	4.85	12.71	2.31
OK6085 1156	12.40	222.99	194.00	210.59	181.60	28.99	25.75	A2	0.07	25.82	3.24	3.17	12.26	1.51
OK6125 1140	16.20	224.52	194.97	208.32	178.77	29.55	24.92	A1	0.08	25.00	4.63	4.55	12.00	2.18
OK6145 1150	13.84	220.77	193.24	206.93	179.40	27.53	25.69	A2	0.07	25.76	1.84	1.77	12.45	0.86

WEISS ASSOCIATES
 5500 Shellmound Street, Emeryville, CA 94608
 Phone: 415-547-5400 Fax: 415-547-5043
 510-450-6000 510
 MARILYN JING

bill to this address referencing project)

Please send analytic results and a
 of the signed chain of custody form to:
 Jim Spencer

Weiss Associates c/o SARA, Inc. 15262 Pipeline Lane

Project ID: 40-0223-4-JWS

Huntington Beach, CA 92647

25067
 Lab Personnel:

☐ PLEASE INCLUDE QA/QC BOX IS
 CHECKED.

- 1) Specify analytic method and detection limit in report.
- 2) Notify us if there are any anomalous peaks in GC or other scans.
- 3) ANY QUESTIONS/CLARIFICATIONS: CALL US.

CHAIN-OF-CUSTODY RECORD AND ANALYTIC INSTRUCTIONS

Sampled by: John Spadaro

Laboratory Name: SARA, Inc.

- agreed compensation \$30.00/sample
- samples contain quartz sand, canola oil and water
- save empty jars

No. of Containers	Sample ID	Container Type	Sample Date	Vol ²	Fil ³	Ref ⁴	Preservative (specify)	Analyze for	Analytic Method	Turn ⁵	COMMENTS
1	OK4245W/O	SCPT	4/24/95	250	N	N	none	Dean-Stark extraction* of pore		N	OK sand w/o excit. 1:00 p
1	OK4255W/O	SCPT	4/25/95	250	N	N	none	fluids per API RP40. Final		N	OK sand w/o excit. 11:00 a
1	OK4265W/O	SCPT	4/26/95	250	N	N	none	report to include:		N	OK sand w/o excit. 3:00
1	OK4285W/O	SCPT	4/28/95	250	N	N	none	wt. of sand w/ oil and water		N	OK sand w/o excit. 8:00
1	OK5015W/O	SCPT	5/1/95	250	N	N	none	vol. water extracted (raw)		N	OK sand w/o excit. 2:00
1	OK5025W/O	SCPT	5/2/95	250	N	N	none	wt. water extracted after corr.		N	OK sand w/o excit. 2:00
1	OK4245918	SCPT	4/24/95	250	N	N	none	wt. of clean dry sand		N	OK sand 918 HZ 7:00
1	OK4255914	SCPT	4/25/95	250	N	N	none	wt. of oil (by difference)		N	OK sand 914 HZ 5:00
1	OK50151112	SCPT	5/1/95	250	N	N	none	ppm oil (calculated)		N	OK sand 1112 HZ 7:00
1	OK50351110	SCPT	5/3/95	250	N	N	none			N	OK sand 1110 HZ 8:00
1	OK50351122	SCPT	5/3/95	250	N	N	none	*analyze whole sample using		N	OK sand 1122 HZ 6:30
1	OK50451102	SCPT	5/4/95	250	N	N	none	large extraction apparatus		N	OK sand 1102 HZ 2:00
1	OK50451128	SCPT	5/4/95	250	N	N	none			N	OK sand 1128 HZ 6:00
1	OK50551100	SCPT	5/5/95	250	N	N	none			N	OK sand 1100 HZ 2:00

1 Released by (Signature), Date

1 Affiliation

2 Lisa Gierdes 5/15/95
 Received by (Signature), Date

2 PTS Laboratories
 Affiliation

3 Released by (Signature), Date

3 Affiliation

4 Shipping Carrier, Method, Date

4 Affiliation

5 Released by (Signature), Date

5 Affiliation

6 Received by Lab Personnel, Date

6 Affiliation, Telephone

Seal intact?

1 Sample Type Codes: W = Water, S = Soil, Describe Other; Container Type Codes: V = VOA/Teflon Septa, P = Plastic, C or B - Clear/Brown Glass, Describe Other;
 Cap Codes: PT = Plastic, Teflon Lined 2 = Volume per container; 3 = Filtered (Y/N); 4 = Refrigerated (Y/N)
 5 Turnaround [N = Normal, W = 1 Week, R = 24 Hour, HOLD (write out)]
 ADDITIONAL COMMENTS, CONDITIONS, PROBLEMS:

WA WEISS ASSOCIATES
 5500 Shellmound Street, Emeryville, CA 94608
 Phone: 415-547-5420 Fax: 415-547-5043
 510-450-6000 510

attn: Ms. Marilyn Jing

CHAIN-OF-CUSTODY RECORD AND ANALYTIC INSTRUCTIONS

bill to this address referencing project ID

Please send analytic results and a copy of the signed chain of custody form to:

Jim Spencer
 Weiss Associates % SARA, Inc. 15262 Pipeline Lane
 Huntington Beach, CA 92647
 Project ID: 40-0223-4-JWS

Lab Personnel:

☒ PLEASE INCLUDE QA/QC IF BOX IS CHECKED.

- ✓ 1) Specify analytic method and detection limit in report.
- 2) Notify us if there are any anomalous peaks in GC or other scans.
- 3) ANY QUESTIONS/CLARIFICATIONS: CALL US.

Sampled by: John Spadaro

Laboratory Name: SARA, Inc.

• compensation \$30.00/sample

• samples contain quartz sand, canola oil and water

No. of Containers	Sample ID	Container Type	Sample Date	Vol ²	Fil ³	Ref ⁴	Preservative (specify)	Analyze for	Analytic Method	Turn ⁵	COMMENTS
1	OK6075W/O	SCPT	6/7/95	250	N	N	none	Dean Stark extraction* of pore fluids per API RP 40. Final report to include:		N	OK sand w/o excitation 10:15
1	OK6125W/O		6/12/95					wt. of sand w/ oil and water			OK sand w/o excitation 9:30
1	OK6135W/O		6/13/95					vol. water extracted (raw)			OK sand w/o excitation 8:50
1	OK60851156		6/8/95					vol. water extracted (corrected)			OK sand 1156 Hz 10:15
1	OK61251140		6/12/95					wt. clean dry sand			OK sand 1140 Hz 14:45
1	OK61451150		6/14/95					wt. of oil extracted			OK sand 1150 Hz 8:30
								wt. of oil (corrected)			
								ppm or % oil (calculated)			
								ppm or % water (calculated)			
								* analyze entire sample using large extraction apparatus. DON'T use sidearm no. A3.			

1 Released by (Signature), Date

3 Released by (Signature), Date

5 Released by (Signature), Date

1 Affiliation

3 Affiliation

5 Affiliation

Received by (Signature), Date
 Lisa Gerdner 6/15/95

4 Shipping Carrier, Method, Date

6 Received by Lab Personnel, Date Seal intact? X

2 PTS Laboratories, Inc.
 Affiliation

4 Affiliation

6 Affiliation, Telephone

1 Sample Type Codes: W = Water, S = Soil, Describe Other; Container Type Codes: V = VOA/Teflon Septa, P = Plastic, C or B - Clear/Brown Glass, Describe Other; Cap Codes: PT = Plastic, Teflon Lined 2 = Volume per container; 3 = Filtered (Y/N); 4 = Refrigerated (Y/N)

5 Turnaround (N = Normal, W = 1 Week, R = 24 Hour, HOLD (write out))

ADDITIONAL COMMENTS, CONDITIONS, PROBLEMS:

Page 1 of 1

PTS Laboratories, Inc.

Geotechnical Services

8100 Secura Way • Santa Fe Springs • CA 90670
Phone (310) 907-3607 • Fax (310) 907-3610

July 17, 1995

James Spencer
Weiss Associates
15262 Pipeline Lane
Huntington Beach, CA 92647

Re: Project No: 40-0223-4-JWS
PTS File: 25069

Dear Mr. Spencer:

Enclosed are final data for analysis conducted on samples submitted from your Project No: 40-0223-4-JWS project. I have included the previous data for your convenience. All analyses were performed by applicable ASTM, EPA or API methodology. Samples will be retained for 30 days before disposal unless prior arrangements are made.

We appreciate the opportunity to be of service and trust these data will prove beneficial in the development of this project. Please feel free to call either myself or Fred Adame, Supervisor, should you have any questions or require additional information.

Sincerely,

PTS Laboratories, Inc.

Larry Kunkel
District Manager

LAK:lg
encl.

PTS Laboratories, Inc.

Client: Weiss Associates

File No: 25069
Date: May 1995

EXTRACTION DATA

(Methodology: API RP40)

Sample ID	Thimble Wt, gm	Sample Wet Wt. w/ Thimble, gm	Sample Dry Wt. w/ Thimble, gm	Sample Wet Wt, gm	Sample Dry Wt., gm	Fluids Removed gm	Extracted Water raw, ml	Sidearm No.	Sidearm Correction ml	Corrected Water, ml	Extracted Oil Wt, gm	Corr. Oil Wt, gm	Saturation percent initial weight	
													Water	Oil
July 6, 1995														
OK622AW/O	14.85	216.97	187.41	202.12	172.56	29.56	18.59	A1	0.08	18.67	10.97	10.89	9.24	5.39
OK622BW/O	12.06	205.50	184.18	193.44	172.12	21.32	17.41	A2	0.07	17.48	3.91	3.84	9.04	1.99
OK6235W/O	14.82	217.51	188.15	202.69	173.33	29.36	28.73	A3	-0.12	28.61	0.63	0.75	14.12	0.37
OK6285W/O	15.82	215.38	186.59	199.56	170.77	28.79	25.05	A1	0.08	25.13	3.74	3.66	12.59	1.83
OK7035W/O	14.78	218.70	188.17	203.92	173.39	30.53	26.04	A2	0.07	26.11	4.49	4.42	12.80	2.17
OK7055W/O*	14.97	234.73	199.38	219.76	184.41	35.35	24.83	A3	-0.12	24.71	10.52	10.64	11.24	4.84
OK62451110	15.02	212.30	184.83	197.28	169.81	27.47	23.81	A1	0.08	23.89	3.66	3.58	12.11	1.81
OK62751140	12.83	218.44	188.87	205.61	176.04	29.57	25.84	A2	0.07	25.91	3.73	3.66	12.60	1.78
OK6305SWP	15.46	219.44	190.10	203.98	174.64	29.34	25.91	A3	-0.12	25.79	3.43	3.55	12.64	1.74
OK7025SWP	13.88	214.91	186.20	201.03	172.32	28.71	25.08	A1	0.08	25.16	3.63	3.55	12.52	1.77
OK7035SWP	16.47	219.79	190.50	203.32	174.03	29.29	25.55	A2	0.07	25.62	3.74	3.67	12.60	1.81

* blind "spike" sample contained 11.09% water and 4.33% canola oil

WA WEISS ASSOCIATES
5500 Shellmound Street, Emeryville, CA 94608
Phone: 415.547.5420 Fax: 415.547.5043
510-450-6000 510
attn: Marylyn Ting

Please send analytic results and a copy of the signed chain of custody form to:

Jim Spencer
Weiss Associates c/o SARA, Inc

Project ID: 40-0223-4-JWS

Lab Personnel:

☐ PLEASE INCLUDE QA/QC DATA IF BOX IS CHECKED.

- 1) Specify analytic method and detection limit in report.
- 2) Notify us if there are any anomalous peaks in GC or other scans.
- 3) ANY QUESTIONS/CLARIFICATIONS: CALL US.

15262 Pipeline Lane
Huntington Beach, CA
92647

CHAIN-OF-CUSTODY RECORD AND ANALYTIC INSTRUCTIONS

Sampled by: John Spadaro

Laboratory Name: SARA, Inc.

compensation \$30.00/sample

Samples contain quartz, solvent, water

No. of Containers	Sample ID	Container Type	Sample Date	Vol ²	Fil ³	Ref ⁴	Preservative (specify)	Analyze for	Analytic Method	Turn ⁵	COMMENTS
1	OK622a W/O	SCPT	6/22/95	250	N	N	none	Dean-Stark extraction* of pore fluids per API RP 40. Final report to follow same format as prior analyses.		N	OK sand w/o excitation 7:45
	OK622b W/O		6/22/95								OK sand w/o excitation 13:15
	OK623S W/O		6/23/95								OK sand w/o excitation 8:15
	OK628S W/O		6/28/95								OK sand w/o excitation 9:00
	OK703S W/O		7/03/95								OK sand w/o excitation 9:00
	OK705S W/O		7/05/95					*analyze entire sample using large extraction apparatus and any side arm			OK sand w/o excitation canola
	OK62451110		6/24/95								OK sand 1110 → 1060 Hz 12:02
	OK62751140		6/27/95								OK sand 1140 Hz 14:45
	OK6305SWP		6/30/95								OK sand 6 frequencies 9:40
	OK7025SWP		7/2/95								OK sand 6 frequencies 13:00
✓	OK7035SWP	✓	7/3/95	✓	✓	✓	✓			✓	OK sand 6 frequencies 14:25

1 Released by (Signature), Date

1 Affiliation

2 Received by (Signature), Date

2 Affiliation

3 Released by (Signature), Date

3 Affiliation

4 Shipping Carrier, Method, Date

4 Affiliation

5 Released by (Signature), Date

5 Affiliation

6 Received by Lab Personnel, Date

6 Affiliation, Telephone

X Seal intact?

1 Sample Type Codes: W = Water, S = Soil, Describe Other; Container Type Codes: V = VOA/Teflon Septa, P = Plastic, C or B - Clear/Brown Glass, Describe Other;
Cap Codes: PT = Plastic, Teflon Lined 2 = Volume per container; 3 = Filtered (Y/N); 4 = Refrigerated (Y/N)
5 Turnaround [N = Normal, W = 1 Week, R = 24 Hour, HOLD (write out)]
ADDITIONAL COMMENTS, CONDITIONS, PROBLEMS:

Page ___ of ___

APPENDIX B

CHRONOLOGICAL LOG OF EXPERIMENTS

CHRONOLOGICAL LOG OF EXPERIMENTS

1/12/95 Began air permeability testing with Oklahoma sand. Recorded air permeability while exciting sample at: (100, 300, 750, 2000, 5500, 10000, 5500, 2000, 750, 300, 100) Hz with function generator at 1.0 Vpp and amplifier at 4. Flow rate = 0.471 l/min and sample confining pressure of 30 psi.

Air permeability experiments are conducted with function generator at 1.0 Vpp unless otherwise noted.

1/13/95 Air permeability with Oklahoma sand. Frequencies the same as 1/12 with amplifier at 6. 30 psi confining pressure and a flow rate of 0.500 l/min.

1/16/95 Prepared sample of Ajax sand for air permeability test. Excited at same frequencies as 1/12 and also included resonance frequency (820 Hz), with amplifier at 6 and a confining pressure of 30 psi. 150 scans were taken at each frequency and averaged to acquire permeability. Flow rate = 0.70 l/min.

Also ran air permeability with reversed air flow (bottom to top).

1/19/95 Ran calibration for air permeability test to get "real" permeability values. Calibration consisted of using a hollow Plexiglas cylinder instead of sample and calculating pressure drop across the lines and sintered bronze as a function of flow rate.

1/20/95 Prepared new Oklahoma sand sample and ran air permeability experiment with new calibration values. Excited at: (100, 300, 750, 1000, 2000, 5500, 10000)Hz and resonance (1039 Hz). Flow rate at 0.5 l/min. Amplifier set at 2 with 30 psi confining pressure. Permeability averaged over 200 scans. Permeability values ranged from $7.0 \mu\text{m}^2$ - $6.6 \mu\text{m}^2$.

1/24/95 Air permeability experiment with Oklahoma sand in morning. Used 5 minute duty cycle (unexcited for 5 minutes then excited for 5 minutes). Each cycle consisted of a different excitation frequency including: (100, 300, 1000, 3000, 10000)Hz. Amplifier set at 2, flow rate at 0.5 l/min and a confining pressure of 30 psi. Permeability was calculated from a 200 scan average.

Ran air permeability test in the afternoon with same setting but with amplifier at 6.

1/25/95 Ran six air permeability tests with 5 minute duty cycle described on 1/24. Test consisted of same parameters as 1/24 but with amplifier setting of: 2, 6, 2, 10, 2. The sixth test used the resonance (930 Hz, 930 Hz, 3730 Hz) as the driving frequency with a five minute duty cycle. All other parameters are the same as 1/24.

- 1/26/95 Ran air permeability test with confining pressure of 10 psi and amplifier setting of 2. All other parameters similar to 1/24, including 5 minute duty cycle.
- 1/27/95 Ran 5 air permeability tests. Four of these test include amplifier settings of 6,2,10,2. All other parameters same as 1/24. Fifth test consisted of using the resonance frequency (708,708,3725)Hz as the driving frequency.
- 1/30/95 Air permeability experiment using impulsive waveforms. Ran three tests at three different amplifier settings: 2, 6, 10. Cell confining pressure of 30 psi. The experiment consisted of a waveform of 1000 Hz with a 5%, 6.3%, 8.3%, 12.5%, 25% and 50% duty cycle (not the same as the 5 minute duty cycle mentioned earlier).
- 1/31/95 Double checked 50% duty cycle values from 1/30.
- 2/1-3/95 Analyzed data from air permeability experiments.
- 2/7/95 Began water permeability experiment with Oklahoma sand. Flowed water with blue dye halfway into sample to see if water is flowing uniformly through sample. Used pressurized reservoir.
- 2/16/95 Repeated dye-flow experiment.
- Began calibration for water permeability experiment. Calibration consisted of using Plexiglas tube and measuring pressure drop across the lines and end caps as a function of flow rate.
- 2/17-20/95 Decided not to use pressurized reservoir and instead switched to a constant head source (dog waterer). Reran calibration to determine coefficients for 'Flow Rate vs Pressure Drop'.
- 2/21/95 Began water permeability test using Oklahoma sand. Ran test with confining pressure of 30 psi, amplifier output at 4.7 Vpp and a five minute duty cycle with 1 kHz and 10 kHz excitation. Sample was evacuated before testing with a hand vacuum pump. Water flow direction from bottom to top. Constant head reservoir was filled to same level before each measurement step to ensure the same flow rate for each group of measurements.
- Also ran water permeability test on Oklahoma sand in the afternoon with amplifier set at 10. All other parameters the same as the morning test.
- 2/22/95 Revisited some of the tests on 2/21 to determine if test is repeatable. Seems to be repeatable but there is a slow downward drift in flow rate. Make sure reservoir water level is the same for each test to minimize the problem.
- Ran two water permeability tests on Oklahoma sand at 10 psi confining pressure. The first test was run with an amplifier output of 4.7 Vpp and the second with an

output of 47 Vpp. Both test consisted of excitation frequencies of 100 Hz, 1 kHz and 10 kHz.

Also repeated test with blue dye to check the uniformity of the water flow through the sample. Used 1 kHz excitation for this test.

Made sample of Ajax sand. Ran water permeability test with Ajax sand with a confining pressure of 30 psi and an amplifier output of 4.7 Vpp. Excitation frequencies were 100 Hz, 1 kHz, 10 kHz.

2/23/95 Rechecked a few values from 2/22 test and found that the permeability of the Ajax sample was lower probably due to clogging within the sample. Reversed the flow direction (top to bottom) to try to unclog the sample but the permeability values were still low.

Proceeded to high amplitude test (with reversed flow) to see if we could unclog the sample with acoustic excitation (amplifier output 46 Vpp), confining pressure 30 psi. At 100 Hz "muddy water" started to flow out of the sample. Continued for first minute or two and then cleared up. No mud at 1000 Hz. Then at 10 kHz "muddy water" began to exit the sample, more than the 100 Hz case.

Ran test at 10 psi with Ajax sand. Returned to normal flow (bottom to top) with amplifier output of 4.7 Vpp and 100 Hz, 1 kHz and 10 kHz excitation. Ran a second test with amplifier output at 47 Vpp. All other parameters are the same as the previous test. At 100 Hz very muddy water flowed out of the exit tube. At 1000 Hz the water was slightly muddy.

2/24/95 Continued water permeability experiment with Ajax. Used 516 Hz excitation and produced the most mud yet. Repeated at 10.3 kHz and produced more mud but sample was still clogged.

Began NAPL experiment. Used Sudan IV to dye canola oil for experiment.

2/25/95 Prepared new Oklahoma sand sample. Determined appropriate experimental procedure for NAPL experiment.

2/28 - 3/15 Spent most of this time trying develop a logical method for performing the NAPL extraction experiment. This consisted of making sure the correct values were being recorded, the sample was prepared for the extraction properly and that a minimum amount of air was allowed to enter the sample once the test began.

3/16/95 Began baseline NAPL extraction experiment using Oklahoma sand.

3/18/95 Ran baseline NAPL extraction experiment using Oklahoma sand.

3/19/95 Ran baseline NAPL extraction experiment using Oklahoma sand.

- 3/20/95 Ran baseline NAPL extraction experiment using Oklahoma sand.
- 3/21/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 10.2 kHz and amplifier set at 10. The signal generator output for the NAPL test is 1.0 Vpp unless otherwise stated. Confining pressure for every NAPL extraction experiment was 30 psi.
- 3/22/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 10.2 kHz and amplifier set at 10.
- 3/23/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 10.2 kHz and amplifier set at 10.
- 3/28/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 270 Hz and amplifier set at 10.
- 3/29/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 270 Hz and amplifier set at 10.
- 3/30/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 270 Hz and amplifier set at 10.
- 3/31/95 Ran baseline NAPL extraction experiment using Oklahoma sand.
- 4/1/95 Ran baseline NAPL extraction experiment using Oklahoma sand.
- 4/3/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 110 Hz and amplifier set at 10.
- 4/4/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 700 Hz and amplifier set at 10.
- 4/5/95 Ran baseline NAPL extraction experiment using Oklahoma sand.
- 4/6/95 Ran excited NAPL extraction with Oklahoma sand with excitation frequency of 770 Hz and amplifier set at 10.
- 4/11/95 Meeting with Joe Iovenetti, Don Hill, Jim Spencer and Hutch in the morning. Discussed where we are with the project and what steps we need to take in order to show some positive results. Met with above + TMR and JPD to talk about possible alternatives to test cell. Phone conference with Jim Mitchell from VMI. His main point was temperature dependence of viscosity for the water.

We decided on the following points:

1. Use screens instead of sintered bronze to: 1) avoid NAPL being trapped in filter and 2) avoid plugging of filters with Ajax sand.

2. Make measurements every minute for the first ten minutes to look more closely to beginning of extraction.
3. Measure temperature and humidity during experiment. Measure temperature of oil and water also.
4. Install digital thermostat with temperature set point.
5. Use grounded funnel when preparing sample to cancel out any static electricity effects.
6. Use Swagelok plugs to reduce experimental uncertainty in measuring saturation weights.
7. Store sand in sealed container.

- 4/13 - 4/20 Implemented above changes. The NAPL extraction test are run with a cell pressure of 30 psi. The excited case NAPL extraction test is run with the SRS function generator output set at 1.0 Vpp and the amplifier set at 10, unless otherwise stated.
- 4/20/95 Prepared Oklahoma sand sample and ran baseline test. Did not take data every minute in the beginning. Used stainless steel rods (1/4" x 1") as plugs until we get the Swageloks.
- 4/21/95 Baseline NAPL extraction with Oklahoma sand. Took data every minute for first ten minutes.
- 4/22/95 Prepared Oklahoma sand sample for NAPL extraction with acoustic excitation at fundamental frequency but developed an air leak when I started the NAPL flow. The sample checked out at the beginning so I don't know what's causing the leak.
- 4/23/95 Prepared Oklahoma sand sample for NAPL extraction. Changed Latex jacket to see if that was the cause of the leak on 4/22. Leak again during NAPL flood.
- 4/24/95 Baseline NAPL extraction with Oklahoma sand in the morning. Acoustically excited NAPL extraction at 918 Hz (fundamental frequency) in the afternoon.
- 4/25/95 Baseline NAPL extraction with Oklahoma sand in the morning. Acoustically excited NAPL extraction at 914 Hz (fundamental frequency) in the afternoon. Replaced S.S. rods with Swagelok plugs.
- 4/26/95 Baseline NAPL extraction with Oklahoma sand.
- 4/28/95 Baseline NAPL extraction in morning and excited at 1060 Hz in the afternoon both on Oklahoma sand. 1060 Hz was chosen because at that frequency the accelerometers were 180 degrees out of phase and nonlinear.

- 5/1/95 Baseline in NAPL extraction in morning and excited at 1112 Hz in the afternoon on Oklahoma sand. Again frequency was chosen where accelerometers are 180 degrees out of phase and nonlinear.
- 5/2/95 Ran baseline NAPL extraction in morning. Removed bottom dynamic pressure transducer for repair. Prepared sample in late afternoon
- 5/3/95 Ran excited NAPL extraction test at 1110 Hz in morning and 1122 Hz in the afternoon.
- 5/4/95 Started NAPL experiment but developed leak during NAPL flood. Made new sample and ran excited NAPL extraction at 1102 HZ in the morning and 1128 HZ in the afternoon.
- 5/5/95 Ran excited NAPL extraction in morning at 1100 Hz. Total of 12 usable experimental results, six baseline and six excited.
- 5/5/95 - 5/11/95 Analyzed data from 12 NAPL extraction experiments. Found 10% increase in production of NAPL with acoustic excitation. Sample were sent out for chemical analysis but showed no difference between excited and baseline tests. Reason is unknown at this time.
- 5/11/95 Ran NAPL baseline experiment with AJAX sand in the morning. Collected graduate cylinders every 2 minutes for first 20 minutes and then switch to 10 minutes intervals for the next 100 minutes. Prepared sample in the afternoon.
- 5/15/95 Ran baseline NAPL experiment with Ajax in morning.
- 5/16/95 Excited NAPL extraction test with Ajax at 809 Hz in morning and excited NAPL extraction with Ajax in afternoon at 810 Hz. Frequencies chosen by looking at the relative phase of the two accelerometers and choosing a point where they were 180 degrees out of phase and nonlinear.
- 5/17/95 Sample leaked during NAPL flood. Prepared new sample and ran excited extraction at 805 Hz.
- 5/18/95 Excited NAPL extraction in morning at 708 Hz. Ran baseline NAPL extraction with Ajax in the afternoon.
- 5/19/95 Ran baseline NAPL extraction with Ajax in the morning.
- 5/20/95 Ran baseline NAPL extraction with Ajax in the afternoon.
- 5/22/95 Ran baseline NAPL extraction with Ajax but data set was scratched because of presence on air in the line. Leak?
- 5/23/95 Excited NAPL extraction experiment at 775 Hz.

- 5/25/95   Excited NAPL extraction experiment at 10.2 kHz Hz.
- 5/26/95   Ran baseline NAPL extraction with Ajax in the morning.
- 5/26-27/95   Ran frequency sweep on Ajax sand. Frequency range 100-11kHz with a sweep time of 5 seconds. Function generator set at 1.0Vpp and amplifier at 10. Used modified version of Test Cell Data Acquisition v0.08.VI. Collected data from the four dynamic sensors with sample dry, water wet, oil wet and mixed.
- 5/28/95   NAPL extraction experiment with Ajax sand with multiple frequency excitation (10.2k, 830, 3k, 180)Hz 15 sec each with function generator @ 2.0 Vpp and amplifier @ 10.
- 5/29/95   Ran frequency sweep with Oklahoma sand. Frequency range 100 - 11kHz with a sweep time of 5 seconds. Function generator set at 1.0Vpp and amplifier at 10. Same technique as 5/26-27.
- 5/30/95   NAPL extraction experiment with Ajax sand with multiple frequencies (930, 10.2k, 180, 6360, 2400, 4200)Hz 20 seconds each with function generator at 1.0 Vpp and amplifier at 10.
- 5/31/95   NAPL extraction experiment with Ajax sand exciting with multiple frequencies (870, 4.9k, 320, 2.3k, 10.3k, 3.8k) Hz 20 seconds each with function generator at 2.0 Vpp and amplifier at 10.
- 6/1/95   Ran water permeability test on Ajax sand to try and quantify the amount of fines removed from the sample during acoustic excitation. Used many different frequencies to excite sample determined by scanning up and down within the frequency range of 100 - 11k Hz. Collected removed fluid from sample and placed in an oven to determine mass of removed fines. $M_f = 1.06g$.
- 6/6/95   Meeting with Joe Iovenetti, Don Hill, TMR, Bill Hutchinson and Jim Spencer. Made the following decisions:
1. Perform 3 baseline and 3 acoustically excited NAPL experiments with Oklahoma sand. Excitation at 1100-1160 Hz and save the ENTIRE sample for chemical analysis (do not trim off ends) with the intention of answering the chemical analysis paradox.
  2. Perform 5 baseline and 5 acoustically excited NAPL extraction tests with Oklahoma sand using Soltrol oil instead of canola (viscosity ~ 5 cp as opposed to 70cp).
  3. Perform silt and clay water permeability tests with and without excitation (one each).
  4. Frequency sweep with Soltrol oil.

- 6/7/95 Met with above people and also Dorothy Bishop from LLNL. She suggested measuring the residual oil in the endcaps and exit tube for the 6 NAPL extraction experiments (3 baseline and 3 excited) to try and help solve the chemical analysis problem.
- 6/7/95 Ran baseline NAPL extraction experiment on Oklahoma sand using above suggestions.
- 6/8/95 Ran excited NAPL extraction with Oklahoma with driving frequency of 1156 Hz.
- 6/12/95 Performed baseline NAPL extraction experiment with Oklahoma sand in morning and excited NAPL extraction in the afternoon at 1140 Hz.
- 6/13/95 Baseline NAPL extraction experiment with Oklahoma sand.
- 6/14/95 Ran excited NAPL extraction with Oklahoma sand at 1150 Hz.
- 6/15-16/95 Performed water permeability test on clay. Excited clay with multiple frequencies (360, 3.2k, 860, 10.2k, 1160, 3.7k)Hz at 20 seconds each with function generator at 1.0Vpp and amplifier at 10.
- Sample confining pressure of 23 psi. Inlet pore pressure of 12 psi.
- 6/17/95 Frequency data taken on 5/26,27,29/95 showed that Labview was not taking continuous data. Sweep had to be repeated. Started to run sweep but new Labview VI was not working properly.
- 6/18/95 Began NAPL experiment with Soltrol oil. Flow rate was too fast!
- 6/21/95 Started another NAPL extraction with Soltrol oil. This time flow was too slow and caused an irregular flow.
- 6/22/95 Ran baseline NAPL extraction on Oklahoma sand with Soltrol oil in the morning and another baseline in the afternoon. NAPL experiments from 6/22 - 7/3 all use Soltrol oil.
- 6/23/95 Performed baseline NAPL extraction on Oklahoma sand.
- 6/24/95 Ran excited NAPL extraction on Oklahoma sand with driving frequency of 1110 - 1060 Hz.
- 6/26/95 Ran frequency sweep on Oklahoma sand with Soltrol oil as described 5/26.
- 6/27/95 Ran excited NAPL extraction on Oklahoma sand with driving frequency of 1140 Hz.
- 6/28/95 Performed baseline NAPL extraction on Oklahoma sand.

- 6/30/95 Ran excited NAPL extraction with Oklahoma sand with multiple frequencies (6.1k, 1.6k, 5.1k, 200, 3k, 1.1k) for 5 seconds each during 1st 5 minutes then 20 seconds each for the remainder of the experiment with function generator at 1.0 Vpp and amplifier at 10.
- 7/2/95 Ran excited NAPL extraction with Oklahoma sand with multiple frequencies (6.1k, 1.6k, 5.1k, 200, 3k, 1.1k) for 5 seconds each during 1st 5 minutes then 20 seconds each for the remainder of the experiment with function generator at 2.0 Vpp and amplifier at 10.
- 7/3/95 Ran baseline NAPL extraction experiment in morning and excited in afternoon with multiple frequencies (6.1k, 200, 10.2k, 1.1k, 5.1k, 3k) for 5 seconds each for 1st 5 minutes then 10 seconds each for remainder of test. Function generator at 2.0Vpp and amplifier at 10.
- 7/6-7/95 Performed water permeability test on clay. Excited clay with multiple frequencies (270, 2930, 830, 9970, 1170, 3720)Hz at 20 seconds each with function generator at 2.0Vpp and amplifier at 10.
- Sample confining pressure of 23 psi. Inlet pore pressure of 12 psi.
- Turn-on of excitation generated shear failure near base of sample.
- Measured permeability during and after excitation and observed time-dependent effects.
- 7/10/95 Initial water permeability test on silt. Excited silt at several frequencies, with function generator at 1.0Vpp and amplifier at 10, but outlet line at top of sample quickly plugged with silt that was passing through the 120 mesh screen. Abandoned test.
- 7/13/95 Repeated water permeability test on silt but reversed flow direction (now from top to bottom) so outlet line won't plug. Also placed single layer of paper towel on lower end cap to keep silt from passing through screen. Sample confining pressure of 20 psi. Excited silt at 665 Hz with function generator at 1.0Vpp and amplifier at 10. Turned excitation ON and OFF at about 5 minute intervals looking for changes in the flow rate.

APPENDIX C

LABORATORY DATA ANALYSIS AND QA/QC

LABORATORY DATA ANALYSIS AND QA/QC

SUMMARY

- A spread-sheet data analysis and graphical displays were developed to quantify the NAPL - water empirical laboratory data collected during Phase I.
- The data analysis is based on monitoring the water saturation, S_w , and relative permeability (both NAPL - water, $K_{N/w}$, and water - NAPL, $K_{w/N}$) variations during the post NAPL flood (second) water flood, see discussion below.
- This type of analysis indicates 1 - 9 saturation unit reductions in residual NAPL saturation as a result of acoustically enhanced remediation (AER). It also indicates that the AER is more efficient through out the water flood cycle than water flood alone.

BACKGROUND

A data analysis spread-sheet and data displays were developed to quantify the empirical laboratory data collected during Phase I. As this methodology was developed additional measurements and data quality checks were identified, which improved the overall quality and reliability of the laboratory data.

LABORATORY EXPERIMENT

The AER data analysis spread sheet and displays described below are best understood in light of the laboratory test protocol, see Section 5 in the main body of this text.

The measurement protocol consists of three sequential core flood measurements (1) an initial water flood which equates to fully saturating the core with water, (2) a NAPL flood which equates to fully saturated the core with NAPL to irreducible water saturation, S_{wir} , and (3) a second water flood which equates to a ground water pump and treat (P&T) of a NAPL spill. The second water flood is conducted either without the vibrator activated (base line measurement) or with the vibrator activated (excited measurement). Because multiphase relative permeability is saturation history dependent, each measurement sequence is, in effect, a destructive measurement and cannot be repeated. Evaluation of AER technology in this investigation is accomplished by comparing measurements on multiple baseline and excited samples. Note that an immediate source of data noise is the fact that the multiple random pack samples will not be identical. Data analysis must accommodate for this certain nonuniformity in measurement samples.

DATA ANALYSIS AND DISPLAY

Table C-1 is an example of the EXCEL® data analysis spread-sheet developed for the aforementioned interpretation of the Phase I laboratory data. Measured data are shown in bold type. Calculated parameters are shown in normal type. Table C-2 is an example of the laboratory data sheet, developed from the Table C-1 data analysis spread sheet. The Table C-2 data sheet is completed by the experimenter during the course of the laboratory tests. The bold italic numbers in parentheses are cross-referenced in Table C-1.

MEASURED DATA

Prior to the initial water flood the sample dimensions and mass are measured. The laboratory protocol uses three length measurements (1) and six diameter measurements (2). Mass measurements (3) consist of (1) sample holder bottom end cap and Mylar® tube, M_b ; (2) sample holder top end cap, M_t ; (3) total mass of the dry random sand pack, end caps, and Mylar® tubing, $M_{T,d}$; and (4) total mass of the dry random sand pack, end caps, Mylar® tubing, and latex sheath, $M_{GT,d}$. The sample assembly mass is also measured (1) after the initial water flood with the sample 100 % saturated with water ($S_w = 100\%$), $M_{T,w}$, and (2) after the NAPL flood with the sample at irreducible water saturation ($S_w = S_{wir}$), M_{Swir} .

At the end of the initial water flood, the water flow rate at $S_w = 100\%$, q_{w100} , is determined (4). At the end of the NAPL flood, the NAPL flow rate at $S_w = S_{wir}$, $q_{N,Swir}$, is determined (5). The water displaced during the NAPL flood, V_{wd} , is recorded (6). The 5 cc "best estimate" end cap fluid volume, V_e , (7) is based on repeated measurement and analysis of water/NAPL flood data and is assumed to be a constant volumetric correction to be applied the measured data.

The canola oil fluid properties (8) of $\mu_N = 68$ cp @ 68°F and $\rho_N = 0.918$ gm/cc @ 68°F were obtained from the manufacturer (Proctor & Gamble) and confirmed by an independent laboratory. Other NAPL (e.g., mineral oil, kerosene, Soltrol 220, or decane) will have different densities and viscosities. The water fluid properties (9) of $\mu_w = 1$ cp @ 68°F and $\rho_w = 1$ gm/cc @ 68°F are reasonable estimated for Huntington Beach, California public water supply. The water pressure head, $h = 150$ cm, is estimated from the elevation of the constant head water supply and the length of the sample holder tail piece (top) drain line syphon. The assumed Oklahoma Sand grain density (10), $\rho_g = 2.65$ gm/cc is a reasonable value for the near 100 % quartz Oklahoma.

During the second water flood, water and NAPL recovery are recorded over time windows to provide a monitor of the water flood progress (11).

DATA ANALYSIS CALCULATIONS

Sample volume (12), V_T , is calculated according to:

$$V_T = 2.45 l_m p \left(\frac{2.54(d_m - 0.008)}{2} \right)^2, \quad 1)$$

where: d_m is the sample mean diameter.
 l_m is the sample mean length.

where: d_m is the sample mean diameter and l_m is the sample mean length.

Equation 1 corrects d_m for the 0.004 in shrink tubing wall thickness and converts V_T to metric units (cm^3), as l_m and d_m are in English units (in).

Sample dry mass (13), m_d , is calculated according to:

$$m_d = M_{T,d} - (M_t + M_b) \quad 2)$$

where: $M_{T,d}$ is total dry mass of the sample, top sample holder end cap, sample bottom end cap, and Mylar® shrink tubing.
 M_b is the mass of the sample holder bottom end cap and Mylar® shrink tubing.
 M_t is the mass of the sample holder top.

Sample wet mass (13), m_{100} , is calculated according to:

$$m_{100} = M_{Tw} - (M_t + M_b + (M_{GT,d} - M_{T,d})), \quad 3)$$

where: M_{Tw} is total wet ($S_w = 100\%$) mass of the sample, top sample holder end cap, sample bottom end cap, Mylar shrink tubing, and protective latex sheath;
 M_b is the mass of the sample holder bottom end cap and Mylar shrink tubing;
 M_t is the mass of the sample holder top;
 $M_{GT,d}$ is total dry mass of the sample, top sample holder end cap, sample bottom end cap, Mylar shrink tubing, and protective latex sheath; and
 $M_{T,d}$ is total dry mass of the sample, top sample holder end cap, sample bottom end cap, and Mylar shrink tubing.

Sample mass at $S_w = S_{wir}$ (13), m_{Swir} , is calculated according to:

$$m_{Swir} = M_{Swir} - (M_t + M_b + (M_{GT,d} - M_{T,d})), \quad 4)$$

where: M_{Swir} is total $S_w = S_{wir}$ mass of the sample, top sample holder end cap, sample bottom end cap, Mylar shrink tubing, and protective latex sheath;
 M_b is the mass of the sample holder bottom end cap and Mylar shrink tubing;
 M_t is the mass of the sample holder top; $M_{GT,d}$ is total dry mass of the sample, top sample holder end cap, sample bottom end cap, Mylar shrink tubing, and protective latex sheath; and

$M_{T,d}$ is total dry mass of the sample, top sample holder end cap, sample bottom end cap, and Mylar shrink tubing.

Sample (total) pore volume (14), V_p , is calculated in two ways:

$$V_p = \frac{m_{100} - m_d - V_e \rho_w}{\rho_w}, \quad 5a)$$

and:

$$V_p = \phi V_T, \quad 5b)$$

where: m_{100} is the sample wet ($S_w = 100\%$) mass;
 m_d is the sample dry mass;
 V_e is the "best estimate" end cap fluid volume;
 ρ_w is the water density;
 ϕ is the sample fractional pore volume porosity (see below); and
 V_T is the sample total volume.

Sample (fractional or %) porosity (15), ϕ , is calculated in two ways:

$$\phi = 100 \frac{1 - \frac{m_d}{V_T \rho_g}}{\rho_g}, \quad 6a)$$

and:

$$\phi = 100 \frac{V_p}{V_T}, \quad 6b)$$

where: m_d is the sample dry mass;
 V_T is the sample total volume;
 ρ_g is the matrix grain density; and
 V_p is the sample total pore volume.

Equations 5a and 6b are based upon sample mass changes due to water saturation. Equations 5b and 6a are based upon the sample dry mass and matrix grain density. Calculating pore volume and porosity two different ways allows a constituency check on the data. The 0.115 porosity unit difference between the two different porosity estimates, in Table C-1, is less than 4 parts in 1000.

Sample hydraulic conductivity (16), K_h , is calculated according to:

$$K_h = \frac{q_{w100} l_m}{152.4 \pi h \left(\frac{d_m - 0.008}{2} \right)^2}, \quad 7)$$

where: q_{w100} is the sample water flow rate at $S_w = 100 \%$;
 l_m is the sample mean length;
 h is the water head; and
 d_m is the sample mean diameter.

Equation 7 converts in to cm and min to sec. The Leverett normalized hydraulic conductivity (16), K'_h , is calculated according to:

$$K'_h = \sqrt{\frac{K_h}{\phi}}, \quad 8)$$

where: K_h is the sample hydraulic conductivity; and
 ϕ is the sample (fractional) porosity.

The initial NAPL fractional volume (17), V_{Ni} , is calculated in two ways:

$$V_{Ni} = \frac{V_{wd} - V_e}{V_p}, \quad 9a)$$

and:

$$V_{Ni} = \frac{\frac{M_{Tw} - MS_{wir}}{\rho_w \cdot \rho_N} - V_e}{V_p}, \quad 9b)$$

where: V_{wd} is the volume of water displaced by NAPL flood;
 V_e is the "best estimate" end cap fluid volume;
 V_p is the sample total pore volume;
 M_{Tw} is the total sample assembly mass with $S_w = 100 \%$;
 MS_{wir} is the total sample assembly mass with $S_w = S_{wir}$;
 ρ_w is the water density; and
 ρ_N is the NAPL density.

Equation 9a is based upon the volume of water displaced by the NAPL flood. Equation 9b is based upon the sample mass change between the initial water flood and NAPL flood. Calculating initial NAPL volume two different ways allows a constituency check on the data. The produced water value appears to be more realistic than the mass change value. The latter appears to still include some sources of unaccounted error.

Sample irreducible water saturation (17), S_{wir} , is calculated according to:

$$S_{wir} = 100(1 - V_{ni}), \quad (10)$$

where: V_{Ni} is the initial NAPL fractional volume.

Sample final NAPL fractional saturation (18), S_{Nf} , is calculated according to:

$$S_{Nf} = V_{Ni} - \sum_{j=1}^n V_{Nj}, \quad (11)$$

where: V_{Ni} is the initial NAPL volume;

V_{Nj} is the volume of NAPL recovered in time window j ; and

n is the total number of time windows for the water flood measurement.

NAPL recovery (19), R_N , is calculated according to:

$$R_N = 100 \left(\frac{\sum_{j=1}^n V_{Nj}}{V_{wd} - V_e} \right), \quad (12)$$

where: V_{Nj} is the volume of NAPL recovered in time window j ;

n is the total number of time windows for the water flood measurement;

V_{wd} is the volume of water displaced by NAPL flood; and

V_e is the "best estimate" end cap fluid volume.

Cumulative Volumetrics Calculations (20)

The cumulative NAPL recovery after water flood window, k , V_{cNk} , is calculated according to:

$$V_{cNk} = \sum_{j=1}^k V_{Nj}, \quad (13)$$

where: V_{Nj} is the volume of NAPL recovered in time window j .

The cumulative water recovery after water flood window, k , V_{cwk} , is calculated according to:

$$V_{cw k} = \sum_{j=1}^k V_{w j} , \quad (14)$$

where: $V_{w j}$ is the volume of NAPL recovered in time window j .

The cumulative water flood after water flood window, k , $V_{w f k}$, is calculated according to:

$$V_{cw f k} = V_{c N k} + V_{cw k} , \quad (15)$$

where: $V_{c N k}$ is the cumulative NAPL volume recovered through water flood time window, k ;
and

$V_{cw k}$ is the cumulative water volume recovered through water flood time window, k .

Pore Volume Volumetrics Calculations (21)

The cumulative NAPL recovery, in PV, after water flood window, k , $V'_{N k}$, is calculated according to:

$$V'_{N k} = \frac{\sum_{j=1}^k V_{N j}}{V_p} , \quad (16)$$

where: $V_{N j}$ is the volume of NAPL recovered in time window j ; and
 V_p is the sample pore volume.

The amount of NAPL remaining, in PV, after the water flood window k , $V'_{N r k}$, is calculated according to:

$$V'_{N r k} = V_{N i} - V_{c N k} , \quad (17)$$

where: $V_{N j}$ is the volume of NAPL recovered in time window j ; and
 $V_{N i}$ is the initial (input) NAPL volume (V_N at $S_w = S_{w i r}$).

The cumulative water recovery, in PV, after water flood window, k , $V'_{w k}$, is calculated according to:

$$V'_{w k} = \frac{\sum_{j=1}^k V_{w j}}{V_p} , \quad (18)$$

where: V_{wj} is the volume of NAPL recovered in time window j ; and
 V_p is the sample pore volume.

The cumulative water flood, in PV, after water flood window, k , V'_{wfk} , is calculated according to:

$$V'_{wfk} = \frac{V_{wfk}}{V_p}, \quad (19)$$

where: V_{wfk} is the cumulative water flood volume through water flood time window, k ; and
 V_p is the sample pore volume.

Flow Rate Calculations (22)

The NAPL flow (recovery) rate, q_{Nj} , for the water flood time window j is calculated according to:

$$q_{Nj} = \frac{V_{Nj}}{T_{w fj} - T_{w fj-1}}, \quad (20)$$

where: V_{Nj} is the NAPL volume recovered during water flood time window, j ;
 $T_{w fj}$ is the cumulative water flood time through water flood time window, j ; and
 $T_{w fj-1}$ is the cumulative water flood time through water flood time window, $j-1$.

The water flow (recovery) rate, q_{wj} , for the water flood time window j is calculated according to:

$$q_{wj} = \frac{V_{wj}}{T_{w fj} - T_{w fj-1}}, \quad (21)$$

where: V_{wj} is the water volume recovered during water flood time window, j ;
 $T_{w fj}$ is the cumulative water flood time through water flood time window, j ; and
 $T_{w fj-1}$ is the cumulative water flood time through water flood time window, $j-1$.

Relative Recovery Rate Calculations (23)

The NAPL relative flow (recovery) rate, q_{rNj} , for the water flood time window j is calculated according to:

$$q_{rNj} = \frac{V_{Nj}}{V_{Nj} + V_{wj}}, \quad (22)$$

where: V_{Nj} is the NAPL volume recovered during water flood time window, j ; and
 V_{wj} is the water volume recovered during water flood time window, j .

The water relative flow (recovery) rate, q_{rwj} , for the water flood time window j is calculated according to:

$$q_{rwj} = \frac{V_{wj}}{V_{Nj} + V_{wj}} , \quad (23)$$

where: V_{Nj} is the NAPL volume recovered during water flood time window, j ; and
 V_{wj} is the water volume recovered during water flood time window, j .

Relative Permeability Calculations (24)

The NAPL relative permeability, $k_{N/wj}$, for the water flood time window j is calculated according to:

$$k_{N/wj} = 100 \frac{q_{Nj}}{q_{Nmx}} , \quad (24)$$

where: q_{Nj} is the NAPL flow (recovery) rate during water flood time window, j ; and
 q_{Nmx} is the maximum NAPL flow (recovery) rate.

The water relative permeability, $k_{w/Nj}$, for the water flood time window j is calculated according to:

$$k_{w/Nj} = 100 \frac{q_{wj}}{q_{wmx}} , \quad (25)$$

where: q_{wj} is the water flow (recovery) rate during water flood time window, j ; and
 q_{wmx} is the maximum water flow (recovery) rate.

The water saturation, S_{wj} , for the water flood time window j is calculated according to:

$$S_{wj} = 100 \frac{V_p - (V_{wd} - V_e) - V_{cNj}}{V_p} , \quad (26)$$

where: V_p is the sample pore volume;
 V_{wd} is the volume of water displaced by NAPL flood;
 V_e is the end cap fluid volume; and
 V_{cNj} is the cumulative NAPL volume recovered through water flood time window, j .

The NAPL saturation, S_{Nj} , for the water flood time window j is calculated according to:

$$S_{Nj} = 100 - S_{wj} , \quad (27)$$

where: S_{wj} is the sample water saturation for the time window, j .

Hydraulic Conductivity Normalized Volumetric Calculations (25)

The volumetric measures in this section of the spread sheet are the items in (21) multiplied by the normalizing factor:

$$\frac{K_{hn}}{K_h} \quad , \quad 28)$$

where: K_{hn} is the normalizing hydraulic conductivity; and
 K_h is the sample hydraulic conductivity.

Hydraulic conductivity normalized volumetric parameters were calculated in an attempt to remove any systematic NAPL recovery variation due to variations in sample hydraulic conductivity. Such systematic variations, if they exist, are very weak.

Leverett Normalized Hydraulic Conductivity Normalized Volumetric Calculations (26)

The volumetric measures in this section of the spread sheet are the items in (21) multiplied by the normalizing factor:

$$\frac{K'_{hn}}{K'_h} \quad , \quad 28)$$

where: K'_{hn} is the Leverett normalized hydraulic conductivity normalizing value; and
 K'_h is the sample Leverett normalized hydraulic conductivity.

Leverett hydraulic conductivity normalized volumetric parameters were calculated in an attempt to remove any systematic NAPL recovery variation due to variations in sample Leverett hydraulic conductivity. The Leverett hydraulic conductivity, K'_h , is used as a normalizing factor in the analysis of capillary pressure data and is dependent upon both porosity and hydraulic conductivity. Any K'_h systematic variations, if they exist, are very weak.

LIST OF SYMBOLS

AER:	Acoustically enhanced remediation.
d_m :	Sample mean diameter.
h :	(water) head.
K'_h :	Leverett normalized hydraulic conductivity.
K'_{hn} :	Normalizing Leverett normalized hydraulic conductivity.
K_h :	Hydraulic conductivity.
K_{hn} :	Normalizing hydraulic conductivity.
$k_{N/wj}$:	NAPL/water relative permeability, for the water flood time window, j.
$k_{w/Nj}$:	Water/NAPL relative permeability, for the water flood time window, j.
l_m :	Sample mean length.
m_{100} :	Sample mass at $S_w = 100\%$.
M_b :	Sample holder bottom and Mylar® shrink tubing mass.
m_d :	Sample dry mass.
$M_{GT,d}$:	Grand total mass of the dry random pack sample, top and bottom end caps, Mylar® shrink tubing, and latex sheath.
m_N :	NAPL viscosity.
m_{Swir} :	Sample mass at $S_w = S_{wir}$.
M_{Swir} :	Total sample assembly mass with $S_w = S_{wir}$.
$M_{T,d}$:	Total mass of the dry random pack sample, top and bottom end caps, and Mylar® shrink tubing.
M_t :	Sample holder top (tail piece) mass.
M_{Tw} :	Total sample assembly mass with $S_w = 100\%$.
m_w :	Water viscosity.
n :	Total number of time windows for the water flood.
NAPL:	Non-aqueous phase liquid.
ϕ :	Sample porosity (fractional or %).
$q_{N,Swir}$:	NAPL flow rate at $S_w = S_{wir}$.
q_{Nj} :	NAPL flow (recovery) rate during water flood time window j.
q_{Nmx} :	Maximum NAPL flow (recovery) rate.
q_{rNj} :	NAPL relative flow (recovery) rate during water flood time window j.
q_{rwj} :	Water relative flow (recovery) rate during water flood time window j.
q_{w100} :	Sample water flow rate at $S_w = 100\%$.
q_{wj} :	Water flow (recovery) rate during water flood time window j.
q_{wmx} :	Maximum water flow (recovery) rate.
ρ_g :	Matrix grain density.
ρ_N :	NAPL density.
R_N :	NAPL recovery.
ρ_w :	Water density.

S_w :	Water saturation (fractional or %).
S_{wir} :	Irreducible water saturation.
T_{wfj-1} :	Cumulative water flood time through water flood time window, j-1.
T_{wfj} :	Cumulative water flood time through water flood time window, j.
V_{cNk} :	Cumulative NAPL volume recovered through water flood time window, k.
V_{cwk} :	Cumulative water volume recovered through water flood time window, k.
V_{cw} :	Cumulative water volume recovered through water flood time window, k.
V_e :	End cap fluid volume.
V_N :	NAPL volume.
V_{Ni} :	Initial (input) NAPL volume (V_N at $S_w = S_{wir}$).
V_{Nj} :	NAPL volume recovered during water flood time window, j.
V_p :	Sample pore volume.
V_T :	Sample total volume.
V_{wd} :	Volume of water displaced by NAPL flood.
V_{wfk} :	Cumulative water flood through water flood time window, k.
V_{wj} :	Water volume recovered during water flood time window, j.

APPENDIX D

AIR AND WATER PERMEABILITY RESULTS

AIR AND WATER PERMEABILITY RESULTS

Air Permeability Results for Oklahoma Sand

Test #1

Confining Pressure = 30 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 0.53 Vpp

Frequency	Permeability (micron ²)	Sigma for 200 Measurements (micron ²)
0	7.30	0.39
100	7.36	0.37
0	7.41	0.42
300	7.46	0.42
0	7.53	0.44
1000	7.53	0.42
0	7.57	0.40
3000	7.54	0.43
0	7.61	0.50
10000	7.53	0.53
0	7.56	0.52

Test #2

Confining Pressure = 30 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 3.0 Vpp

Frequency	Permeability (micron ²)	Sigma for 200 Measurements (micron ²)
0	7.58	0.42
100	7.60	0.42
0	7.74	0.45
300	7.75	0.44
0	7.73	0.47
1000	7.73	0.50
0	7.67	0.45
3000	7.69	0.50
0	7.64	0.44
10000	7.54	0.49
0	7.61	0.48

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #3

Confining Pressure = 30 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 0.53 Vpp

Frequency	Permeability (micron ²)	Sigma for 200 Measurements (micron ²)
0	7.65	0.43
100	7.69	0.45
0	7.67	0.45
300	7.58	0.42
0	7.58	0.46
1000	7.58	0.48
0	7.56	0.46
3000	7.53	0.44
0	7.51	0.48
10000	7.53	0.48
0	7.41	0.47

Test #4

Confining Pressure = 30 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 24 Vpp

Frequency	Permeability (micron ²)	Sigma for 200 Measurements (micron ²)
0	7.37	0.47
100	7.42	0.40
0	7.27	0.41
300	7.32	0.42
0	7.29	0.43
1000	7.23	0.38
0	7.21	0.43
3000	7.23	0.40
0	7.12	0.44
10000	7.12	0.45
0	7.01	0.37

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #5

Confining Pressure = 30 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 0.53 Vpp

Frequency	Permeability (micron ²)	Sigma for 200 Measurements (micron ²)
0	6.96	0.36
100	7.00	0.39
0	6.99	0.36
300	7.02	0.38
0	6.99	0.39
1000	6.96	0.34
0	6.88	0.36
3000	6.79	0.30
0	6.75	0.36
10000	6.66	0.34
0	6.74	0.38

Test #6

Confining Pressure = 30 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 24 Vpp

Frequency	Permeability (micron ²)	Sigma for 200 Measurements (micron ²)
930	6.64	0.28
0	6.58	0.29
930	6.63	0.31
0	6.57	0.31
3730	6.57	0.30
0	6.47	0.30

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #7

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 0.53 Vpp

Frequency	Permeability (micron ²)	Sigma for 50 Measurements (micron ²)
0	7.64	0.35
100	7.56	0.38
0	7.36	0.36
300	7.30	0.35
0	7.23	0.34
1000	7.20	0.36
0	7.16	0.36
3000	6.99	0.32
0	6.92	0.36
10000	6.93	0.37
0	6.93	0.36

Test #8

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 3.0 Vpp

Frequency	Permeability (micron ²)	Sigma for 50 Measurements (micron ²)
0	7.60	0.36
100	7.63	0.37
0	7.63	0.36
300	7.77	0.36
0	7.73	0.40
1000	7.81	0.44
0	7.88	0.39
3000	7.99	0.41
0	8.03	0.41
10000	8.12	0.48
0	8.20	0.47

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #9

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 0.53 Vpp

Frequency	Permeability (micron ²)	Sigma for 50 Measurements (micron ²)
0	7.78	0.42
100	7.71	0.37
0	7.80	0.47
300	7.87	0.37
0	7.83	0.41
1000	7.79	0.38
0	7.87	0.41
3000	7.79	0.41
0	7.84	0.46
10000	7.78	0.51
0	7.81	0.46

Test #10

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 24 Vpp

Frequency	Permeability (micron ²)	Sigma for 50 Measurements (micron ²)
0	7.55	0.43
100	7.46	0.39
0	7.51	0.41
300	7.37	0.36
0	7.46	0.42
1000	7.36	0.38
0	7.37	0.38
3000	7.32	0.38
0	7.31	0.44
10000	7.38	0.47
0	7.32	0.43

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #11

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 24 Vpp

Frequency	Permeability (micron ²)	Sigma for 50 Measurements (micron ²)
708	7.36	0.38
0	7.35	0.35
708	7.36	0.35
3725	7.28	0.34
0	7.25	0.33

Test #12 (Using Impulsive Waveforms)

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 0.46 Vpp

Frequency of Impulsive Waveforms = 1000

Hz

Duty Cycle of Waveform = (Pulse Width Time / Full Cycle Time) *100%

(i.e. 1000 Hz wave with a 50 microsecond pulse width yields

$(50e-6/(1/1000))*100\% = 5\%$)

Duty Cycle (%)	Permeability (microns ²)	Sigma for 50 Measurements (micron ²)
0	7.54	0.35
5	7.69	0.94
0	7.52	0.41
6.3	7.60	0.39
0	7.63	0.38
8.3	7.75	0.47
0	7.95	0.71
12.5	7.40	0.69
0	7.50	0.79
25	7.50	0.39
0	7.50	0.41
50	7.51	0.58
0	7.46	0.40

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #13 (Using Impulsive Waveforms)

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 2.9 Vpp

Frequency of Impulsive Waveforms = 1000 Hz

Duty Cycle (%)	Permeability (microns ²)	Sigma for 50 Measurements (micron ²)
5	7.50	0.68
0	7.61	0.63
6.3	7.51	0.38
0	7.53	0.43
8.3	7.57	0.55
0	7.60	0.41
12.5	7.62	0.38
0	7.71	0.40
25	7.76	0.41
0	7.85	0.46
50	7.83	0.43
0	7.82	0.43

Test #14 (Using Impulsive Waveforms)

Confining Pressure = 10 psi

Flow Rate = 0.500 l/min

Amplifier Output Amplitude = 23 Vpp

Frequency of Impulsive Waveforms = 1000 Hz

Duty Cycle (%)	Permeability (microns ²)	Sigma for 50 Measurements (micron ²)
0	7.44	0.79
5	7.44	0.39
0	7.50	0.40
6.3	7.38	0.35
0	7.33	0.34
8.3	7.43	0.37
0	7.35	0.33
12.5	7.45	0.38
0	7.38	0.39
25	7.25	0.32
0	7.27	0.35
50	7.31	0.38
0	7.19	0.42

Air Permeability Results for Ajax Sand

Test #1

Confining Pressure = 30 psi

Flow Rate = 0.700 l/min

Amplifier Output Amplitude = 5.6 Vpp

Frequency	Permeability (microns ²)	Sigma for 150 Measurements
0	3.41	0.13
100	3.27	0.11
300	3.43	0.11
750	3.34	0.12
1000	3.26	0.14
2000	3.23	0.10
5500	3.31	0.11
10000	3.22	0.13
5500	3.31	0.12
2000	3.12	0.11
1000	3.19	0.10
750	3.16	0.11
300	3.22	0.12
100	3.30	0.11
820	3.14	0.11
0	3.00	0.12

Test #2

(Flowed air from bottom to top)

Confining Pressure = 30 psi

Flow Rate = 0.700 l/min

Amplifier Output Amplitude = 5.6 Vpp

Frequency	Permeability (microns ²)	Sigma for 100 Measurements
0	2.16	0.04
0 *	2.28	0.05
100	2.10	0.05
300	2.13	0.05
750	2.10	0.06
1000	2.08	0.05
2000	2.11	0.05
5500	2.05	0.04
10000	2.04	0.05
5500	2.07	0.04
2000	2.16	0.05
1000	2.11	0.04
750	2.11	0.04
300	2.08	0.05
100	2.05	0.04
820	2.04	0.06
0	1.97	0.06

* Flowed air from top to bottom (normal flow)

Water Permeability Results (Ajax Sand)

Test #1

Confining Pressure = 30 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 4.7 Vpp

Frequency	Permeability (micron ²)	Sigma for 150 Measurements (micron ²)
0	5.11	0.12
100	5.58	0.17
0	6.17	0.17
1000	5.79	0.15
0	6.06	0.17
10000	5.86	0.26
0	5.74	0.16

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #2

Confining Pressure = 30 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 46 Vpp

Frequency	Permeability (micron ²)	Sigma for 150 Measurements (micron ²)
0	5.59	0.17
100	Very Muddy ! Unable to record permeability	
0	5.71	0.16
1000	5.19	0.18
0	5.12	0.15
10000	4.93 (very muddy)	0.27
0	4.51	0.13

Test #3

Confining Pressure = 10 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 4.7 Vpp

Frequency	Permeability (micron ²)	Sigma for 150 Measurements (micron ²)
0	4.92	0.15
100	4.93	0.16
0	5.05	0.15
1000	5.09	0.17
0	5.13	0.16
10000	5.11	0.21
0	5.15	0.17

Test #4

Confining Pressure = 10 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 47 Vpp

Frequency	Permeability (micron ²)	Sigma for 150 Measurements (micron ²)
0	5.73	0.17
100	Very muddy! Unable to record permeability	
0	4.12	0.12
1000	3.11	0.07
10000	2.34 (slightly muddy)	0.10

Water Permeability Results (Oklahoma Sand)

Test #1

Confining Pressure = 30 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 4.7 Vpp

Frequency	Permeability (micron ²)	Sigma for 150 Measurements (micron ²)
0	7.65	0.25
1000	7.38	0.23
0	6.88	0.20
10000	6.54	0.31
0	6.38	0.18

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #2

Confining Pressure = 30 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 23 Vpp

Frequency	Permeability (micron ²)	Sigma for 150 Measurements (micron ²)
0	6.10	0.13
1000	5.97	0.16
0	5.89	0.16
10000	5.56	0.33
0	5.40	0.14
100	4.83	0.79
0	4.93	0.13

Test #3

Confining Pressure = 10 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 4.7 Vpp

Frequency	Permeability (micron ²)	Sigma for 150 Measurements (micron ²)
0	6.92	0.24
100	7.12	0.26
0	7.06	0.22
1000	7.07	0.22
0	6.92	0.23
10000	6.99	0.35
0	7.05	0.21

Acoustically Enhanced Remediation Of Contaminated Soil And Ground Water

Test #4

Confining Pressure = 10 psi

Flow Rate ~0.2 cc/s

Amplifier Output Amplitude = 46 Vpp

Frequency	Permeability (micron^2)	Sigma for 150 Measurements (micron^2)
100	6.49	0.87
0	7.15	0.24
1000	6.81	0.25
0	7.06	0.25
10000	6.75	0.46
0	6.33	0.21