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APPENDICES

APPENDIX A
LEACHING TEST

Leachate Extraction Procedure

The leachate extraction procedure outlined in the 6th Notification of the Ministry of Industry (1997) is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes. The method is

1. For liquid wastes (i.e., those containing less than 0.5% dry solid material), the waste, after filtration through a 0.6 to 0.8 μm glass fiber filter, is defined as the leachate extract.
2. For wastes containing greater than or equal to 0.5% solids
   - 2.1 The liquid, if any, is separated from the solid phase and stored for later analysis. Prepare the solid portion of the waste for extraction by crushing, cutting, or grinding the waste to pass a 9.5 mm sieve.
   - 2.2 Weigh 100 gm of waste from 2.5.2.1 add with leachant or synthetic acid rain extraction fluid until the pH of mixture is 5.0
   - 2.3 Adjust the volume of mixture to the ratio leachant is 20 times of the weigh of waste.
   - 2.4 Put the extraction fluid to the extractor vessel. Close the extractor bottle tightly and place in rotary agitation device, and rotate at 30 rpm for 18 hours at ambient temperature.
   - 2.5 Filtrate the fluid through a 0.6 to 0.8 μm glass fiber filter, is defined as the leachate extract.

Table 4.2.1 Leachability of heavy metals from Sand 1

	Sample 1 (mg/l)	Sample 2 (mg/l)	Sample 3 (mg/l)	Average (mg/l)	Detection limit (mg/l)
As	< 0.05	< 0.05	< 0.05	< 0.05	0.050
Ba	1.498	1.458	1.397	1.451	0.001
Cd	0.034	0.022	0.019	0.025	0.005
Cr	1.571	1.324	1.432	1.442	0.007
Pb	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Hg	< 0.040	< 0.040	< 0.040	< 0.040	0.040
Se	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Ag	< 0.007	< 0.007	< 0.007	< 0.007	0.007

Table 4.2.2 Leachability of heavy metals from Sand 2

	Sample 1 (mg/l)	Sample 2 (mg/l)	Sample 3 (mg/l)	Average (mg/l)	Detection limit (mg/l)
As	< 0.05	< 0.05	< 0.05	< 0.05	0.050
Ba	0.532	0.495	0.506	0.511	0.001
Cd	<0.005	<0.005	<0.005	<0.005	0.005
Cr	0.004	0.004	0.004	0.004	0.007
Pb	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Hg	< 0.040	< 0.040	< 0.040	< 0.040	0.040
Se	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Ag	< 0.007	< 0.007	< 0.007	< 0.007	0.007

Table 4.2.3 Leachability of heavy metals from Sand 3

	Sample 1 (mg/l)	Sample 2 (mg/l)	Sample 3 (mg/l)	Average (mg/l)	Detection limit (mg/l)
As	< 0.05	< 0.05	< 0.05	< 0.05	0.050
Ba	0.495	0.789	0.763	0.682	0.001
Cd	<0.005	<0.005	<0.005	<0.005	0.005
Cr	< 0.007	< 0.007	< 0.007	< 0.007	0.007
Pb	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Hg	< 0.040	< 0.040	< 0.040	< 0.040	0.040
Se	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Ag	< 0.007	< 0.007	< 0.007	< 0.007	0.007

Table 4.2.4 Leachability of heavy metals from Sand 4

	Sample 1 (mg/l)	Sample 2 (mg/l)	Sample 3 (mg/l)	Average (mg/l)	Detection limit (mg/l)
As	< 0.05	< 0.05	< 0.05	< 0.05	0.050
Ba	0.495	0.487	0.501	0.494	0.001
Cd	<0.005	<0.005	<0.005	<0.005	0.005
Cr	<0.007	<0.007	<0.007	<0.007	0.007
Pb	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Hg	< 0.040	< 0.040	< 0.040	< 0.040	0.040
Se	< 0.050	< 0.050	< 0.050	< 0.050	0.050
Ag	< 0.007	< 0.007	< 0.007	< 0.007	0.007

APPENDIX B
TOTAL ORGANIC CONTENT

Total organic content

Total organic carbon (TOC) content of each foundry sands was measured by using a solid TOC analyzer. Inorganic carbon existing in the form of calcite or dolomite was removed beforehand by adding 4 M HCl as described in Methods of Soil Anlaysis (Nelson and Sommers, 1982).

Sample	Rep	Sample size (mg)	Area (cts)	Mass (mg of C)	Conc. (% Carbon)
Sand 1	1	31.00	1755	0.59	1.89
	2	31.30	1801	0.60	1.92
	3	31.20	1895	0.63	2.03
				average	1.95
Sand 2	1	53.50	2457	0.82	1.54
	2	54.00	2873	0.96	1.78
	3	53.80	2936	0.98	1.82
				average	1.71
Sand 3	1	56.90	2092	0.70	1.23
	2	57.30	1870	0.63	1.09
	3	57.50	2048	0.68	1.19
				average	1.17
Sand 4	1	100.20	1562	0.52	0.52
	2	100.40	1274	0.43	0.42
	3	100.50	1631	0.48	0.48
				average	0.47
Bentonite 1	1	159.00	647	0.22	0.14
	2	159.20	656	0.22	0.14
	3	161.40	696	0.23	0.14
				average	0.14
Bentonite 2	1	159.00	1201	0.40	0.25
	2	159.00	1129	0.38	0.24
	3	156.90	1113	0.37	0.24
				average	0.24

APPENDIX C
CLAY CONTENT

Clay content

The methylene blue titration was conducted on each foundry sand following ASTM C 837-99 to measure total amount of clay content. A 1.00 g sample of green sand has been dried in accordance with the procedure in test method C 324. Add 300 ml of distilled water to the beaker and stir with the mixer until the clay is uniformly dispersed. Determine the pH of the slurry and add sufficient sulfuric acid to bring the pH within the range from 2.5 to 3.8. With the slurry still under the mixer, fill the buret with the methylene blue solution and observe the appearance of a light blue halo around the drop on the filter paper.

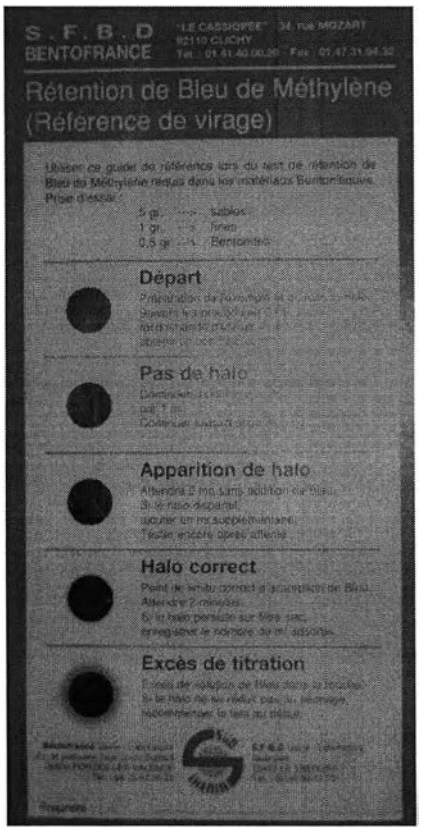

Figure C Blue Halo

Bentonite Content

Pure bentonite

Sample	Bentonite (g)	Bentonite + pure sand (g)	% Bentonite	MB (ml)
1	0.2994	1.0037	29.83	58.00
2	0.2995	1.0036	29.84	67.00
3	0.2983	1.0019	29.77	62.00
		Average	29.82	62.33

Bentonite 29.82 % use MB 62.33 ml

Spent sand

Sample	No.	Sand (g)	MB (ml)	% Bentonite
Sand 1	1	1.0014	39	18.66
	2	1.0010	40	19.14
	3	1.0090	41	19.61
			Average	19.14
Sand 2	1	1.0011	23	11.00
	2	1.0011	23	11.00
	3	1.0008	22	10.52
			Average	10.84
Sand 3	1	1.0005	3	1.44
	2	1.0009	3	1.44
	3	1.0006	3	1.44
			Average	1.44
Sand 4	1	1.0009	0	0
	2	1.0001	0	0
	3	1.0006	0	0
			Average	0

* Determined by Standard for Foundry Sand Mould Bentonite

APPENDIX D
TOTAL IRON CONTENT

Total Iron Analyses

An acid digestion was conducted following USEPA Method 3051 to measure the total iron content. A 0.5 g sample of green sand was digested in 10 ml of concentrated nitric acid for 10 min using a microwave oven (Lee et al. 2004). Fluorocarbon digestion vessels were used. Groups of six vessels were evenly located on the turntable in the microwave oven. Fluorocarbon digestion vessels were used. The vessels were diluted to 1: 1 using distillated water, and solids and suspended materials were removed using a glass fiber filter.

Concentration of iron in digestions were measured by flame atomic adsorption using a Varian® SpectrAA 800 following USPA method SW846 7000A. Calibration standards were prepared by diluting stock standard solutions. Concentration of total iron content in solid samples (C in mg/l) was calculated by:

$$C = \frac{A \times V}{W}$$

Where A is the concentration (mg/l) of metal in digested sample from the calibration curve, V is the final volume of the diluted sample, and W is the weight of sample (g)

Total Iron Content from Total Iron Analyses on Waste Foundry sands

Foundry sand	Total Iron Content	
	mg/kg	% by weight
Sand 1	43,728	4.37
Sand 2	4,839	0.48
Sand 3	44,647	4.46
Sand 4	-	-

APPENDIX E
SIEVE ANALYSIS

Sieve Analyses

Description of soil: Iron filing
Date: 4/11/2004
Mass of oven dry sample, W = 500g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	3.69	0.74	0.74	99.26
40	0.425	5.91	1.18	1.92	98.08
70	0.212	144.52	28.90	30.82	69.18
100	0.150	143.50	28.70	59.52	40.48
140	0.106	195.60	39.12	98.64	1.36
170	0.090	0.15	0.03	98.67	1.33
200	0.075	2.14	0.43	99.10	0.90
Pan	-	4.29			
Σ		499.80	$= W_1$		

$$\text{Mass loss during sieve analysis} = \frac{W - W_1}{W} \times 100$$

$$= 0.04\ \%$$

Description of soil: Bentonite 1
Date: 4/11/2004
Mass of oven dry sample, W = 503.35 g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	0.00	0.00	0.00	100.00
40	0.425	0.20	0.04	0.04	99.96
70	0.212	4.40	0.87	0.91	99.09
100	0.150	10.53	2.09	3.01	96.99
140	0.106	216.37	42.99	45.99	54.01
170	0.090	63.22	12.56	58.55	41.45
200	0.075	42.49	8.44	66.99	33.01
Pan	-	165.89			
Σ		503.10	= W_1		

$$\text{Mass loss during sieve analysis} = \frac{W - W_1}{W} \times 100$$

$$= 0.05\ \%$$

Description of soil: Bentonite 2
Date: 5/11/2004
Mass of oven dry sample, W = 500.35g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	0.71	0.14	0.14	99.86
40	0.425	3.01	0.60	0.74	99.26
70	0.212	28.79	5.75	6.50	93.50
100	0.150	44.06	8.81	15.30	84.70
140	0.106	208.90	41.75	57.05	42.95
170	0.090	40.61	8.12	65.17	34.83
200	0.075	47.80	9.55	74.72	25.28
4	4.750	0.00	0.00	0.00	100.00
Pan	-	106.38			
	Σ	480.26	= W_1		

$$\text{Mass loss during sieve analysis} = \frac{W - W_1}{W} \times 100$$

$$= 4.02\ \%$$

Description of soil: Coal dust
Date: 5/11/2004
Mass of oven dry sample, W = 150.25 g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	1.04	0.69	0.69	99.31
40	0.425	9.12	6.07	6.76	93.24
70	0.212	22.99	15.30	22.06	77.94
100	0.150	48.53	32.30	54.36	45.64
140	0.106	16.46	10.96	65.32	34.68
170	0.090	4.67	3.11	68.43	31.57
200	0.075	2.09	1.39	69.82	30.18
Pan	-	44.35			

Σ 149.25 = W1

$$\text{Mass loss during sieve analysis} = \frac{W - W_1}{W} \times 100$$

$$= 0.67\ \%$$

Name: Sand 1
Description of soil: Waste foundry sand
Date: 9/9/2004
Mass of oven dry sample, W = 500g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	0.00	0.00	0.00	100.00
40	0.425	0.34	0.07	0.07	99.93
70	0.212	55.82	11.16	11.23	88.77
100	0.150	70.70	14.14	25.37	74.63
140	0.106	246.94	49.39	74.76	25.24
170	0.090	42.39	8.48	83.24	16.76
200	0.075	27.40	5.48	88.72	11.28
Pan	-	54.75			
Σ		498.34	= W_1		

Mass loss during sieve analysis $= \dfrac{W - W_1}{W} \times 100$

$= 0.33\ \%$

Name: Sand 2
Description of soil: Waste foundry sand
Date: 9/9/2004
Mass of oven dry sample, W = 500g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	28.46	5.69	5.69	94.31
40	0.425	44.15	8.83	14.52	85.48
70	0.212	205.88	41.18	55.70	44.30
100	0.150	76.52	15.30	71.00	29.00
140	0.106	104.67	20.93	91.94	8.06
170	0.090	0.25	0.05	91.99	8.01
200	0.075	13.37	2.67	94.66	5.34
Pan	-	26.39			
Σ		466.69	= W_1		

Mass loss during sieve analysis $= \dfrac{W - W_1}{W} \times 100$

$= 0.06\ \%$

Name: Sand 3
Description of soil: Waste foundry sand
Date: 9/9/2004
Mass of oven dry sample, W = 500g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	1.33	0.27	0.27	99.73
40	0.425	32.11	6.42	6.69	93.31
70	0.212	273.81	54.76	61.45	38.55
100	0.150	83.72	16.74	78.19	21.81
140	0.106	99.54	19.91	98.10	1.90
170	0.090	0.04	0.01	98.11	1.89
200	0.075	1.65	0.33	98.44	1.56
Pan	-	5.18			
Σ		497.38	$= W_1$		

$$\text{Mass loss during sieve analysis} = \frac{W - W_1}{W} \times 100$$

$$= 0.52\ \%$$

Name: Sand 4
Description of soil: Waste foundry sand
Date: 9/9/2004
Mass of oven dry sample, W = 500g

Sieve No.	Sieve Opening (mm)	Mass of soil retained on each sieve, W_n, (g)	Percent of Mass retained on each sieve, R_n	Cumulative percent retained, ΣR_n	Percent finer, $100 - \Sigma R_n$
4	4.750	0.00	0.00	0.00	100.00
10	2.000	0.00	0.00	0.00	100.00
20	0.850	9.33	1.87	1.87	98.13
40	0.425	0.00	0.00	1.87	98.13
70	0.212	130.53	26.11	27.97	72.03
100	0.150	135.50	27.10	55.07	44.93
140	0.106	215.60	43.12	98.19	1.81
170	0.090	0.15	0.03	98.22	1.78
200	0.075	2.14	0.43	98.65	1.35
Pan	-	6.49			
Σ		499.74	= W_1		

$$\text{Mass loss during sieve analysis} = \frac{W - W_1}{W} \times 100$$

$$= 0.05\ \%$$

APPENDIX F
BATCH KINETIC TESTS

Zinc concentration during batch kinetic tests
Initial zinc concentration: 50 mg/l
Initial solution pH: 3.72

		Iron filling				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	26.41	26.98	26.10	26.50	0.45
3	2	24.30	24.30	24.30	24.30	0.00
4	4	23.43	25.60	24.74	24.59	1.09
5	8	22.03	23.77	20.51	22.11	1.63
6	12	25.77	24.41	25.43	25.20	0.71
7	24	19.40	24.41	25.43	23.08	3.23

		Bentonite 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	28.28	29.84	28.45	28.86	0.86
3	2	25.32	26.43	26.68	26.14	0.73
4	4	23.72	24.82	23.72	24.09	0.64
5	8	22.89	20.01	21.54	21.48	1.44
6	12	23.88	24.67	23.89	24.15	0.45
7	24	19.85	20.34	20.61	20.27	0.39

		Bentonite 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	38.40	38.48	39.79	38.89	0.78
3	2	34.48	35.36	34.34	34.73	0.55
4	4	30.04	32.02	30.63	30.90	1.01
5	8	27.95	25.52	29.84	27.77	2.17
6	12	29.73	28.55	28.36	28.88	0.74
7	24	26.08	24.51	27.98	26.19	1.74

		Sand 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	39.71	34.11	36.59	36.80	2.80
3	2	30.45	27.47	29.92	29.28	1.59
4	4	24.88	25.28	25.42	25.19	0.28
5	8	21.57	22.38	20.08	21.34	1.16
6	12	22.25	23.60	24.88	23.57	1.32
7	24	27.06	26.71	26.26	26.68	0.40

		Sand 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	37.69	40.71	38.97	39.12	1.52
3	2	30.13	32.17	33.47	31.92	1.68
4	4	29.90	28.44	30.55	29.63	1.08
5	8	23.56	28.76	26.43	26.25	2.60
6	12	27.71	26.99	29.31	28.00	1.19
7	24	27.03	26.43	30.33	27.93	2.10

		Sand 3				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	47.93	48.62	48.84	48.46	0.47
2	1.00	39.42	40.06	40.99	40.16	0.79
3	2.00	36.22	37.67	35.12	36.34	1.27
4	4.00	34.01	34.01	33.82	33.95	0.11
5	8.00	31.29	31.14	32.28	31.57	0.62
6	12.00	32.86	33.11	33.38	33.12	0.26
7	24.00	31.74	33.59	32.31	32.55	0.95

		Sand 4				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	47.93	48.62	48.84	48.46	0.47
2	1.00	44.20	45.74	43.79	44.58	1.03
3	2.00	42.23	42.01	44.62	42.95	1.44
4	4.00	36.66	37.87	37.84	37.45	0.69
5	8.00	38.62	40.16	37.12	38.64	1.52
6	12.00	41.43	41.40	42.85	41.90	0.83
7	24.00	38.50	40.61	39.95	39.69	1.08

		Coal dust				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	29.38	29.32	29.38	29.36	0.03
3	2	27.95	28.01	27.92	27.96	0.05
4	4	26.30	26.39	26.37	26.35	0.05
5	8	26.06	25.87	25.84	25.92	0.12
6	12	24.13	23.76	24.11	24.00	0.21
7	24	22.35	22.27	22.44	22.35	0.09

Zinc concentration during batch kinetic tests
Initial zinc concentration: 50 mg/l
Initial solution pH: 6.59

		Iron filing				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	22.01	22.47	22.16	22.21	0.24
3	2	16.78	14.41	14.78	15.32	1.28
4	4	11.43	10.60	11.74	11.26	0.59
5	8	9.03	8.77	10.51	9.44	0.94
6	12	7.07	9.44	9.99	8.83	1.55
7	24	7.40	8.91	9.35	8.55	1.02

		Bentonite 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	23.28	21.24	24.64	23.05	1.71
3	2	25.76	24.20	26.11	25.36	1.02
4	4	17.79	16.08	15.25	16.37	1.30
5	8	10.71	10.01	11.54	10.75	0.77
6	12	8.19	8.48	9.35	8.68	0.60
7	24	9.85	8.34	10.61	9.60	1.16

		Bentonite 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	25.36	26.01	29.32	26.89	2.13
3	2	20.67	21.23	20.56	20.82	0.36
4	4	22.41	20.26	23.65	22.11	1.72
5	8	13.47	12.28	12.33	12.69	0.67
6	12	12.89	12.73	11.67	12.43	0.66
7	24	13.37	11.25	13.97	12.87	1.43

		Sand 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	29.52	28.41	29.22	29.05	0.58
3	2	31.24	30.23	31.46	30.97	0.66
4	4	22.64	20.18	22.32	21.72	1.34
5	8	13.07	12.58	14.18	13.27	0.82
6	12	9.87	9.60	9.88	9.78	0.16
7	24	8.27	9.35	10.40	9.34	1.06

		Sand 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	31.81	30.00	31.47	31.09	0.96
3	2	26.52	22.07	25.12	24.57	2.27
4	4	23.62	25.55	24.36	24.51	0.98
5	8	17.12	16.03	18.71	17.28	1.35
6	12	6.56	7.88	7.55	7.33	0.68
7	24	10.69	11.21	13.00	11.63	1.21

		Sand 3				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	32.56	34.78	33.03	33.46	1.17
3	2	27.05	28.33	26.41	27.26	0.98
4	4	19.40	18.23	17.38	18.34	1.02
5	8	11.35	12.58	13.44	12.46	1.05
6	12	9.92	12.63	12.04	11.53	1.43
7	24	14.01	14.87	13.95	14.28	0.51

		Sand 4				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	36.75	35.70	36.79	36.41	0.61
3	2	24.12	26.51	24.28	24.97	1.34
4	4	26.54	27.71	29.40	27.88	1.44
5	8	22.27	21.35	21.76	21.79	0.46
6	12	19.44	20.08	20.05	19.86	0.36
7	24	20.30	20.71	21.23	20.75	0.47

		Coal dust				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	27.33	28.46	27.54	27.78	0.60
3	2	28.67	27.34	26.82	27.61	0.96
4	4	22.55	22.78	24.10	23.14	0.83
5	8	14.10	14.57	14.82	14.50	0.37
6	12	10.04	10.53	11.64	10.74	0.82
7	24	10.02	11.43	10.61	10.69	0.71

Zinc concentration during batch kinetic tests
Initial zinc concentration: 50 mg/l
Initial solution pH: 8.01

		Iron filing				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	19.49	17.98	17.39	18.29	1.08
3	2	14.34	14.91	14.28	14.51	0.34
4	4	12.69	9.49	13.84	12.01	2.26
5	8	8.03	8.50	9.30	8.61	0.64
6	12	4.63	4.85	4.21	4.56	0.33
7	24	5.26	4.91	5.21	5.12	0.19

		Bentonite 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	23.28	21.24	24.64	23.05	1.71
3	2	25.76	24.20	26.11	25.36	1.02
4	4	17.79	16.08	15.25	16.37	1.30
5	8	10.71	10.01	11.54	10.75	0.77
6	12	3.84	3.62	3.05	3.50	0.41
7	24	4.32	4.64	3.37	4.11	0.66

		Bentonite 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	20.64	21.50	21.76	21.30	0.59
3	2	18.46	18.34	17.59	18.13	0.47
4	4	16.13	14.48	16.90	15.84	1.24
5	8	13.47	12.28	12.33	12.69	0.67
6	12	10.81	9.54	10.68	10.34	0.70
7	24	10.48	9.15	9.11	9.58	0.78

		Sand 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	27.20	26.09	24.39	25.89	1.41
3	2	17.47	18.16	17.37	17.67	0.43
4	4	10.65	10.57	12.70	11.31	1.20
5	8	6.99	6.19	7.24	6.80	0.55
6	12	2.74	1.94	2.31	2.33	0.40
7	24	2.65	2.47	2.21	2.44	0.22

		Sand 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	31.81	30.00	31.47	31.09	0.96
3	2	26.52	22.07	25.12	24.57	2.27
4	4	19.62	21.55	19.36	20.18	1.20
5	8	12.47	13.15	12.07	12.56	0.55
6	12	5.71	4.55	5.89	5.38	0.73
7	24	6.95	5.06	5.95	5.99	0.95

		Sand 3				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	19.97	20.17	19.94	20.02	0.13
3	2	16.05	17.64	16.46	16.72	0.82
4	4	12.46	14.91	13.75	13.71	1.22
5	8	10.72	10.25	10.43	10.46	0.24
6	12	7.32	7.87	6.33	7.17	0.78
7	24	6.31	5.95	6.03	6.10	0.19

		Sand 4				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	24.65	24.00	25.32	24.65	0.66
3	2	19.32	20.51	20.09	19.97	0.60
4	4	17.28	17.31	17.30	17.30	0.02
5	8	14.60	14.90	15.15	14.88	0.28
6	12	11.80	11.78	11.55	11.71	0.14
7	24	10.26	9.84	9.15	9.75	0.56

		Coal dust				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	47.93	48.62	48.84	48.46	0.47
2	1	21.94	20.72	21.36	21.34	0.61
3	2	24.01	24.78	25.13	24.64	0.57
4	4	15.79	14.43	15.93	15.38	0.82
5	8	10.23	10.45	9.08	9.92	0.74
6	12	4.44	4.24	4.90	4.53	0.34
7	24	3.92	3.75	3.83	3.84	0.08

Solution pH during batch kinetic tests
Initial zinc concentration: 50 mg/l
Initial solution pH: 3.72

		Iron filling				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	3.69	3.73	3.74	3.72	0.03
2	1	7.76	7.78	7.80	7.78	0.02
3	2	7.64	7.68	7.63	7.65	0.03
4	4	7.61	7.62	7.63	7.62	0.01
5	8	7.76	7.95	8.14	7.95	0.19
6	12	7.85	7.87	7.86	7.86	0.01
7	24	7.73	7.76	7.90	7.80	0.09

		Bentonite 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	3.69	3.73	3.74	3.72	0.03
2	1	7.95	7.96	7.94	7.95	0.01
3	2	7.81	7.84	7.81	7.82	0.02
4	4	7.89	7.86	7.83	7.86	0.03
5	8	7.83	7.83	7.84	7.83	0.01
6	12	7.94	7.97	7.93	7.95	0.02
7	24	8.02	8.09	8.07	8.06	0.04

		Bentonite 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	3.69	3.73	3.74	3.72	0.03
2	1	7.25	7.26	7.24	7.25	0.01
3	2	7.23	7.22	7.21	7.22	0.01
4	4	7.26	7.27	7.31	7.28	0.03
5	8	7.25	7.26	7.26	7.26	0.01
6	12	7.26	7.26	7.26	7.26	0.00
7	24	7.26	7.25	7.26	7.26	0.01

		Sand 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	3.69	3.73	3.74	3.72	0.03
2	1	7.13	7.17	7.13	7.14	0.02
3	2	7.12	7.09	7.09	7.10	0.02
4	4	7.08	7.06	7.07	7.07	0.01
5	8	7.07	7.05	7.07	7.06	0.01
6	12	7.10	7.08	7.09	7.09	0.01
7	24	6.89	6.71	6.97	6.86	0.13

		Sand 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	3.69	3.73	3.74	3.72	0.03
2	1	5.79	5.91	5.82	5.84	0.06
3	2	6.53	6.56	6.61	6.57	0.04
4	4	6.67	6.72	6.73	6.71	0.03
5	8	6.83	6.86	6.89	6.86	0.03
6	12	6.71	6.72	6.74	6.72	0.02
7	24	6.65	6.62	6.64	6.64	0.02

		Sand 3				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	3.69	3.73	3.74	3.72	0.03
2	1.00	4.61	4.59	4.63	4.61	0.02
3	2.00	4.82	4.87	4.87	4.85	0.03
4	4.00	5.41	5.40	5.44	5.42	0.02
5	8.00	5.19	5.32	5.32	5.28	0.08
6	12.00	5.48	5.43	5.47	5.46	0.03
7	24.00	5.47	5.46	5.47	5.47	0.01

		Sand 4				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	3.69	3.73	3.74	3.72	0.03
2	1.00	3.87	3.92	3.89	3.89	0.03
3	2.00	3.77	3.81	3.76	3.78	0.03
4	4.00	4.34	4.40	4.38	4.37	0.03
5	8.00	4.25	4.26	4.25	4.25	0.01
6	12.00	4.19	4.20	4.17	4.19	0.02
7	24.00	4.23	4.24	4.23	4.23	0.01

		Coal dust				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	3.69	3.73	3.63	3.68	0.05
2	1	6.24	6.28	6.31	6.28	0.04
3	2	6.92	6.99	6.93	6.95	0.04
4	4	7.12	7.14	7.13	7.13	0.01
5	8	7.63	7.67	7.64	7.65	0.02
6	12	7.86	6.87	7.86	7.53	0.57
7	24	7.89	7.92	7.90	7.90	0.02

Solution pH during batch kinetic tests
Initial zinc concentration: 50 mg/l
Initial solution pH: 6.59

		Iron filling				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	6.58	6.64	6.55	6.59	0.05
2	1	8.64	8.66	8.77	8.69	0.07
3	2	8.67	8.65	8.63	8.65	0.02
4	4	8.65	8.51	8.65	8.60	0.08
5	8	8.62	8.73	8.57	8.64	0.08
6	12	8.91	8.64	8.61	8.72	0.17
7	24	8.83	8.80	8.81	8.81	0.02

		Bentonite 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	6.58	6.64	6.55	6.59	0.05
2	1	7.19	7.24	7.28	7.24	0.04
3	2	7.80	7.83	7.80	7.81	0.02
4	4	7.85	8.04	7.94	7.94	0.10
5	8	8.10	8.14	8.99	8.41	0.50
6	12	8.17	8.12	9.18	8.49	0.60
7	24	8.14	8.15	8.14	8.14	0.01

		Bentonite 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	6.58	6.64	6.55	6.59	0.05
2	1	8.28	8.33	8.33	8.31	0.03
3	2	8.47	8.48	8.70	8.55	0.13
4	4	8.44	8.40	8.41	8.42	0.02
5	8	8.47	8.51	8.51	8.50	0.02
6	12	8.54	8.58	8.56	8.56	0.02
7	24	8.57	8.59	8.58	8.58	0.01

		Sand 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	6.58	6.64	6.55	6.59	0.05
2	1	8.23	8.17	8.13	8.18	0.05
3	2	8.09	8.09	8.09	8.09	0.00
4	4	8.07	8.06	8.07	8.07	0.01
5	8	8.05	8.05	8.07	8.06	0.01
6	12	8.17	8.13	8.15	8.15	0.02
7	24	8.12	8.09	8.11	8.11	0.02

		Sand 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	6.58	6.64	6.55	6.59	0.05
2	1	7.79	7.91	7.82	7.84	0.06
3	2	7.53	7.56	7.61	7.57	0.04
4	4	7.57	7.52	7.53	7.54	0.03
5	8	7.99	7.96	7.99	7.98	0.02
6	12	7.91	7.92	7.94	7.92	0.02
7	24	7.89	7.92	7.91	7.91	0.02

		Sand 3				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	6.58	6.64	6.55	6.59	0.05
2	1.00	7.37	7.36	7.36	7.36	0.01
3	2.00	6.84	6.90	6.99	6.91	0.08
4	4.00	7.04	7.08	7.08	7.07	0.02
5	8.00	7.47	7.46	7.50	7.48	0.02
6	12.00	7.33	7.33	7.35	7.34	0.01
7	24.00	7.35	7.37	7.39	7.37	0.02

		Sand 4				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	6.58	6.64	6.55	6.59	0.05
2	1.00	6.78	6.78	6.77	6.78	0.01
3	2.00	6.64	6.67	6.68	6.66	0.02
4	4.00	6.78	6.83	6.79	6.80	0.03
5	8.00	6.76	6.81	6.79	6.79	0.03
6	12.00	6.81	6.79	6.79	6.80	0.01
7	24.00	6.83	6.82	6.77	6.81	0.03

		Coal dust				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	6.58	6.64	6.55	6.59	0.05
2	1	8.31	8.34	8.32	8.32	0.02
3	2	8.36	8.41	8.36	8.38	0.03
4	4	8.39	8.40	8.38	8.39	0.01
5	8	8.41	8.42	8.41	8.41	0.01
6	12	8.44	8.46	8.46	8.45	0.01
7	24	8.49	8.50	8.48	8.49	0.01

Solution pH during batch kinetic tests
Initial zinc concentration: 50 mg/l
Initial solution pH: 8.01

		Iron filling				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	8.05	7.97	8.00	8.01	0.04
2	1	10.35	10.41	10.39	10.38	0.03
3	2	10.21	10.18	10.20	10.20	0.02
4	4	10.33	10.32	10.30	10.32	0.02
5	8	10.28	10.31	10.29	10.29	0.02
6	12	10.37	10.34	10.34	10.35	0.02
7	24	10.34	10.35	10.34	10.34	0.01

		Bentonite 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	8.05	7.97	8.00	8.01	0.04
2	1	10.36	10.36	10.33	10.35	0.02
3	2	9.98	10.01	10.04	10.01	0.03
4	4	10.23	10.21	10.22	10.22	0.01
5	8	10.28	10.29	10.25	10.27	0.02
6	12	10.27	10.27	10.27	10.27	0.00
7	24	10.28	10.26	10.27	10.27	0.01

		Bentonite 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	8.05	7.97	8.00	8.01	0.04
2	1	10.11	10.15	10.09	10.12	0.03
3	2	9.47	9.48	9.70	9.55	0.13
4	4	9.44	9.40	9.41	9.42	0.02
5	8	9.87	9.73	9.79	9.80	0.07
6	12	9.54	9.58	9.56	9.56	0.02
7	24	9.57	9.59	9.58	9.58	0.01

		Sand 1				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	8.05	7.97	8.00	8.01	0.04
2	1	10.12	10.11	10.13	10.12	0.01
3	2	10.08	10..5	10.08	10.08	0.00
4	4	10.35	10.37	10.34	10.35	0.02
5	8	10.38	10.41	10.37	10.39	0.02
6	12	10.41	10.40	10.40	10.40	0.01
7	24	10.39	10.40	10.40	10.40	0.01

		Sand 2				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	8.05	7.97	8.00	8.01	0.04
2	1	9.83	9.89	9.88	9.87	0.03
3	2	9.83	9.86	9.81	9.83	0.03
4	4	9.67	9.72	9.73	9.71	0.03
5	8	9.83	9.86	9.89	9.86	0.03
6	12	9.91	9.92	9.94	9.92	0.02
7	24	10.01	9.99	10.00	10.00	0.01

		Sand 3				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	8.05	7.97	8.00	8.01	0.04
2	1.00	8.48	8.48	8.47	8.48	0.01
3	2.00	8.14	8.17	8.18	8.16	0.02
4	4.00	8.58	8.43	8.59	8.53	0.09
5	8.00	8.16	8.20	8.17	8.18	0.02
6	12.00	8.31	8.39	8.37	8.36	0.04
7	24.00	8.23	8.22	8.21	8.22	0.01

		Sand 4				
No.	Designed time, hr	1	2	3	AVG	SD
1	0.00	8.05	7.97	8.00	8.01	0.04
2	1.00	8.48	8.48	8.47	8.48	0.01
3	2.00	8.14	8.17	8.18	8.16	0.02
4	4.00	8.58	8.43	8.59	8.53	0.09
5	8.00	8.16	8.20	8.17	8.18	0.02
6	12.00	8.31	8.39	8.37	8.36	0.04
7	24.00	8.23	8.22	8.21	8.22	0.01

		Coal dust				
No.	Designed time, hr	1	2	3	AVG	SD
1	0	8.05	7.97	8.00	8.01	0.04
2	1	10.12	10.09	10.15	10.12	0.03
3	2	10.13	10.15	10.12	10.13	0.02
4	4	10.18	10.20	10.18	10.19	0.01
5	8	10.24	10.21	10.22	10.22	0.02
6	12	10.23	10.24	10.21	10.23	0.02
7	24	10.23	10.24	10.22	10.23	0.01

Multivariate regression analysis

pH 3.72 **Removal (%) = 3.414 + 0.089 Clay + 1.081Iron + 20.289 TOC**

Sample	Clay (%)	Iron Content (%)	TOC (%)	experiment (1)	regression (2)	SSE = $[(1)-(2)]^2$	SSR = $[(2) - \text{avg of } (1)]^2$	SST = SSE + SSR	r^2 = SSR/SST
Sand1	19.14	4.37	2.03	51.02	51.03	0.00	274.09	274.09	1.00
Sand 2	10.84	0.48	1.82	41.82	41.82	0.00	54.04	54.04	1.00
Sand 3	1.44	4.46	1.17	32.10	32.10	0.00	5.62	5.62	1.00
Sand 4	0.00	0.00	0.47	12.95	12.95	0.00	463.23	463.23	1.00
			avg of (1)	34.47				avg of r^2	1.00

pH 6.59 **Removal (%) = 50.189 - 0.385 Clay + 1.148 Iron + 18.194 TOC**

Sample	Clay (%)	Iron Content (%)	TOC (%)	experiment (1)	regression (2)	SSE = $[(1)-(2)]^2$	SSR = $[(2) - \text{avg of } (1)]^2$	SST = SSE + SSR	r^2 = SSR/SST
Sand1	19.14	4.37	2.03	84.77	84.77	0.00	2529.91	2529.91	1.00
Sand 2	10.84	0.48	1.82	79.68	79.68	0.00	2043.69	2043.69	1.00
Sand 3	1.44	4.46	1.17	76.04	76.04	0.00	1728.00	1728.00	1.00
Sand 4	0.00	0.00	0.47	58.74	58.74	0.00	588.92	588.92	1.00
			avg of (1)	74.81				avg of r^2	1.00

pH 8.01 **Removal (%) = 58.275 - 0.770 Clay + 0.825 Iron + 22.287 TOC**

Sample	Clay (%)	Iron Content (%)	TOC (%)	experiment (1)	regression (2)	SSE = $[(1)-(2)]^2$	SSR = $[(2) - \text{avg of } (1)]^2$	SST = SSE + SSR	r^2 = SSR/SST
Sand1	19.14	4.37	2.03	92.39	92.39	0.00	3353.86	3353.86	1.00
Sand 2	10.84	0.48	1.82	90.89	90.89	0.00	3182.54	3182.54	1.00
Sand 3	1.44	4.46	1.17	86.92	86.92	0.00	2750.90	2750.90	1.00
Sand 4	0.00	0.00	0.47	68.75	68.75	0.00	1174.94	1174.94	1.00
			avg of (1)	84.74				avg of r^2	1.00

APPENDIX G
COMPARISON TEST

Comparison test between spent foundry sand and synthetic sand

Amount of sorbent: 2 g.
Volume of solution: 50 ml.

1. Zinc removed by synthetic sand (4.37 % iron, 19.14 % clay and 2.03 % TOC)

Rep.	C_0 (mg/l)	C_e (mg/l)	% removal of zinc	q_e(mg/g)	Mass sorbed (mg/kg)
1.00	47.93	19.52	59.28	0.71	710.30
2.00	48.62	19.66	59.56	0.72	723.93
3.00	47.84	19.47	59.30	0.71	709.23
AVG	48.13	19.55	59.38	0.71	714.48
SD	0.42	0.10	0.16	0.01	8.19

2. Zinc removed by enhanced synthetic (45 % iron, 19.14% clay and 2.03 % TOC)

Rep.	C_0 (mg/l)	C_e (mg/l)	% removal of zinc	q_e(mg/g)	Mass sorbed (mg/kg)
1.00	47.93	5.13	89.30	1.07	1070.13
2.00	48.62	4.83	90.06	1.09	1094.63
3.00	47.84	4.91	89.73	1.07	1073.18
AVG	48.13	4.96	89.70	1.08	1079.31
SD	0.42	0.15	0.38	0.01	13.35

BIOGRAPHY

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