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Combined Chemical and Biological Oxidation of Slurry Phase Polycyclic Aromatic Hydrocarbons

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ABSTRACT

Bioslurry treatment of polycyclic aromatic hydrocarbon (PAH)-impacted soils was demonstrated under the Superfund Innovative Technologies Evaluation - Emerging Technologies Program (SITE ETP) as an extension of research previously funded by IT Corporation (IT) (Brown and Sanseverino, 1993) and additional investigations supported by the U.S. Environmental Protection Agency (EPA) (Davila et al., 1994).

During the demonstration, IT operated two 60-liter (L) TEKNO Associates bioslurry reactors (Salt Lake City, Utah) and a 10-L fermentation unit in semicontinuous, plug-flow mode for a 2-month period. The first 60-L reactor received fresh feed daily and supplements of salicylate and succinate to enhance PAH biodegradation.

Effluent from the first reactor was fed to the second 10-L reactor in series, where Fenton's reagent was added to accelerate oxidation of four- to six-ring PAH. The third reactor in series was used as a polishing reactor for the removal of any partially-oxidized contaminants remaining following addition of Fenton's reagent.

During operation, the bioslurry reactor system demonstrated average PAH and carcinogenic PAH (CPAH) removals of 84 and 66 percent, respectively. The reactors will be operated over the

next four months to increase the rate and extent of PAH biodegradation. The objective of the demonstration is to illustrate bioslurry treatment of impacted soils and sludges as an effective and economically attractive remedial option.

INTRODUCTION

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the EPA to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable." CERCLA also prefers remedial actions in which treatment that "permanently and significantly reduces the volume, toxicity or mobility of the hazardous substances, pollutants, and contaminants is a principal element." During this demonstration, innovative methods for the biological treatment of PAH-impacted soils were evaluated to determine their compliance with the mandates of CERCLA.

The primary objective of reactor 1 (R1) operation was to increase the biological removal of organic carbon. Salicylate was used to induce the naphthalene degradation operon on NAH plasmids. This system has been shown to degrade phenanthrene and anthracene (Sanseverino et al., 1993). The naphthalene pathway may also play a role in CPAH metabolism. Succinate, a byproduct of naphthalene metabolism, served as a general carbon source during this investigation. The first reactor in series removed easily degradable carbon and increased biological activity against more recalcitrant PAH (i.e., three-ring compounds and higher).

Effluent from R1 was fed to reactor 2 (R2) where Fenton's reagent was continuously introduced. Fenton's reagent (hydrogen peroxide in the presence of iron salts) produces a free radical which has been shown effective in extensively oxidizing multi-ring aromatic hydrocarbons (Gauger et al., 1990; Elizardo, 1991). The objective of Fenton's reagent addition was not PAH mineralization, but the hydroxylation of multi-ring PAH, since hydroxylation of high molecular weight PAH is generally the rate limiting step in biological oxidation.

Reactor 3 (R3) was used for biological polishing of R2 effluent. Overall, the primary objective of the investigation was to demonstrate increased CPAH and PAH removal using combined biological and chemical oxidation.

MATERIALS AND METHODS

Impacted soils with PAH and CPAH concentrations of 4,380 and 300 milligrams per kilogram (mg/kg), respectively, were collected from a Southeastern wood treating facility. Soils were wet sieved on site and submitted to IT's Biotechnology Applications Center (BAC) located in Knoxville, Tennessee for testing.

Prior to bioslurry treatment, soils were wet sieved to less than 30 mesh. All reactors were charged with a 40 percent total solids (TS) slurry of the screened soils and operated in batch for a period of two weeks prior to the initiation of semi-continuous flow. During batch treatment, several operational difficulties were encountered including, significant foaming and tar ball formation.

During semi-continuous flow 6 liters per day (L/day) of influent slurry was manually introduced to R1, resulting in a hydraulic retention time (HRT) of 10 days. To induce biological activity against PAH salicylate and succinate were added weekly to achieve a final reactor concentration of 86 and

4.4 milligrams per liter (mg/L), respectively. This addition rate was increased to 3 times per week following 4 weeks of operation. Reactor pH, dissolved oxygen, ammoniacal nitrogen, and ortho-phosphate concentrations were maintained at optimal for biological activity.

The second reactor in series received dilute concentrations of Fenton's reagent to accelerate oxidation of multi-ring PAH. Fenton's reagent was prepared by mixing a 1:1 ratio of 35 percent hydrogen peroxide and 1.5 molar (M) iron sulfate solution. Fenton's reagent was applied to R2 at 2.0 L/day. The influent feed rate to R2 was 6 L/day resulting in a substrate HRT of 1 day; the total system HRT averaged 0.75 days. The reactor pH was maintained at 2 to enhance the effectiveness of Fenton's addition.

The last reactor (R3) in series will be used as a polishing reactor for the removal of any partially-oxidized contaminants remaining following addition of Fenton's reagent. The system received 8.0 L/day of influent feed from R2, resulting in a HRT of 7.5 days. All operational parameters were maintained similar to R1. The process flow diagram (PFD) for the pilot-scale system is presented in Figure 1.

During operation, slurry in R1, R2, and R3 was monitored weekly for TS, volatile solids (VS) concentrations and slurry density. Microbial enumerations of total heterotrophs and naphthalene degraders was also conducted on the same schedule. Aqueous- and solid-phase PAH concentrations in R1, R2, and R3 were also monitored once per week. Volatilization of constituents was monitored monthly in R1 off gas.

RESULTS AND DISCUSSION

The bioslurry reactor system demonstrated 84 and 66 percent removal of PAH and CPAH, respectively. Table 1 illustrates the reduction in concentration of all PAH compounds. Overall, the biologically active reactors (R1 and R3) illustrated a decreasing effectiveness in PAH removal as a function of compound molecular weight. For example, on October 19, 1994 R1 and R3 demonstrated 80 and 89 percent removal of fluorene, respectively. Removal rates were decreased to 18 and 0 percent, respectively, for the removal of benzo(a)pyrene on the same date. R2, however, demonstrated greater than 94 percent removal of benzo(a)pyrene on the same date.

The TS distribution in all reactors was maintained consistently at 40 percent. The pH in R1, R2, and R3 averaged approximately 6.5, 2.0, and 6.5, respectively.

Total heterotrophic counts in R1 and R3 ranged from 10^8 to 10^9 colony forming units/milliliter slurry (CFU/mL). Despite severe conditions maintained in R2, microbial enumerations measured greater than 10^4 CFU/mL.

CONCLUSIONS AND RECOMMENDATIONS

The demonstration illustrated the potential effectiveness of combined bioslurry treatment and chemical oxidation for the treatment of PAH-impacted soils. Continuing operation of the reactors to effectively increase the removal efficiencies demonstrated during the first two months of operation will be pursued over the next four months.

REFERENCES

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LIST OF FIGURE AND TABLE CAPTIONS

OCTOBER 10, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	328	5.88U	5.88U	5.88U	99	0	0	99.1
ACENAPHTHYLENE	127	2.23U	2.23U	7.78	99	0	0	93.9
ACENAPHTHENE	142	67.7	78.1	80.2	52	0	22.9	57.6
FLUORENE	255	12.3	96.9	52.5	95	0	45.8	79.5
PHENANTHRENE	700	9.6	260	101	99	0	61.2	85.6
ANTHRACENE	129	13.6	80.5	48.1	89	0	40.3	62.7
FLUORANTHENE	865	218	442	321	75	0	27.4	62.9
PYRENE	748	129	409	288	83	0	29.6	61.5
BENZ(A)ANTHRACENE	50.2	20.1	33.1	20.4	60	0	38.4	59.4
CHRYSENE	62	25.1	38.6	27.3	30	0	29.3	56
BENZO(B)FLUORANTHENE	22.3	9.83	17.2	8.09	56	0	53	63.7
BENZO(K)FLUORANTHENE	14.5	6.64	10.3	3.41	54	0	66.9	76.5
BENZ(A)PYRENE	20.5	7.58	10.9	2.92U	63	0	36.6	92.9
DIBENZ(A,H)ANTHRACENE	10.9	4.11	6.19	4.44	62	0	28.3	59.3
BENZO(G,H,I)PERYLENE	7.65	2.83	4.39	2.25	63	0	48.7	70.6
INDENOPYRENE	6.47	2.23	3.28	2.14	66	0	34.8	66.9
TOTAL PAH	3489	533	1495	955	85	0	36.1	72.6
TOTAL CPAH	194	78.4	124	73.3	60	0	40.9	62.2

OCTOBER 19, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	5.88U	5.88U	5.88U	5.88U	0	0	0	0
ACENAPHTHYLENE	4.74	9.94	2.23U	2.23U	0	88.6	0	76.5
ACENAPHTHENE	81.2	178	34.2	6.60U	0	80.8	90	95.[illegible]
FLUORENE	324	64.4	11.8	1.29	80.1	81.7	89	99.6
PHENANTHRENE	1101	78.4	42.4	3.42	92.9	45.9	92	99.7
ANTHRACENE	252	68.4	7.68	1.69	72.9	88.8	78	99.3
FLUORANTHENE	1417	617	315	91.2	56.5	48.9	71	93.6
PYRENE	1358	454	200	83.8	66.6	55.9	58	93.8
BENZ(A)ANTHRACENE	88.6	58.3	27.6	5.74	34	52.9	79	93.5
CHRYSENE	111	74.2	36.2	10.6	33.2	51.2	71	90.5
BENZO(B)FLUORANTHENE	37.6	26.2	12	11.3	30.3	54.2	5.8	69.9
BENZO(K)FLUORANTHENE	20.7	17.3	5.44	5.92	16.4	68.6	0	71.4
BENZ(A)PYRENE	30.3	24.9	2.92U	2.92U	17.8	94.1	0	95.2
DIBENZ(A,H)ANTHRACENE	14	11.5	5.06	4.26	17.9	56	16	69.5
BENZO(G,H,I)PERYLENE	7.45	8	3.87	3.54	0	52.3	7.3	52.5
INDENOPYRENE	6.25	6.58	3.01	2.63	0	54.3	13	57.9
TOTAL PAH	4856	1700	710	234	65	58.2	67	95.2
TOTAL CPAH	316	227	97.5	49.6	28.2	56.9	49	84.3

OCTOBER 26, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	38.6	5.88U	5.88U	5.88U	92	0	0	92.4
ACENAPHTHYLENE	16.4	15.1	38.2	11.7	7.9	0	69.4	28.7
ACENAPHTHENE	112	147	75.1	14.7	0	48.9	80.4	86.9
FLUORENE	276	117	48	10.6	58	59	77.9	96.2
PHENANTHRENE	853	296	123	35.2	65	58.4	71.4	95.9
ANTHRACENE	181	131	34.2	8.27	28	73.9	75.8	95.4
FLUORANTHENE	1166	919	570	246	21	38	56.8	78.9
PYRENE	982	817	458	178	17	43.9	61.1	81.9
BENZ(A)ANTHRACENE	123	112	62	34.9	8.9	44.6	43.7	71.6
CHRYSENE	67.7	35.1	54.2	29.5	0	43	45.6	56.4
BENZO(B)FLUORANTHENE	4.25	31.4	18	13.3	0	42.7	26.1	0
BENZO(K)FLUORANTHENE	18.5	23.3	8.72	10.5	0	62.5	0	43.2
BENZ(A)PYRENE	30.1	34.1	7.46	10.3	0	78.1	0	65.8
DIBENZ(A,H)ANTHRACENE	18.5	11	6.6	4.73	41	40	49.3	74.6
BENZO(G,H,I)PERYLENE	9.29	10.2	5.91	4.16	0	42.1	29.6	55.2
INDENOPYRENE	9.43	8.47	4.89	3.39	10	42.3	30.7	64.1
TOTAL PAH	3906	2771	1518	618	29	45.2	59.3	84.2
TOTAL CPAH	281	326	168	111	0	48.5	33.9	60.5

NOVEMBER 2, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	38.6	9.67	5.88U	5.88U	74.9	69.8	0	92.4
ACENAPHTHYLENE	16.4	13.8	12.1	2.23U	0	28	91	93.2
ACENAPHTHENE	112	270	91.6	60.7	0	66.1	34	45.8
FLUORENE	276	17.2	15.3	2.34	93.8	11	85	99.2
PHENANTHRENE	853	16.4	30.7	5.76	98.1	0	81	99.3
ANTHRACENE	181	18.5	7.87	1.63	89.8	57.5	79	99.1
FLUORANTHENE	1166	690	471	257	40.8	31.7	45	78
PYRENE	982	425	287	177	56.7	32.5	38	82
BENZ(A)ANTHRACENE	123	64.5	41.6	25.4	47.6	35.5	39	79.3
CHRYSENE	67.7	98.5	65.7	41	0	33.3	38	39.4
BENZO(B)FLUORANTHENE	4.25	33.6	20.3	18.5	0	39.6	8.9	0
BENZO(K)FLUORANTHENE	18.5	16.9	9.27	8.8	8.65	45.1	5.1	52.4
BENZ(A)PYRENE	30.1	25.8	7.13	8.45	14.3	72.4	0	71.9
DIBENZ(A,H)ANTHRACENE	18.6	14.6	7.95	7.52	21.5	45.5	5.4	59.6
BENZO(G,H,I)PERYLENE	9.29	11.8	6.64	6.4	0	43.7	3.6	31.1
INDENOPYRENE	9.43	8.6	4.62	4.72	8.8	46.3	0	49.9
TOTAL PAH	3906	1738	1082	629	55.5	37.7	42	83.9
TOTAL CPAH	[illegible]	274	163	121	2.49	40.5	26	56.9

U = NUMBER IS 1/2 MDL
[+] = AREA COUNTS ARE OVER THE HIGHEST CALIBRATION STANDARD
THE NEW MDL FOR NAPHTHALENE IS BASED ON THE AVERAGE RELATIVE SD AND HIGHEST DILUTION FACTOR USED.

NOVEMBER 9, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	38.6	98	58.9	35.9	0	40.7	38.9	6.99
ACENAPHTHYLENE	16.4	31.6	26.3	7	0	16.8	73.4	57.3
ACENAPHTHENE	112	194	86.9	38.1	0	55.2	56.2	66
FLUORENE	276	15	10.1	2.28	94.57	32.7	77.4	99.2
PHENANTHRENE	853	21.7	32.1	5.06	97.46	0	84.2	99.4
ANTHRACENE	181	14.4	6.73	1.43	92.04	53.3	78.8	99.2
FLUORANTHENE	1166	609	493	256	47.77	19.9	47.5	78
PYRENE	982	327	243	178	66.7	25.7	26.7	81.9
BENZ(A)ANTHRACENE	123	79.4	60.9	30.2	35.45	23.3	50.4	75.4
CHRYSENE	67.7	92.1	76.1	44.5	0	17.4	41.5	34.3
BENZO(B)FLUORANTHENE	4.25	34	26.5	16.3	0	21.8	38.7	0
BENZO(K)FLUORANTHENE	18.5	19.7	14.8	6.88	0	24.9	53.5	62.8
BENZ(A)PYRENE	30.1	28.4	13.4	7.24	5.65	52.8	46	75.9
DIBENZ(A,H)ANTHRACENE	18.6	14.4	10.7	6.65	22.58	25.7	37.9	64.2
BENZO(G,H,I)PERYLENE	9.29	10	8.12	5.49	0	18.8	32.4	40.9
INDENOPYRENE	9.43	8	5.65	3.74	15.16	25.9	36.1	60.3
TOTAL PAH	3906	1593	1177	644.8	59.22	26.7	44.8	83.5
TOTAL CPAH	281	284	216	121	0	23.9	44	56.9

NOVEMBER 16, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	38.6	5.88U	5.88U	5.88U	92.4	0	0	[illegible]
ACENAPHTHYLENE	16.4	2.23U	9.12	2.23U	93.2	0	87.8	93.2
ACENAPHTHENE	112	59.2	6.6	6.6	47.14	89	0	94.1
FLUORENE	276	30.1	8.22	0.874	89.09	73	89.4	99.7
PHENANTHRENE	853	51.5	38.3	3.96	93.96	26	89.7	99.5
ANTHRACENE	181	36.6	4.02	0.625U	79.78	89	92.2	99.8
FLUORANTHENE	1166	629	445	85.3	46.05	29	80.8	92.7
PYRENE	982	431	243	187	56.11	44	23	81
BENZ(A)ANTHRACENE	123	62.8	34.2	2.5U	48.94	46	96.3	99
CHRYSENE	67.7	101	49.5	11.2	0	51	77.4	83.5
BENZO(B)FLUORANTHENE	4.25	35.7	14.6	21	0	59	0	0
BENZO(K)FLUORANTHENE	18.5	11.6	7.33	10.1	37.3	37	0	45.4
BENZ(A)PYRENE	30.1	13.3	4.3	8.78	55.81	68	0	70.8
DIBENZ(A,H)ANTHRACENE	18.6	13.4	8.03	8.91	27.96	40	0	52.1
BENZO(G,H,I)PERYLENE	9.29	9.76	5.83	5.26	0	40	9.78	43.4
INDENOPYRENE	9.43	7.48	4.34	4.42	20.68	42	0	53.1
TOTAL PAH	3906	1496	882	356	61.7	41	59.6	90.9
TOTAL CPAH	281	255	128	71	9.253	50	44.5	74.7

NOVEMBER 22, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	25.1	195	79.2	5.88U	0	59.4	96.3	88.3
ACENAPHTHYLENE	30	25.3	60.8	5.54	15.67	0	90.9	81.5
ACENAPHTHENE	6.6U	145	63.5	6.6U	0	56.2	94.8	0
FLUORENE	378	90.4	27	0.680	76.06	70.1	97.5	99.8
PHENANTHRENE	1377	185	106	9.2	86.56	42.7	91.3	99.3
ANTHRACENE	344	162	11.5	2.12	52.91	92.9	81.6	99.4
FLUORANTHENE	1742+	871	575	169	50	34	70.6	90.3
PYRENE	1526	704	374	167	53.87	46.9	55.3	89.1
BENZ(A)ANTHRACENE	105	93	67.9	17.5	11.43	27	74.2	83.3
CHRYSENE	158	95.9	69.1	25.2	39.3	27.9	63.5	84.1
BENZO(B)FLUORANTHENE	56.3	30.5	21.4	16.3	45.83	29.8	23.8	71
BENZO(K)FLUORANTHENE	29	21.5	11.9	10.6	25.86	44.7	10.9	63.4
BENZ(A)PYRENE	31.8	26.2	7.57	10.7	17.61	71.1	0	66.4
DIBENZ(A,H)ANTHRACENE	25.9	16.3	10.8	7.85	37.07	33.7	27.3	69.7
BENZO(G,H,I)PERYLENE	15	10.6	7.13	5.42	29.33	32.7	24	63.9
INDENOPYRENE	13	8.17	5.2	4.13	37.15	36.4	20.6	68.2
TOTAL PAH	5859	2620	1496	457	55.28	42.9	69.5	92.2
TOTAL CPAH	434	302	201	98	30.41	33.4	51.2	77.4

DECEMBER 2, 1994

COMPOUND	INF	CONCENTRATION R1	CONCENTRATION R2	CONCENTRATION R3	% REDUCTION R1	% REDUCTION R2	% REDUCTION R3	OVERALL % REDUCTION
NAPHTHALENE	25.1	5.88U	5.88U	5.88U	[illegible]	0	0	88.3
ACENAPHTHYLENE	30	17.2	7.9	12.2	42.67	54	-63	57
ACENAPHTHENE	3.3	84.6	45.4	[illegible]	-2463	46	92.7	0
FLUORENE	378	243	28.9	30.9	35.71	88	-6.9	91.8
PHENANTHRENE	1377	499	163	109	63.76	69	28.8	92.1
ANTHRACENE	344	201	8.36	17	41.57	96	-103	95.1
FLUORANTHENE	1742	1426	683	456	18.14	52	33.2	73.8
PYRENE	1526	1216	448	342	20.31	63	23.7	77.6
BENZ(A)ANTHRACENE	105	116	44.5	35.5	-10.47	62	20.2	66.2
CHRYSENE	158	148	84.2	[illegible]	6.33	43	33.5	64.6
BENZO(B)FLUORANTHENE	56.3	52	22.3	17.8	7.64	57	20.2	68.4
BENZO(K)FLUORANTHENE	29	18.4	12.4	10.2	36.55	33	17.7	64.8
BENZ(A)PYRENE	31.8	24.8	5.48	7.63	22.01	78	[illegible]	76
DIBENZ(A,H)ANTHRACENE	25.9	5.2	9.23	2.39	79.92	-78	74.1	90.8
BENZO(G,H,I)PERYLENE	15	13.3	7	5.88	11.33	47	16.3	60.9
INDENOPYRENE	13	11.3	4.65	4.44	13.08	59	4.52	65.8
TOTAL PAH	5859	4079	1567	1114	30.38	62	28.9	81
TOTAL CPAH	434	389	190	140	10.37	51	26.3	67.7

U = NUMBER IS 1/2 MDL
(+) = AREA COUNTS ARE OVER THE HIGHEST CALIBRATION STANDARD
THE NEW MDL FOR NAPHTHALENE IS BASED ON THE AVERAGE RELATIVE SD AND HIGHEST DILUTION FACTOR USED.

DECEMBER 8, 1994

COMPOUND	INF	CONCENTRATION			% REDUCTION			OVERALL % REDUCTION
		R1	R2	R3	R1	R2	R3	
NAPHTHALENE	25.1	5.88	5.88	5.88	88.29	0	0	76.6
ACENAPHTHYLENE	30	13.1	81.3	20	56.33	-521	75.4	33.3
ACENAPHTHENE	3.3	97	13.6	18.4	-2839	86	-35	-458
FLUORENE	378	107	31.8	46.4	71.69	70.3	-46	87.7
PHENANTHRENE	1377	156	113	139	88.67	27.6	-23	89.9
ANTHRACENE	344	7.1	7.74	22.7	97.94	-9.01	-193	93.4
FLUORANTHENE	1742	981	615	513	43.69	37.3	16.6	70.6
PYRENE	1526	863	392	405	43.45	54.6	-3.3	73.5
BENZ(A)ANTHRACENE	105	84	36.1	37.3	20	57	-3.3	64.5
CHRYSENE	158	118	75.7	69.6	25.3	35.8	8.06	55.9
BENZO(B)FLUORANTHENE	56.3	33.9	15.5	19	39.96	54.1	-23	66.3
BENZO(K)FLUORANTHENE	29	10.7	6.5	8.82	63.1	39.3	-36	69.6
BENZ(A)PYRENE	31.8	20.3	4.22	8.52	36.16	79.2	-102	73.[illegible]
DIBENZ(A,H)ANTHRACENE	25.9	11.5	7.15	9.5	55.6	37.8	-33	65.3
BENZO(G,H,I)PERYLENE	15	11.9	6.17	7.73	20.67	48.2	-25	48.5
INDENOPYRENE	13	9.31	4.04	5.18	28.38	56.6	-28	60.3
TOTAL PAH	5859	2527	1413	1333	56.87	44.1	5.66	77.2
TOTAL CPAH	434	300	155	166	30.88	48.3	-7.1	61.8

DECEMBER 15, 1994

COMPOUND	INF	CONCENTRATION			% REDUCTION			OVERALL % REDUCTION
		R1	R2	R3	R1	R2	R3	
NAPHTHALENE	25.1	5.88	5.88	5.88	88.3	0	0	76.6
ACENAPHTHYLENE	30	11.1	43.2	9.65	63	-289	77.7	67.8
ACENAPHTHENE	3.3	99.4	22.3	15.2	-2912	78	31.8	-361
FLUORENE	378	69.6	17.7	27.6	81.6	75	-55	92.7
PHENANTHRENE	1377	26.5	47.4	88.4	98.1	-79	-86	93.6
ANTHRACENE	344	57.5	6.16	13.3	83.3	89	-116	96.1
FLUORANTHENE	1742	848	699	448	51.3	18	35.9	74.3
PYRENE	1526	435	350	217	71.5	20	38	85.8
BENZ(A)ANTHRACENE	105	76.6	67.4	36.9	26.9	25	35.7	64.9
CHRYSENE	158	121	118	69.2	23.4	2.5	41.4	56.2
BENZO(B)FLUORANTHENE	56.3	31.7	28.6	15.3	43.7	6.6	46.3	72.8
BENZO(K)FLUORANTHENE	29	13.2	10.3	8.12	54.5	22	21.2	72
BENZ(A)PYRENE	31.8	17.9	5.47	6.21	43.7	69	-14	80.5
DIBENZ(A,H)ANTHRACENE	25.9	10.2	11.3	8.59	60.6	-11	24	66.8
BENZO(G,H,I)PERYLENE	15	[illegible]	10.5	8.67	18	15	17.4	42.2
INDENOPYRENE	13	8.86	6.11	5.88	31.8	31	3.76	54.8
TOTAL PAH	5859	1842	1437	981	68.6	22	31.7	83.3
TOTAL CPAH	434	292	249	169	32.7	15	36.1	63.4

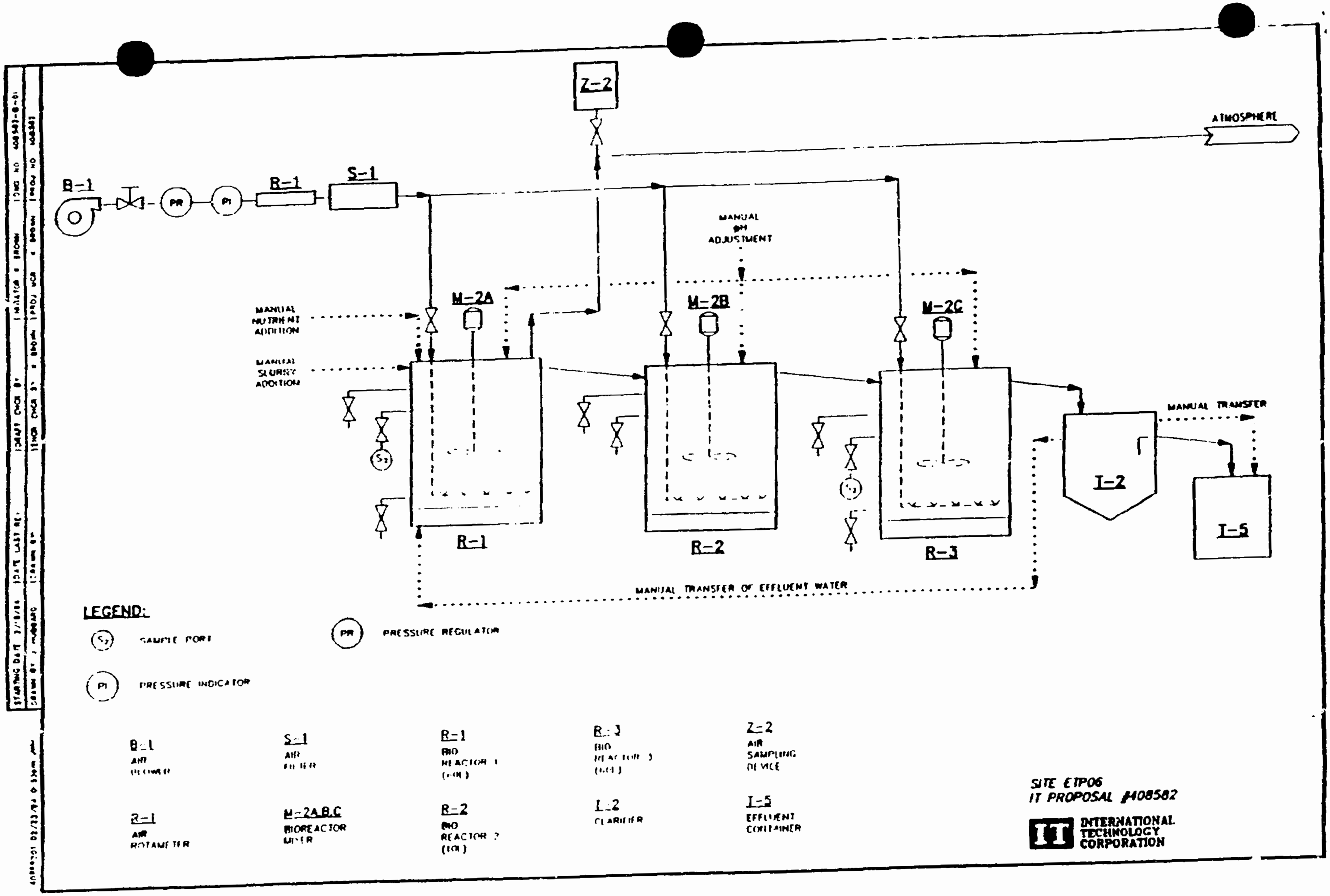
DECEMBER 30, 1994

COMPOUND	INF	CONCENTRATION			% REDUCTION			OVERALL % REDUCTION
		R1	R2	R3	R1	R2	R3	
NAPHTHALENE	25.1	0	0	0	100	0	0	100
ACENAPHTHYLENE	30	5.02	8.05	16.2	83.27	-60.4	-101	46
ACENAPHTHENE	3.3	0	0	0	100	0	0	100
FLUORENE	378	43.3	15.3	16.3	88.54	64.7	-6.5	95.7
PHENANTHRENE	1377	185	70.6	47.7	86.56	61.8	32.4	96.5
ANTHRACENE	344	55.4	6.09	7.43	83.9	89	-22	97.8
FLUORANTHENE	1742	640	378	358	63.26	40.9	5.29	79.4
PYRENE	1526	490	195	194	67.89	60.2	0.51	87.3
BENZ(A)ANTHRACENE	105	50.1	23.5	19.5	52.29	53.1	17	81.4
CHRYSENE	158	84.8	58.8	56.7	46.27	30.7	3.57	64.1
BENZO(B)FLUORANTHENE	56.3	26.6	15.7	14.8	52.75	41	6.1	73.6
BENZO(K)FLUORANTHENE	29	19.4	8.91	10.1	33.1	54.1	-13	65.2
BENZ(A)PYRENE	31.8	18.8	5.17	5.78	40.88	72.5	-12	81.8
DIBENZ(A,H)ANTHRACENE	25.9	17.4	11.7	6.32	32.82	32.8	46	75.6
BENZO(G,H,I)PERYLENE	15	25.7	14.1	6.61	-71.3	45.1	53.1	55.9
INDENOPYRENE	13	1.9	1.61	0.71	85.38	15.3	55.9	94.5
TOTAL PAH	5859	1664	813	760	71.6	51.1	6.52	87
TOTAL CPAH	434	245	139	121	43.55	43.3	12.9	72.1

JANUARY 5, 1995

COMPOUND	INF	CONCENTRATION			% REDUCTION			OVERALL % REDUCTION
		R1	R2	R3	R1	R2	R3	
NAPHTHALENE	25.1	0	0	0	100	0	0	100
ACENAPHTHYLENE	30	7.48	7.76	24.6	75.1	-3.7	-217	18
ACENAPHTHENE	3.3	116	0	0	-3415	100	0	100
FLUORENE	378	52	7.44	9.33	86.2	86	-25	97.5
PHENANTHRENE	1377	299	96.2	61.1	78.3	68	36.5	95.6
ANTHRACENE	344	78.5	4.23	4.99	77.2	95	-18	98.5
FLUORANTHENE	1742	750	339	374	56.9	55	-10	78.5
PYRENE	1526	561	195	205	63.2	65	-5.6	86.5
BENZ(A)ANTHRACENE	105	75.3	21	32.6	28.3	72	-55	69
CHRYSENE	158	84.1	47.9	53.2	46.8	43	-11	66.3
BENZO(B)FLUORANTHENE	56.3	28.5	13	16.2	49.4	54	-25	71.2
BENZO(K)FLUORANTHENE	29	19	7.46	9.91	34.5	61	-33	65.8
BENZ(A)PYRENE	31.8	18.7	2.8	4.46	41.2	85	-59	86
DIBENZ(A,H)ANTHRACENE	25.9	16.3	7.3	9.33	37.1	55	-28	64
BENZO(G,H,I)PERYLENE	15	26.2	11.2	14	-74.7	57	-25	6.67
INDENOPYRENE	13	0.73	0.36	0.41	94.4	51	-14	96.8
TOTAL PAH	5859	2133	761	420	63.6	64	44.8	92.8
TOTAL CPAH	434	269	111	140	38	59	-26	67.7

U = NUMBER 1/2 MDL
(+) = AREA COUNTS ARE OVER THE HIGHEST CALIBRATION STANDARD
THE NEW MDL FOR NAPHTHALENE IS BASED ON THE AVERAGE RELATIVE SD AND HIGHEST DILUTION FACTOR USED.


Z-2
ATMOSPHERE
B-1
PR
PI
R-1
S-1
MANUAL
pH
ADJUSTMENT
MANUAL
NUTRIENT
ADDITION
MANUAL
SLURRY
ADDITION
M-2A
M-2B
M-2C
MANUAL TRANSFER
R-1
R-2
R-3
I-2
I-5
MANUAL TRANSFER OF EFFLUENT WATER
LEGEND:
SAMPLE PORT
PRESSURE REGULATOR
PRESSURE INDICATOR
B-1
AIR
S-1
AIR
R-1
BIO
R-3
BIO
Z-2
AIR
SAMPLING
DEVICE
R-1
AIR
ROTAMETER
M-2A,B,C
BIOREACTOR
R-2
BIO
REACTOR 2
I-2
I-5
EFFLUENT
CONTAINER
SITE ETP06
IT PROPOSAL #408582
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CORPORATION

TECHNICAL REPORT DATA
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16. ABSTRACT Bioslurry treatment of polycyclic aromatic hydrocarbon (PAH)-impacted soils was demonstrated under the Superfund Innovative Technologies Evaluation (SITE)/Emerging Technologies Program (ETD) as an extension of research previously funded by IT Corporation (IT) (Brown and Sanseverino, 1993) and additional investigations supported by the U.S. Environmental Protection Agency (EPA) (Davila et al., 1994).

During the demonstration, IT operated two 60-liter (L) TEKNO Associates bioslurry reactors (Salt Lake City, Utah) and a 10-L fermentation unit in semicontinuous, plug-flow mode for a 2-month period. The first 60-L reactor received fresh feed daily and supplements of salcylate and succinate to enhance PAH degradation.

Effluent from the first reactor was fed to the second 10-L reactor in series, where Fenton's reagent was added to accelerate oxidation of four- to six-ring PAH. The third reactor in series was used as a polishing reactor for the removal of any partially-oxidized contaminants remaining following addition of Fenton's reagent.

During operation, the bioslurry reactor system demonstrated average PAH and carcinogenic PAH (CPAH) removals of 84 and 66 percent, respectively. The reactors will be operated over the next four months to increase the rate and extent of PAH biodegradation. The objective of the demonstration is to illustrate bioslurry treatment of impacted soils and sludges as an effective and economically attractive remedial option.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Bioremediation, bioreactors, slurry, chemical-biological, Fenton's reagent, polycyclic aromatic hydrocarbons (PAHs)		

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