EPA/600/A-92/188

Removal of Creosote from Soil by Bioslurry Reactors

by

Richard P.Lauch and Jonathan G. Herrmann
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

William R. Mahaffey and Alan B. Jones
ECOVA Corporation
Redmond, Washington 98052

Majid Dosani and Judy Hessling
International Technology Corporation
Cincinnati, Ohio 45246

Presented at the AIChE
Spring National Meeting
New Orleans, Louisiana
March 29 - April 2, 1992

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Removal of Creosote from Soil by Bioslurry Reactors

by

Richard P.Lauch and Jonathan G. Herrmann
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

William R. Mahaffey and Alan B. Jones
ECOVA Corporation
Redmond, Washington 98052

Majid Dosani and Judy Hessling
International Technology Corporation
Cincinnati, Ohio 45246

ABSTRACT

Biological slurry reactors were tested for removal of polynuclear aromatic hydrocarbons (PAHs) from creosote contaminated soil. Five bioslurry reactors, operated in parallel, kept the soil aerated, partially suspended and well mixed. The reactors were inoculated with indigenous microbes of the Genus Pseudomonas. Nutrients were added to maintain the optimum ratio of carbon, nitrogen, and phosphorus. Temperature within the reactors was approximately 25°C. The slurry consisted of approximately 30% contaminated soil.

Results of pilot studies showed that approximately 90% of the total PAHs were removed in the first two weeks. Total PAH concentration in the soil was reduced from approximately 10973 mg/kg to 1097 mg/kg. Two and three ring PAHs, such as naphthalene, fluorene, and phenanthrene were approximately 96% removed in the first two weeks and higher ring compounds such as chrysene, benzo-a-pyrene, and benzo(b) fluoranthene were approximately 83% removed in the first two weeks.

INTRODUCTION

This study was performed for the U.S. EPA to supply information as part of the data base on Best Demonstrated Available Technologies (BDAT) for soil remediation. The data base will be used to develop soil standards for Land Disposal Restrictions (LDRs). IT Environmental Programs (ITEP) and ECOVA Corporation, in conjunction with the U.S. EPA's Risk Reduction Engineering Laboratory (RREL), evaluated the performance of pilot-scale bioslurry treatment on creosote contaminated soil. ECOVA performed testing, monitoring, and analysis at the U.S. EPA Test and Evaluation (T&E) facility in Cincinnati, Ohio. IT Analytical Services (ITAS) performed analyses for the critical parameters that will be used in the development of the LDRs.

Biodegradation involves the oxidation of organic compounds by microorganisms. The ultimate goal of biodegradation is to convert organic wastes into biomass and relatively harmless byproducts of microbial metabolism such as carbon dioxide (CO_2), methane (CH_4), water, and inorganic salts. Several biodegradation technologies are available for the remediation of soils and sludges contaminated with organic compounds. These technologies include composting, in situ biodegradation, solid-phase treatment, and slurry-phase treatment. In slurry-phase bioremediation (bioslurry), contaminated soil is excavated and treated in a bioreactor in which the soil is mixed with water to form a slurry. If necessary, nutrients, microorganisms, and surfactants are added to the slurry to enhance the biodegradation process. The pretreatment soil was analyzed for the Contaminated Soil and Debris (CS&D) List of Contaminants. The organic contaminants that were found were identified as the critical contaminants of interest for this study. These contaminants are listed in Table 1. The contaminants are all aromatic compounds. The

volatiles are single ring compounds. The semivolatiles are two to six ring compounds and they are listed in order of increasing rings and increasing molecular weight.

This paper is a summary of the full Onsite Engineering Report (OER)[1] that completely describes the operation, sampling, analyses, and results of the pilot-scale study.

PILOT SCALE TREATMENT SYSTEM & PROCEDURES

Reactors--

Five EIMCO Biolift™ Reactors each with 64 liters capacity, were used for this study (Figure 1). These reactors are made of stainless steel and equipped with agitation, aeration, and temperature controls. Agitation is provided by three mechanical methods. First, a rake mechanism moves the settled material from the bottom of the reactor to the second agitation mechanism, an airlift circulation system that circulates the material to the top of the reactor. The third agitation mechanism is a low-sheer impeller located on the central shaft of the reactor. Aeration is supplied by a set of air diffusers that are attached to the rake arm shaft near the bottom of the reactor. Temperature is controlled by a heat tape system with a digital readout.

The EIMCO Biolift™ Reactor can be sampled in two ways. An opening at the front top of the reactor allows access at the top surface of the liquid. This permits visual inspection of the mechanical actions within the reactor as well as data collection with hand-held instruments that can be inserted into the slurry from the top. Samples are collected from the three sampling ports located along the side of the reactor at three vertical penetrations through the reactor wall. Samples collected from each of the three ports represent

three distinct zones of the slurry. The bottom sampling port provides sample material from within the rake mixing zone where the heaviest particles are likely to be present. The middle sampling port provides sample material from within the most well-mixed zone of optimal grain size. Finally, the top sampling port provides sample material from the finest mixing distribution. Samples of the contaminated material, collected by means of these three ports, are crucial in the evaluation of the mechanical efficiency of the reactor.

Sampling--

The five bioslurry reactors were operated in parallel and composite samples were collected from each reactor at approximately the same time for pre- and post treatment analysis and throughout the study to monitor system operation. Sampling volumes, taken from each port, were proportioned so the composited sample contained 30% solids which was representative of the total slurry. Composite sampling ensured that analyses were performed with a representative sample of the entire slurry column. These composite samples were centrifuged to separate the liquid and solid layers and both layers were analyzed for PAHs. Some analyses (e.g., particle size distribution, plate counts) were performed on samples collected from individual ports to determine potential differences among the three slurry zones.

All parameters in this study were monitored in accordance with the sampling schedule presented in Table 2. Week T_0 corresponds to May 8, 1991, and Week T_{12} corresponds to July 31, 1991. The values in Table 2 refer to the volumes of slurry, soil, or water taken for each analysis at each point in time.

Air sampling was also conducted to characterize the off-gases emitted from the bioreactors during the operations and to determine organic

constituent loss through volatilization. These samples were collected for information only and were not used to evaluate the technology's performance. All five reactors were vented through stainless steel piping into a manifold system before carbon filtration and eventual exhausting to the outside air. The air monitoring was conducted at a point prior to the collection manifold to obtain emissions from two individual reactors.

Two sampling trains were constructed to collect samples of volatile and semivolatile organics. Volatile organics were collected in a SUMMA passivated canister, and semivolatiles were collected in XAD-2 resin tubes. The XAD-2 resin tubes and canisters were installed in the venting systems for the tested reactors. The XAD-2 resin tubes were analyzed for semivolatile organic compounds, and the SUMMA passivated canisters were analyzed for volatile organic compounds.

Soil Particle Size--

A major factor of concern from the initiation of the pilot-scale phase was the particle size of the slurried soil. It was important to decrease the settling velocity of the soil by increasing the viscosity so as to maintain a manageable slurry suspension that could be recirculated within the bioreactors Also, bioavailability of the soil-bound PAH residues as a function of the path length from the particle surface to the innermost recesses was crucial for maintaining a timely and efficient biodegradation rate. The soil was therefore wet-milled by passing it through a ball mill three times before using it to charge the reactors. Particle-sizing samples were taken before and after milling and at Week T_8. These samples were analyzed in accordance with ASTM D422-62. The resulting comminution of the soil particles is shown in Figure 2. As a percentage of the total solids, soil directly from the site

(premilled) had a diameter that was approximately 32% greater then 0.3 mm. After milling (postmilling), the fraction of this soil particle size greater than 0.3 mm was about 8%. Examination of the particle size data (Figure 2) for Week T_8 soil reveals a further phenomenon that must have occurred within the reactors themselves. The percentage of the soil with smaller "particle" size at Week T_8 appears to be greater than that for the pre- or postmilled soil. This indicates a further comminution of the soil particles to a greater fraction of smaller particles within the reactors over time. Comminution increases the viscosity of the slurry and as the number of particles increases, the path length that the PAHs within the soil particles must diffuse to the surface decreases (hence, the mass transfer limitations decrease). This creates greater surface area to which bacteria can attach and adsorb PAHs for metabolism, and probably increases the extraction efficiency of soil-bound PAHs.

RESULTS OF BENCH-SCALE TESTS

Bench-scale tests were performed to determine optimum conditions for the pilot-scale studies. One objective was to determine which combination of nutrients, inoculum, and surfactant would yield the best biodegradation results. These results are shown in Figures 3 and 4. These Figures show that nutrients plus inoculum gave results that were slightly better than nutrients alone and just as good as nutrients, inoculum, and Tween™ (surfactant). Therefore, nutrients plus inoculum were used for the pilot-scale tests. Surfactant was not added because it did not enhance degradation and it would cause additional foaming within the reactors.

A microbial evaluation of the contaminated soil was conducted to determine the size and diversity of bacterial populations and the ability of

these organisms to degrade polycyclic aromatic hydrocarbons. Enrichment culture techniques and selective plating procedures were used to isolate and characterize PAH degrading organisms. Seventeen distinct isolates were identified as having the ability to degrade PAHs. The most prevalent species identified were Pseudomonas fluorescens and Pseudomonas stutzeri. Three of the isolates were chosen for use in an inoculum on the basis of their broad substrate oxidation range: Alcaligenes sp. (CFL-1), P. stutzeri (CPH-1), and P. fluorescens (CP-3). The pilot scale reactors were inoculated with these PAH degrading organisms at a concentration of 9.3×10^7 per gram of soil. Inorganic nutrient data were collected (table below) to determine whether, based upon TOC, the levels and ratio of N and P were sufficient to support optimal microbial activity.

Baseline Inorganic Chemical Analyses

Analysis	Replicates		Means
Calcium	43.3	44.1	43.7
Magnesium	8.33	8.40	8.37
Potassium	2.72	3.15	5.90
Sodium	5.28	5.12	5.20
Ammonia (NH_4-N)	37.5	36.1	36.8
Nitrate (NO_3-N)	0.559*	0.565*	n/a
Ortho-Phosphorous (PO_4-N)	0.559*	0.565*	n/a
Total Kjeldahl Nitrogen	874.	882.	878.
Total Organic Carbon	34000.	37000.	35000.

* Detectable but below the limit of quantitation

The pilot scale reactors were supplemented initially with ammonia-nitrogen and phosphorus at a TOC:N:P ratio of 100:10:1.

RESULTS OF PILOT SCALE TESTS

Soil Sampling--

Table 3 summarizes the results of the baseline (Week T_0) characterization of the soil used in the pilot-scale phase of this study. Fluoranthene, naphthalene, and acenaphthene are the constituents present at the highest concentrations followed by fluorene and benzo(a)anthracene. Total PAH concentration in these soils averaged 10973 mg/kg. The 2- and 3-ring PAHs constitute 5892 mg/kg of the total, and the 4-ring and higher PAHs account for 5081 mg/kg.

Total PAH degradation averaged 93.4 ± 3.2 percent over all five operating reactors during the 12-week study (Tables 4 and 5). After only 2 weeks of slurry-phase treatment, total PAH degradation averaged 89.3 ± 3.9 percent for the five reactors. Average degradation rates (mg/kg/wk) for 2- and 3-ring PAHs were appreciably higher at two weeks (95.9 ± 1.8%) than they were for 4 and higher ring PAHs (81.6 ± 3.9%). The more rapid degradation of the lower molecular-weight PAHs reflects the preference of the bacterial populations for these PAHs over the higher molecular-weight PAHs. The final concentrations at week T_{12} averaged 653.5 ± 178.9 mg/kg for total PAHs, 152.1 ± 81.9 m/l for 2- and 3-ring PAHs, and 501.4 ± 103.5 mg/kg for 4- and higher ring PAHs.

As shown in Figures 5, 6, and 7, the degradation of the different PAHs varied appreciably during the course of the study, reflecting changes in the reactor environments. Figure 5 shows that a very large amount of the total PAH was degraded after only 2 weeks; however, the apparent level of soil-bound PAH residues began to rise slightly for some reactors through Week T_6, to decrease through Week T_9, to rise again through Week T_{11}, and finally, to

decrease through Week T_{12}. It is important to note that these data necessarily reflect not only the nominal concentrations of soil-bound PAHs, but also the extraction efficiency of the analytical method. Apparent increases in the levels of soil-bound PAHs probably reflect an increased PAH extraction efficiency rather than the unlikely production of soil-bound PAHs during the study.

A comparison of Figures 6 and 7 shows almost complete degradation of the 2- and 3-ring PAHs, whereas, degradation of 4- through 6-ring PAHs was less complete. Also, there was less variation between reactors for concentrations of 2- and 3-ring PAHs (Figure 6) and more variation between reactors for concentrations of 4- to 6-ring PAHs (Figure 7).

Immediately after sampling at Week T_9, Reactors 2 and 4 were reinoculated with fresh bacterial populations, and Reactors 5 and 6 were both reinoculated and amended with the surfactant Tween 80. Reactor 1 was not amended in any way. At Week T_{11}, levels of total PAHs in unamended Reactor 1 and Reactors 2 and 4 increased dramatically; whereas total levels in reinoculated and surfactant-amended Reactors 5 and 6 essentially did not change (Figures 5, 6, and 7). By Week T_{12} the total levels in Reactors 1, 2, and 4 had again declined, but total levels in Reactors 5 and 6 increased.

Anomalies in the PAH degradation rates occurred in reactor 4 for 4 and higher ring PAHs at Weeks T_1 and T_6 (Figure 7). For these times, the total PAH level was appreciably higher than for the other reactors. Among the individual PAHs, levels of acenaphthene were clearly higher than those of other 2- and 3-ring PAHs at Weeks T_4 and T_{11} (Figure 8). The anomaly may be related to widely varying levels of acenaphthene among the five reactors which was observed from the standard deviation data for acenaphthene.

A final anomaly was the surge in both the mean levels and standard deviations for the 4 and higher ring PAHs at Week T_1 (Figure 9). This was not exhibited by the 2- and 3-ring PAHs for that time point.

These anomalies are indicative of several problems and events. Clearly, further comminution of the soil particles accounted for a portion of the rise in soil-bound PAH residues by reducing the resistance to mass transfer. This, in turn, allowed a higher extraction efficiency in the analytical method and, therefore, higher apparent concentrations. Although acenaphthene is an identifiable compound in an analytical method, it is difficult to quantitate accurately. It has the lowest molar extinction coefficient of all the PAHs in ECOVA's analytical method and is therefore the PAH most subject to errors in quantitation. After Week T_2, PAH residue levels were low enough that a small error in the area assessed for acenaphthene could have an enormous effect on the total levels of PAH residues.

Air Sampling--

Air sampling for semivolatile, volatile, and total organics was conducted during the first 9 weeks of treatment. Total hydrocarbon (THC) was determined as methane. This sampling was conducted continuously at the main exhaust line for the first 5 days of operation. Figure 10 is a graph of the THC data during the 5 days of continuous monitor operation. The THC data compare well with the other organic data, showing high emissions the first 2 days of process operation, followed by a steady decline and close to baseline recordings by the fifth day of operation.

Semivolatile organic emissions were sampled on Reactors 1 and 2 for the first 4 days of operation. The main exhaust line was sampled for the remainder of the operation. Table 6 lists the results of semivolatile organic

emissions that were detected during the study. Semivolatile organic emissions (naphthalene, 2-methylnaphthalene, acenaphthylene, acenaphthene, dibenzofuran, fluorene, phenanthrene, and anthracene) were detectable during the first 4 days of sampling. Beginning the fifth day of operation, very small quantities (at or below detection) of semivolatilies were found. Note that the semivolatiles were all lower molecular weight 2-and-3 ring compounds. These lower ring compounds were more readily diffused into solution and volatilized. The highest concentrations was for naphthalene. These lower ring compounds are easily degraded and Table 6 shows that insignificant concentrations of napthhalene remained after the second day. All of the semivolatiles were below the detection limit after 6 days of operation.

Volatile organic sampling was conducted simultaneously with semivolatile organic sampling on Reactors 1 and 2 for the first 4 days of operation. The main exhaust line was sampled for the remainder of the program. Table 7 lists the volatile organic concentrations. The table shows that relatively low concentrations of volatiles (mostly benzene, toluene, ethylbenzene, xylenes, and styrene) were detected during the first few days of operation and then dropped off to concentrations that were near or below the detection limits. This is expected because the volatiles are all lower molecule weight single ring compounds that are very easy to degrade.

Very low to zero concentrations of volatiles were detected in the pretreatment soil and the reason they were detected in the off-gas is probably because they were products of degradation of the higher ring compounds.

CONCLUSIONS

Bench tests were performed first to determine the optimum conditions for the pilot scale tests. Results of the bench tests showed that inoculum plus nutrients should be added for the pilot tests. Surfactant addition did not enhance degradation and it would cause additional foaming. During the bench tests isolates of Pseudomonas (P. fluorescens, P. stutzeri and Alcaligenes sp.) were distinguished as having the best ability to degrade creosote and high concentrations of these indigenous organisms were inoculated into the pilot reactors. During the bench test a TOC:N:P ratio of 100:10:1 was determined. Other minerals,including potassium, magnesium, calcium and iron were added to the pilot reactors.

After two weeks of pilot test treatment, total PAH degradation averaged 89.3%. Degradation of 2- and 3-ring PAHs averaged 95.9% and degradation of 4- and higher-ring PAHs averaged 81.6%. After two weeks of pilot operation, total 2- and 3-ring PAHs were reduced from an average concentration of 5892 mg/kg to 227 mg/kg and total 4- and higher-ring PAHs were reduced from an average concentration of 5081 mg/kg to 870 mg/kg.

There was considerable variation between reactors for individual and total PAH concentrations. This variation was higher for higher ring compounds.

Some PAH concentrations (especially for higher ring compounds) appeared to increase from one week to the following week. This is probably do to increased extraction efficiency with time because of additional soil comminution and the longer time required for the heavier higher ring compounds to be worked out of the soil. Very low concentrations of PAHs were detected in the water phase because the organisms are able to degrade PAHs very quickly in

this phase.

During the air sampling, low concentrations of volatiles (toluene, benzene, xylene) and low concentrations of lower 2-and 3- ring semivolatiles (napthalene, fluorene, phenanthrene) were detected for the first few days of operation. All of these contaminants diminished to concentrations that were below the detection limit after 5 days of operation. The lower molecular weight volatile compounds were probably products of degradation of the higher molecular weight compounds because the pretreatment data showed that most of the volatiles were below the detection limit.

ACKNOWLEDGMENT

The authors acknowledge Mr. Michael Smith from IT Corp., Mr. Ernie Grossman, Mr. Leo Fichter, and Mr. Charles Euth all from the U.S. EPA, and Ms. Madonna Brinkmann and Mr. Christopher Krauskopf from ECOVA Corp. for their technical contributions to the project.

DISCLAIMER

This paper has been reviewed in accordance with the U.S. Environmental Progection Agency's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commerical products does not constitute endorsement or recommendation for use.

REFERENCES

1. IT Environmental Programs, Inc., Onsite Engineering Report of the Slurry-Phase Biological Reactor for Pilot-Scale Testing on Contaminated Soil. Volumes I and II. EPA Contract No. 68-C9-0036, WA No. 69, U.S. EPA Cincinnati, Ohio, In Preparation.

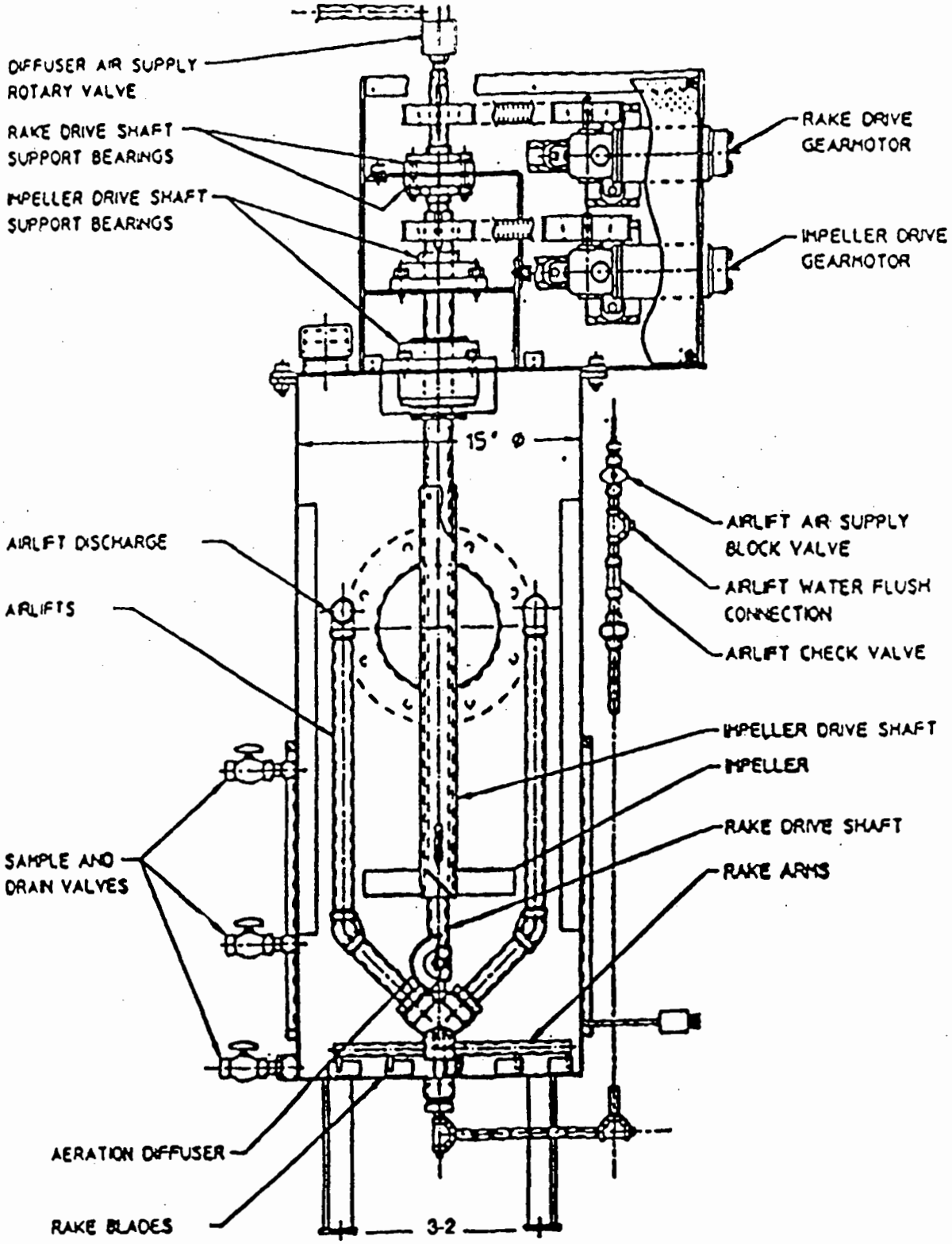

Figure 1. EIMCO BIOLIFT™ REACTOR.

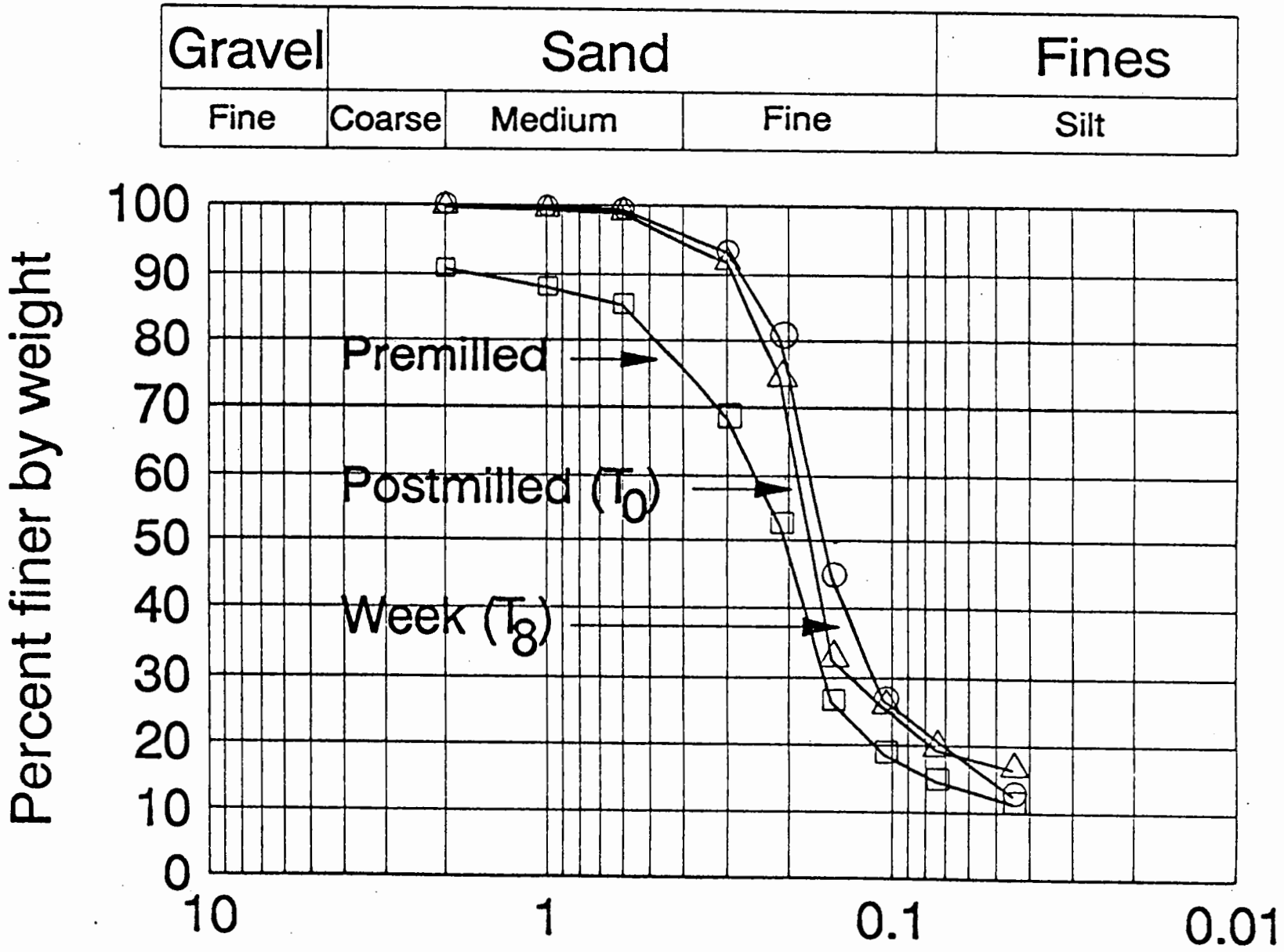
Gravel
Sand
Fines
Fine
Coarse
Medium
Fine
Silt
100
90
80
70
60
50
40
30
20
10
0
Percent finer by weight
Premilled
Postmilled (T_0)
Week (T_8)
10
1
0.1
0.01
GRAIN DIAMETER (millimeters)

Figure 2.

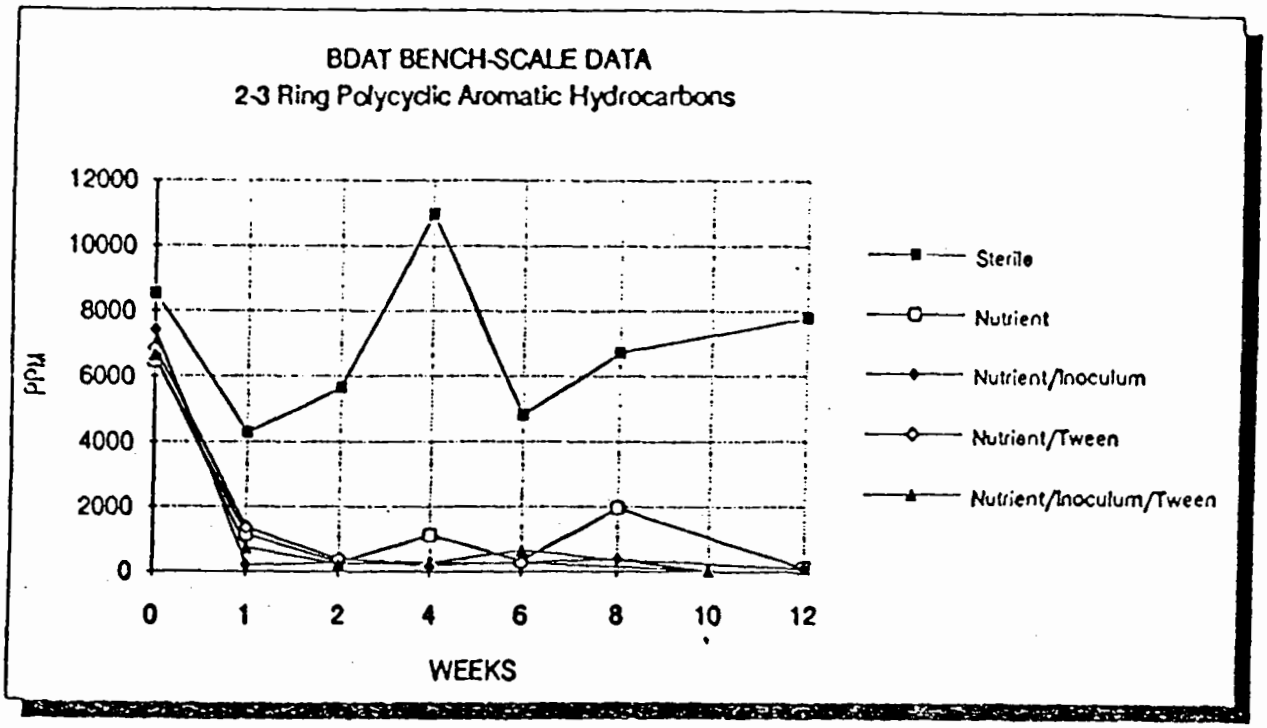

Figure 3.

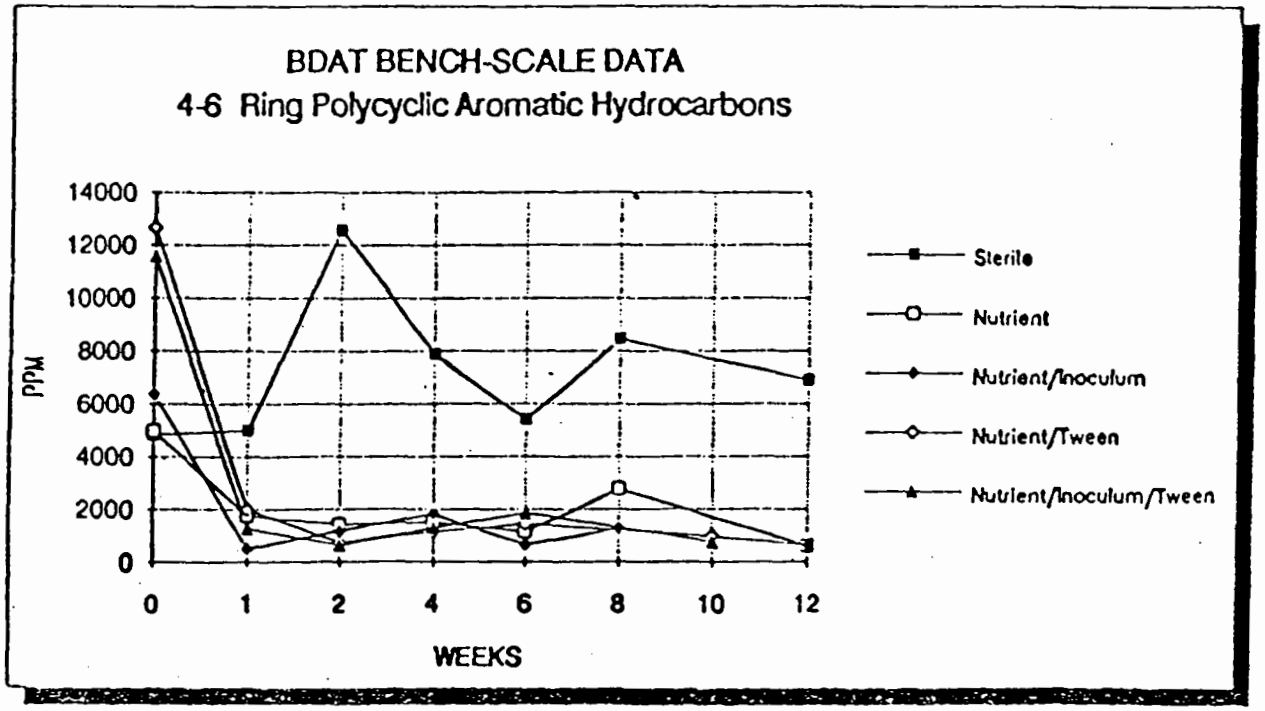

Figure 4.

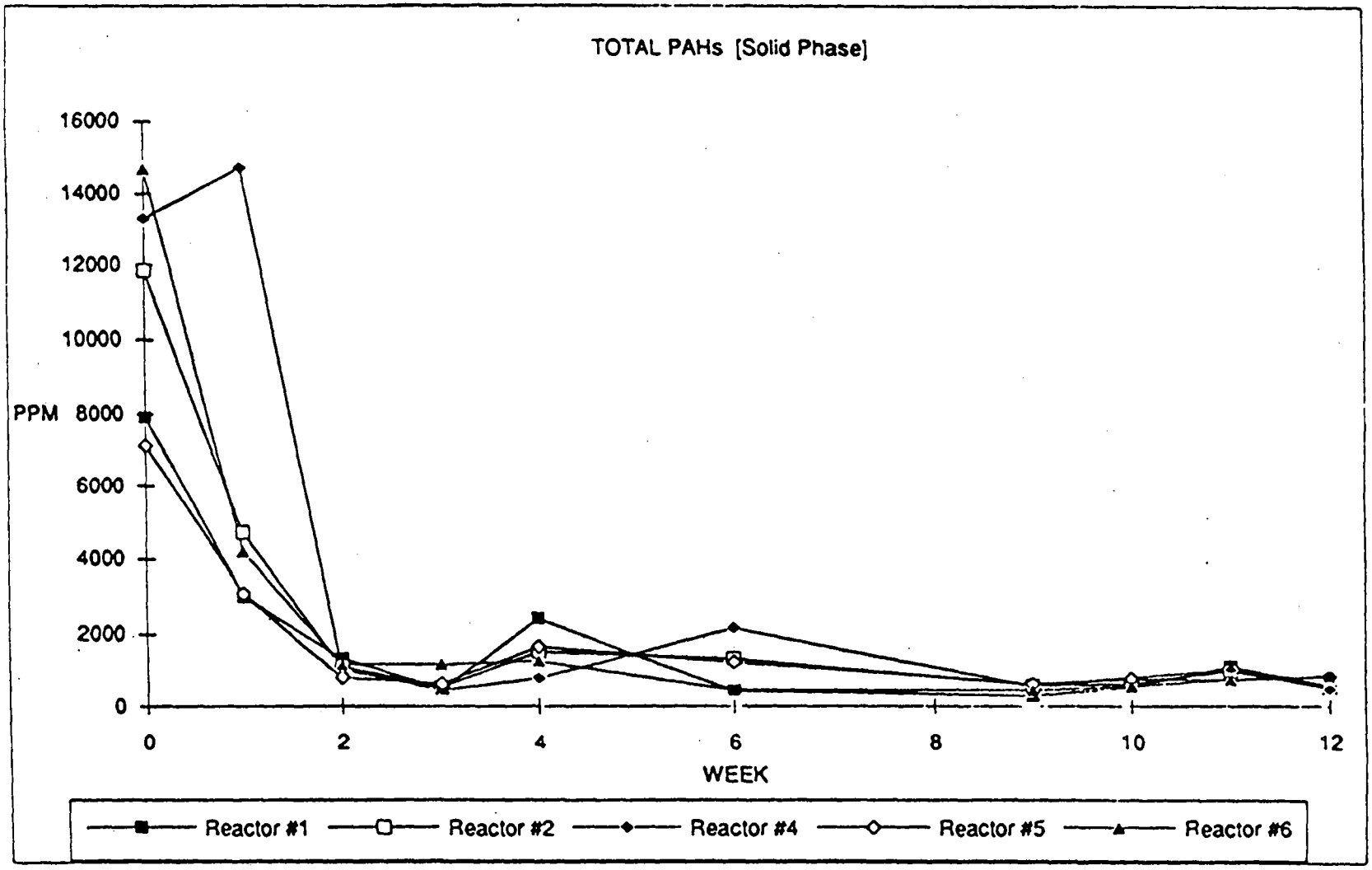

Figure 5. Total PAH soil residue levels.

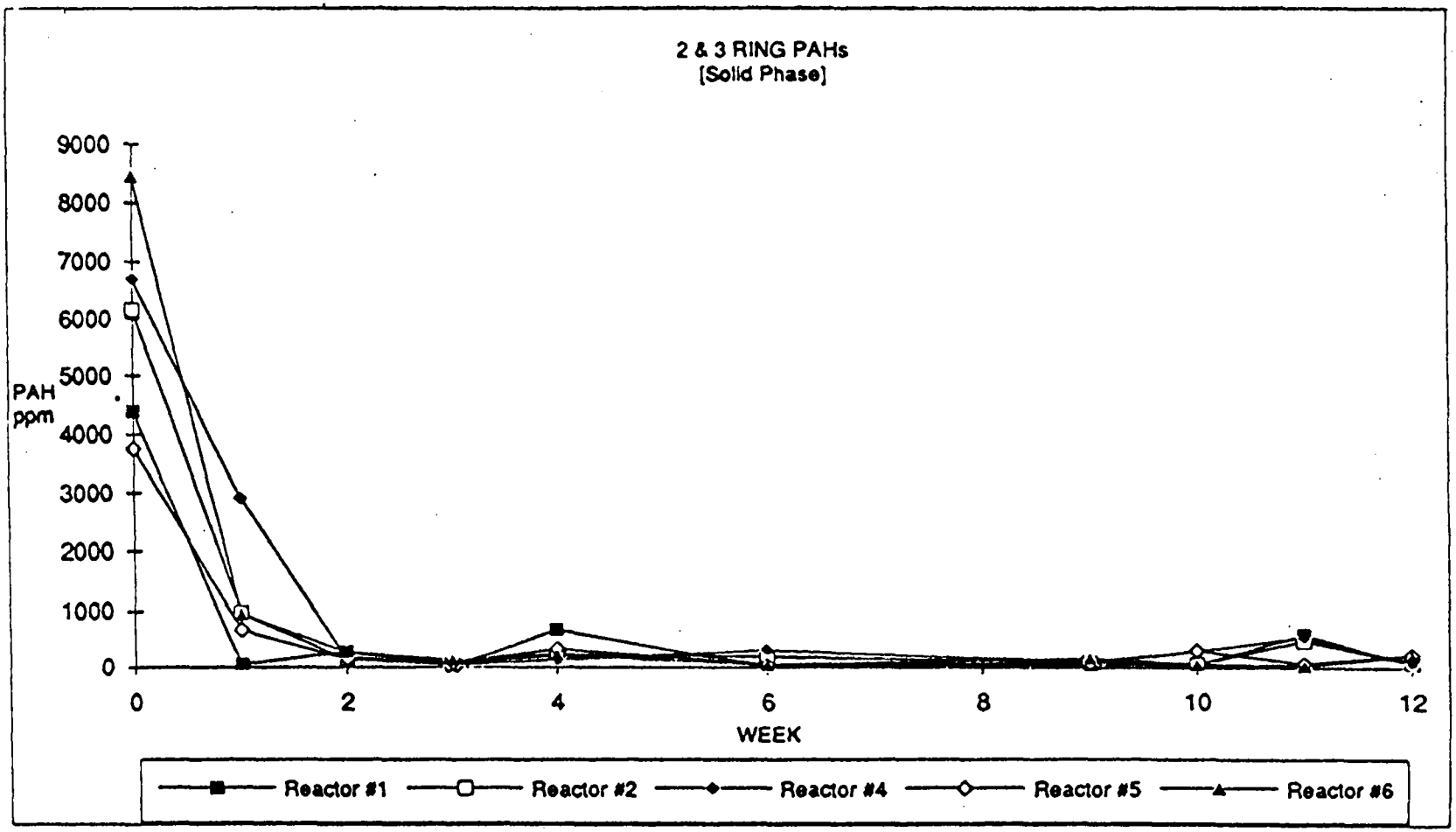

Figure 6. Two- to three-ring individual mean PAH levels.

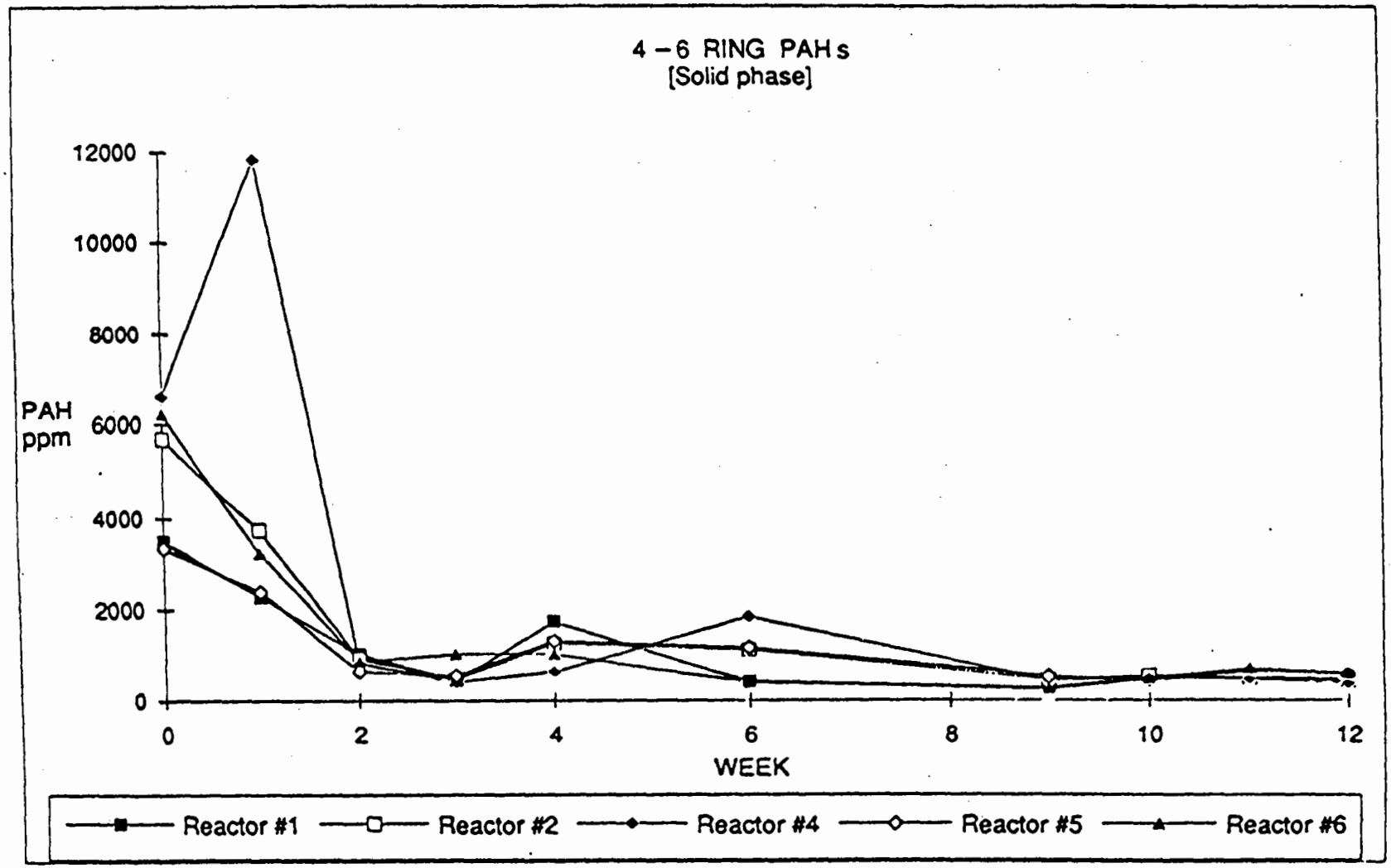

Figure 7. Four- to six-ring PAH soil residue levels.

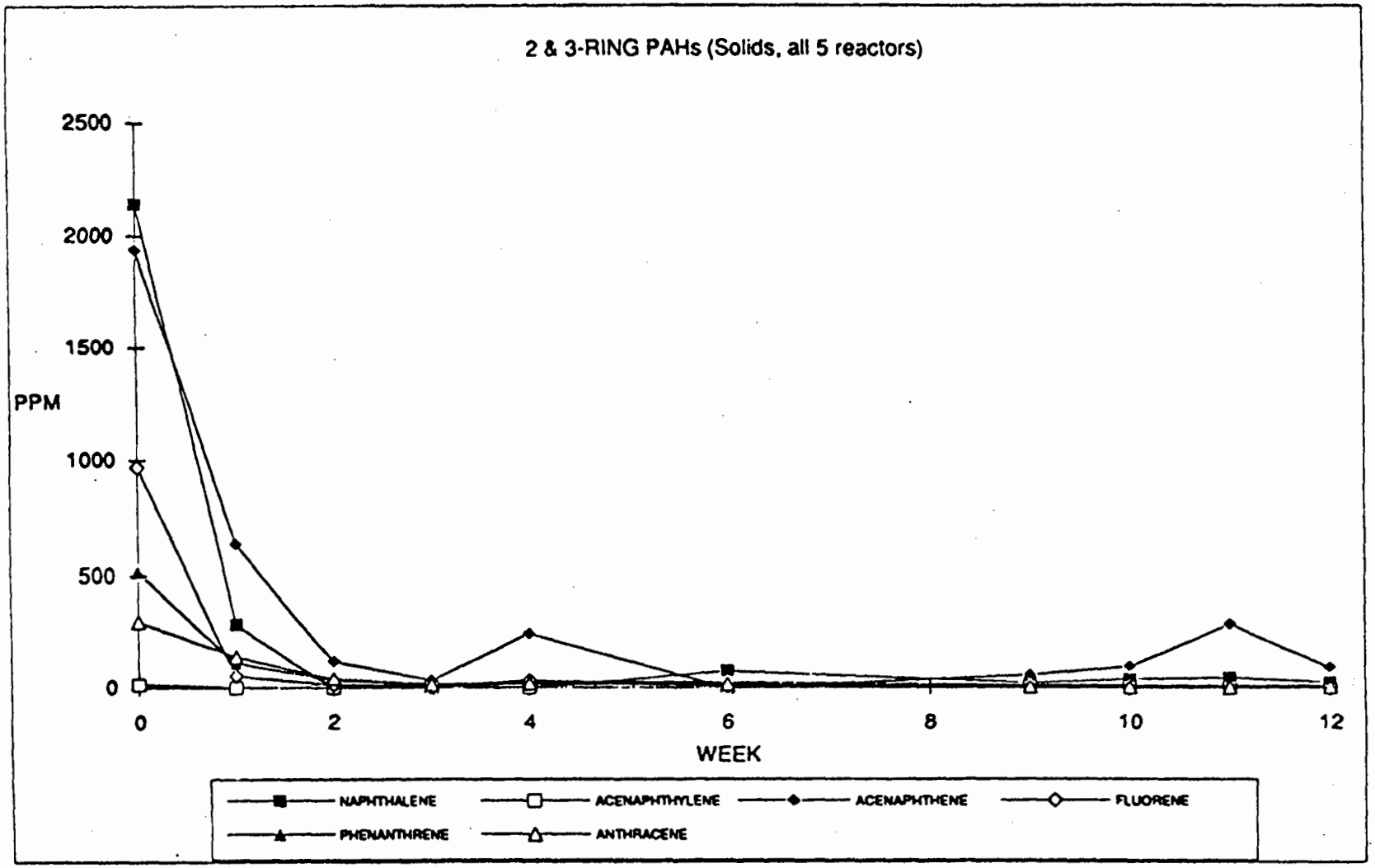

Figure 8. Two- to three-ring individual mean PAH levels.

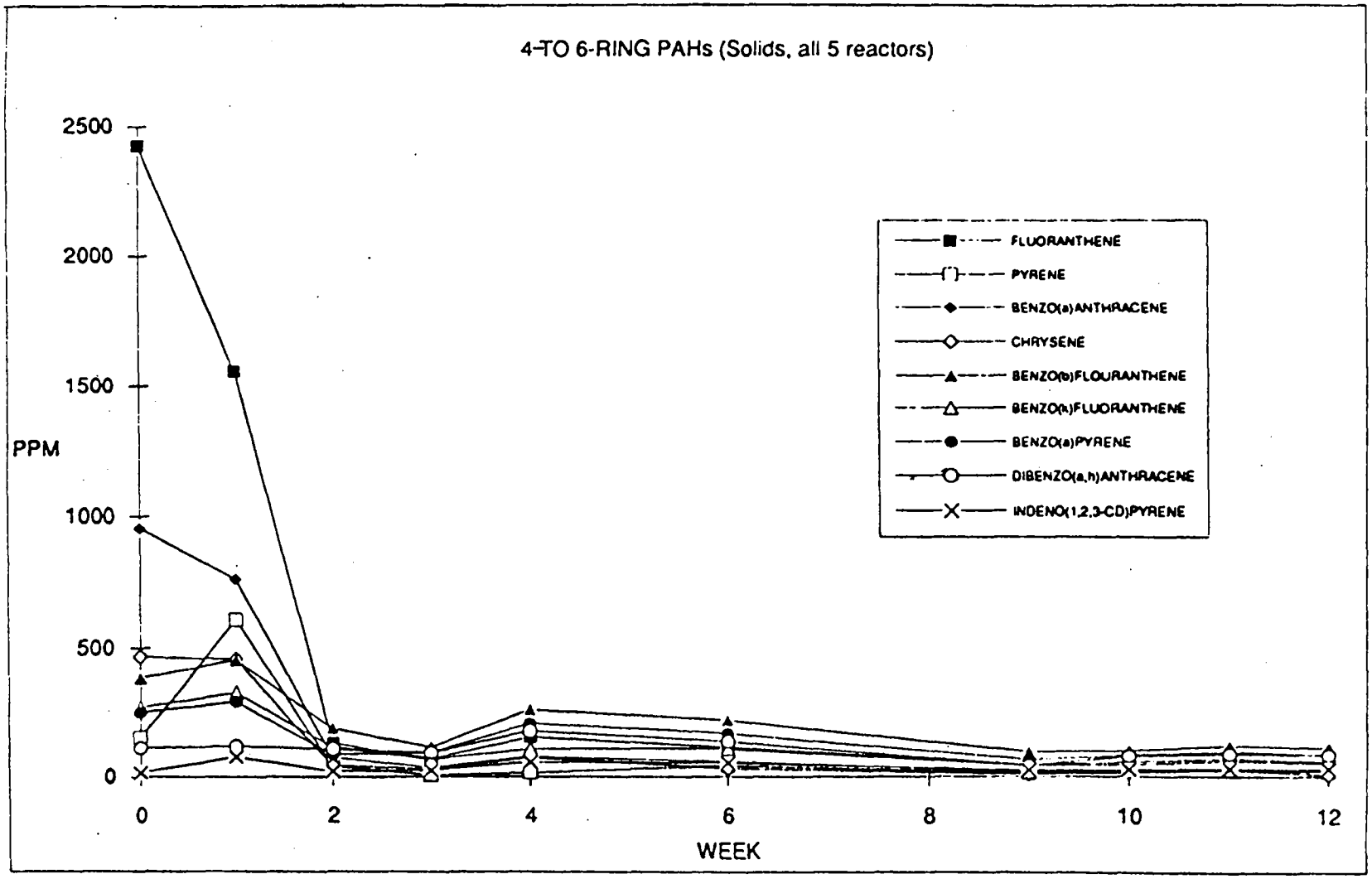

Figure 9. Four- to six-ring individual mean PAH levels

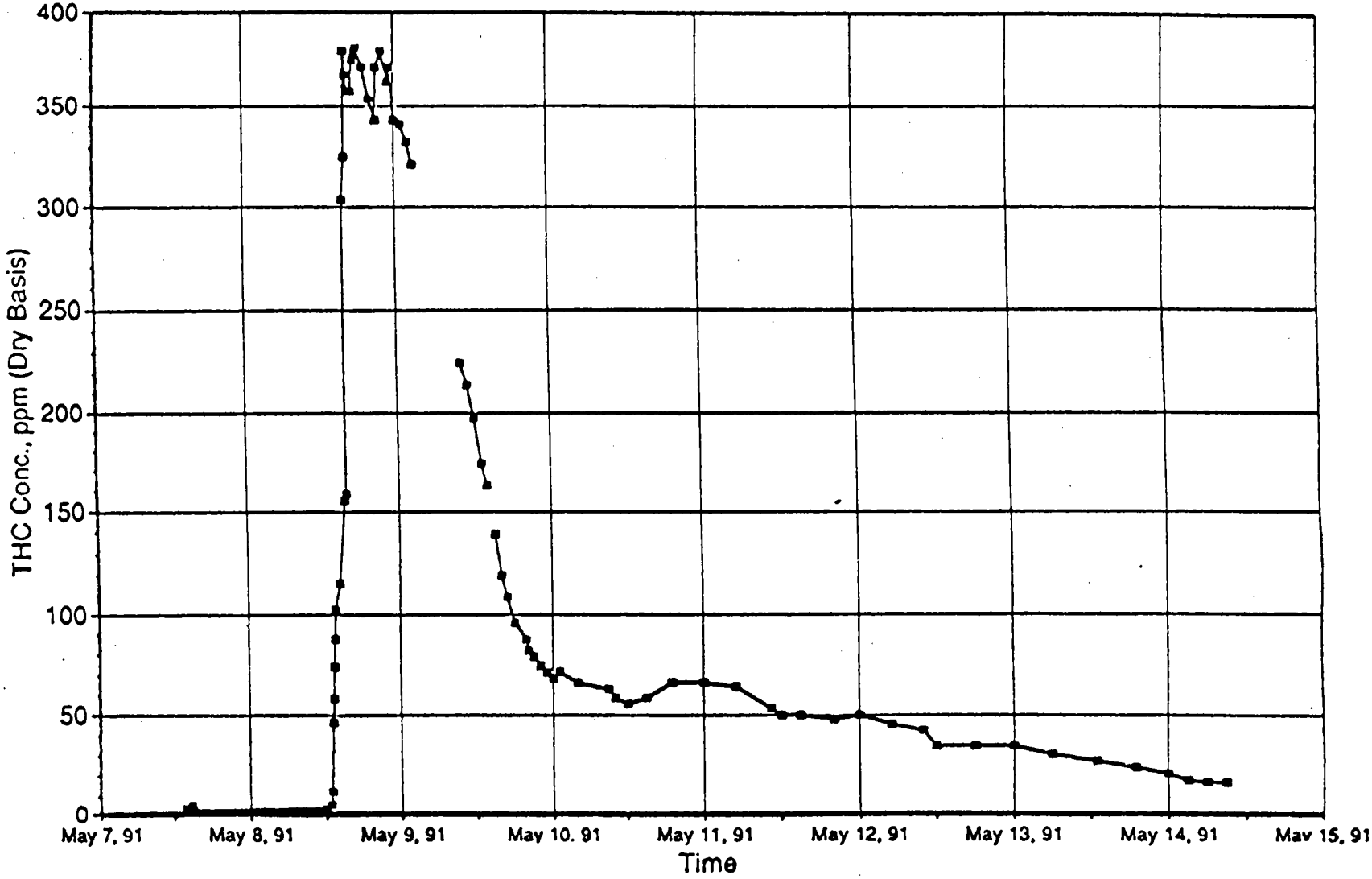

Figure 10. THC emission data.

Table 1. Critical Contaminants of Interest

Semivolatile Organics	Volatile Organics
Naphthalene	2-Butanone
Acenaphthylene	Benzene
Acenaphthene	Toluene
Fluorene	Ethylbenzene
Phenanthrene	Styrene
Anthracene	Total Xylenes
Fluoranthene	
Pyrene	
Benzo(a)anthracene	
Chrysene	
Benzo(b)fluoranthene	
Benzo(k)fluoranthene	
Benzo(a) pyrene	
Dibenzo(a,h)anthracene	
Ideno(1,2,3-cd)pyrene	

TABLE 2. REACTOR MONITORING SCHEDULE

Analysis	Sample Volume Per Reactor, Slurry-Phase Pilot Test — Week 0	1	2	3	4	5	6	7	8	9	10	11	12
Semivolatile organics (mL)	2000									2000			2000
PAH/HPLC-Water/Soil (mL)	60	60	60	60	60		60			60	60	240	60
O&G/TPH (mL)	100		100	100	100		100			100	100	100	100
TOC (mL)	100		100		100		100			100	100		100
Nutrients (mL)	40		40		40		40			40	40		40
Ammonia (mL)	10		10		10		10			10	10		10
Total heterotrophs (mL)	10	10	10	10	10		20			10	10		10
PAH degraders (mL)	10		10		10		20			10	10	10	10
Microtox (mL)	20		20		20					20	20		20
TS (mL)	60	60	60	60	60		60			60	60	60	60
TSS & TVSS (mL)	250		150	70	100		100			100	100	100	100
Dissolved oxygen	DR[a]	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR
Temperature	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR
pH	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR	DR
Total volume (mL)	2660	130	560	300	510	0	510	0	0	2510	510	510	2510
IT vol. per week (mL)	2160		100	100	100		100			2100	100	100	2100
Ecova vol. per week (mL)	250	70	250	70	250		250			250	250	250	250
Ecova (T&E facility) (mL)	250	60	210	130	160		160			160	160	160	160
Total volume (L)	64	64	64	64	64	64	64	64	64	64	64	64	64
Sample % solids	30	30	30	30	30	30	30	30	30	30	30	30	30.0
Slurry wt. removed (mL)	296	51	218	78	199	0	199	0	0	199	199	199	199
Soil wt. removed (g)	228	39	168	60	153	0	153	0	0	153	153	153	153
Slurry % solids remaining	29.73	29.68	29.48	29.41	29.22	29.22	29.04	29.04	29.04	28.85	28.67	28.49	28.30

[a]DR = Measured using a direct-reading instrument.

TABLE 3. BASELINE SOIL PAH CONCENTRATIONS

AVERAGE OF 5 REACTORS (WEEK T_0)

PAH	MEAN (5) mg/kg	Std. Dev. mg/kg
Naphthalene	2143.3	710
Acenaphthylene	17.4	7.6
Acenaphthene	1937.1	1016.8
Fluorene	967.8	288.4
Phenanthrene	518.9	12.1
Anthracene	307.0	34.7
TOTAL 2-& 3-ring PAHs	5891.5	
Fluoranthene	2428.7	732.6
Pyrene	161.1	51.2
Benzo(a)anthracene	957.2	284.8
Chrysene	468.1	129.6
Benzo(b)fluoranthene	389.4	112.7
Benzo(k)fluoranthene	279.6	83.1
Benzo(a,)pyrene	260.2	75.4
DiBenzo(a,h)anthracene	119.9	94.1
Indeno(1,2,3-cd)pyrene	17.2	4.8
TOTAL 4-6 ring PAHs	5081.4	
TOTAL PAHs	10972.9	

TABLE 4. TOTAL, 2-3 RING AND 4-6 RING PAH LEVELS (SOLID PHASES)

BDAT Pilot-Scale Polyaromatic Hydrocarbon Levels										
	Week									
	0	1	2	3	4	6	9	10	11	12
	2 – 3 Ring PAHs									
Reactor 1	4380.59	64.26	312.25	37.55	682.82	31.66	63.09	56.66	600.95	78.42
Reactor 2	6158.29	970.17	160.72	55.66	247.76	212.93	116.37	72.96	492.38	95.29
Reactor 4	6699.04	2904.45	189.59	41.48	150.26	333.88	124.09	307.52	551.41	104.97
Reactor 5	3758.81	683.53	168.53	85.05	359.75	69.2	85.04	317.95	80.12	249.72
Reactor 6	8460.94	948.59	304.9	144.92	241.23	51.62	183.71	66.04	42.44	232.32
	4 – 6 Ring PAHs									
Reactor 1	3526.33	2273.11	1043.28	445.29	1734.92	417.93	238.82	470.94	524.9	488.13
Reactor 2	5696.53	3754.18	942.26	480.62	1278.03	1132.16	463.94	552.36	503.44	432.39
Reactor 4	6603.17	11827.2	840.23	409.88	645.52	1830.56	449.57	503.68	481	375.2
Reactor 5	3360.94	2397.9	644.33	559.17	1318.67	1178.01	549.64	449.14	654.13	593.56
Reactor 6	6220.41	3259.33	877.3	1035.39	1035.92	402.25	274.42	498.19	715.29	617.6
	Total PAHs									
Reactor 1	7906.92	3015.94	1355.53	482.84	2417.74	449.59	301.91	527.6	1125.85	566.55
Reactor 2	11854.8	4724.35	1102.98	536.28	1525.79	1345.09	580.31	625.32	995.82	527.68
Reactor 4	13302.21	14731.62	1029.82	451.36	795.78	2164.44	573.66	811.2	1032.41	480.17
Reactor 5	7119.75	3081.43	812.86	644.22	1678.42	1247.21	634.68	767.09	734.25	843.28
Reactor 6	14681.4	4207.92	1182.2	1180.31	1277.15	453.87	458.13	564.23	757.73	849.92

TABLE 5. TOTAL, 2-3 RING AND 4-6 RING PAH DEGRADATION RATES (SOLID PHASES)

BDAT Pilot-Scale Polyaromatic Hydrocarbon Levels									
	Week								
	1	2	3	4	6	9	10	11	12
	2 – 3 Ring PAH Degradation Rate, % Degradation								
Reactor 1	98.53	92.87	99.14	84.41	99.28	98.56	98.71	86.28	98.21
Reactor 2	84.25	97.39	99.10	95.98	96.54	98.11	98.82	92.00	98.45
Reactor 4	56.64	97.17	99.38	97.76	95.02	98.15	95.41	91.77	98.43
Reactor 5	81.82	95.52	97.74	90.43	98.16	97.74	91.54	97.87	93.36
Reactor 6	88.79	96.40	98.29	97.15	99.39	97.83	99.22	99.50	97.25
	4 – 6 Ring PAH Degradation Rate, % Degradation								
Reactor 1	35.54	70.41	87.37	50.80	88.15	93.23	86.65	85.11	86.16
Reactor 2	34.10	83.46	91.56	77.56	80.13	91.86	90.30	91.16	92.41
Reactor 4	-79.11	87.28	93.79	90.22	72.28	93.19	92.37	92.72	94.32
Reactor 5	28.65	80.83	83.36	60.76	64.95	83.65	86.64	80.54	82.34
Reactor 6	47.60	85.90	83.35	83.35	93.53	95.59	91.99	88.50	90.07
	Total PAH Degradation Rate, % Degradation								
Reactor 1	61.86	82.86	93.89	69.42	94.31	96.18	93.33	85.76	92.83
Reactor 2	60.15	90.70	95.48	87.13	88.65	95.10	94.73	91.60	95.55
Reactor 4	-10.75	92.26	96.61	94.02	83.73	95.69	93.90	92.24	96.39
Reactor 5	56.72	88.58	90.95	76.43	82.48	91.09	89.23	89.69	88.16
Reactor 6	71.34	91.95	91.96	91.30	96.91	96.88	96.16	94.84	94.21

TABLE 6. SEMIVOLATILE ORGANIC EMISSIONS DATA
(µg/sample)

Compound	SAMPLE NO. - DAY										
	XAD1-1	XAD2-1	XAD1-2	XAD2-2	XAD1-3	XAD2-3	XAD2-4	XAD1-5	XAD2-5	XAD1-6	XAD2-6
Naphthalene	8650	8600	98	247	10	20	9	10	10	10	10
2-methylnaphthalene	1500	1559	200	376	10	10	10	10	10	10	10
Acenaphthylene	78	70	55	69	35	64	62	10	10	10	10
Acenaphthene	330	390	360	420	390	500	703	15	15	10	13
Dibenzofuran	170	180	160	160	140	200	230	10	10	10	10
Fluorene	120	110	110	120	140	170	220	10	2	10	10
Phenanthrene	31	33	41	54	41	69	69	10	10	10	10
Anthracene	6	7	8	10	8	13	23	10	10	10	10

TABLE 7. VOLATILE ORGANIC EMISSIONS DATA (ppb)

	SAMPLE NO. - DAY									
Compound	1-1	2-1	1-2	2-2	1-3	2-3	1-4	1-5	2-5	DL
Benzene	55	45	1.5	2.3	1.8	2.4	1.2	0.79	0.82	0.4
Toluene	240	230	3.2	4.6	5.6	8.0	3.2	2.6	2.2	0.4
Ethylbenzene	150	160	2.2	3.4	0.86	1.5	0.91	0.63	0.5	0.4
m- and/or p-Xylene	720	800	12.0	17.0	0.32	7.3	3.0	1.9	1.4	0.4
o-Xylene	300	320	7.7	14.0	1.4	3.5	1.4	0.7	0.53	0.4
Styrene	44	81	1.8	3.6		0.85	0.45	0.42		0.4

DL = Detection Limit

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before compl

1. REPORT NO.	2.	3
EPA/600/A-92/188		

4. TITLE AND SUBTITLE
Removal of Creosote from Soil by Bioslurry Reactors

5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
R. P. Lauch, J. G. Herrmann, W. R. Mahaffey,
A. B. Jones, M. Dossani, and J. Hessling

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
IT Environmental Programs, Inc.
Cincinnati, OH 45246
ECOVA Corporation
Redmond, Washington 98052

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-C9-0036

12. SPONSORING AGENCY NAME AND ADDRESS
Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

13. TYPE OF REPORT AND PERIOD COVERED
Published Paper

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES Project Officer = Richard P. Lauch (513) 569-7237
Presented at AICHE Spring National Meeting, New Orleans, LA, 3/29-4/2/92

16. ABSTRACT

Biological slurry reactors were tested for removal of polynuclear aromatic hydrocarbons (PAHs) from creosote contaminated soil. Five bioslurry reactors, operated in parallel, kept the soil aerated, partially suspended and well mixed. The reactors were inoculated with indigenous microbes of the Genus Pseudomonas. Nutrients were added to maintain the optimum ratio of carbon, nitrogen, and phosphorus. Temperature within the reactors was approximately 25°C. The slurry consisted of approximately 30% contaminated soil.

Results of pilot studies showed that approximately 90% of the total PAHs were removed in the first two weeks. Total PAH concentration in the soil was reduced from approximately 10973 mg/kg to 1097 mg/kg. Two and three ring PAHs, such as naphthalene, fluorene, and phenanthrene were approximately 96% removed in the first two weeks and higher ring compounds such as chrysene, benzo-a-pyrene, and benzo(b) fluoranthene were approximately 83% removed in the first two weeks.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Soils, contaminants, aromatic polycyclic hydrocarbons, treatment, biological, degradation	Soil remediation, bioslurry reactors, creosote contamination, polynuclear aromatic hydrocarbons	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to public	Unclassified	31
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	