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Biodegradation of a dilute waste oil emulsion applied to soil*

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SUMMARY

The use of land treatment for disposal of a dilute waste oil emulsion generated by an aluminum rolling industry was investigated. Major components of the waste, identified by gas chromatography and mass spectrometry, were linear and branched (C_{12}–C_{25}) and fatty acid emulsifiers (primarily isomers of oleic acid). Hexadecane and pristane were readily biodegraded in vitro when added to soil collected from the waste disposal site. Hydrocarbons and fatty acids extracted from the waste were similarly biodegraded, however, the rate of decomposition may have depended on the history of waste applications to soil collected from the land treatment site. The apparent half-life of resolvable waste hydrocarbons and fatty acids was 9.5 days in soil which had received waste applications averaging 25.4 l m^{-2} wk^{-1}. In contrast, soil receiving either 50.8 l m^{-2} wk^{-1} or no waste application during summer 1987 apparent exhibited half-lives of 28.1 and 60.3 days, respectively. Waste components were restricted to the upper 48 cm of the soil cores collected from the disposal site. Core samples also provided evidence for biodegradation of hydrocarbons and fatty acids, as well as an accumulation of other compounds not readily resolvable by gas chromatography

INTRODUCTION

Many industries produce oily wastes that must be disposed of in both an environmentally acceptable and cost effective manner. Land treatment is a disposal method with the potential to satisfactorily achieve both goals, taking advantage of both physical sorption of hydrocarbons onto soil surfaces [1,2,23] and metabolism of indigenous microorganisms to biodegrade the oily waste [6,18,22,25,28,34–36]. Others have demonstrated that, under favorable environmental conditions, significant biodegradation of hydrocarbons can occur in soils [7–10,12,15,17,20,23,29].

Oil-in-water emulsions are widely used in industry as coolants and lubricants in metal working operations [2,11,14]. The Ravenswood Works (Ravenswood, WV) of Kaiser Aluminum and Chemical

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Corporation, Inc. (KACC) currently utilizes an oil-in-water emulsion as a coolant for the plant's aluminum rolling mills. This emulsion, comprised mainly of mineral oils and triethanolamine oleate soaps, has a finite usage period. Periodic disposal of the emulsion is necessary since the heat from the aluminum rolling process and microbial utilization of the fatty acid and oil components renders the coolant unusable. The spent oil emulsion is pumped to holding ponds where weakly emulsified oil physically separates from the aqueous phase and is reclaimed. The aqueous phase, which still contains 0.2 to 0.5% emulsified oil, is disposed of by spray irrigation onto a silt loam soil. KACC has utilized land treatment for disposal of this dilute waste oil emulsion (OE) since 1972.

Early studies of the KACC sprayfield [4,24] suggested that OE hydrocarbons were retained after application in the upper 60 cm of the soil column and indicated no apparent groundwater contamination. Hydrocarbon-biodegrading bacteria were isolated from the site, but no direct evidence for hydrocarbon biodegradation in the soil was found. An accumulation of 40 g kg^{-1} of hexane extractable material in surface soils after 5 years of waste application was noted. The purpose of the present study was to evaluate the current potential for hydrocarbon biodegradation in KACC sprayfield soil. We also identified major hydrocarbons and fatty acids contained in the OE, and determined the distribution of these hydrocarbons in the soil column after OE application.

MATERIALS AND METHODS

Site description and sampling regime

The OE disposal site is located in Jackson County, WV within a 56 ha field owned by KACC (81°46′ W, 39°25′ N). Soil at this site is a deep, well-drained Huntington silt loam (fine-silty, mixed, mesic Fluventic Hapludoll). Two 5.7 ha waste irrigation areas, designated east sprayfield (ESF) and west sprayfield (WSF), are located on the site. The ESF has been in operation since 1972, and the WSF since 1979. Each area consists of 2 rows of 5 irrigation hydrants (Eastern Rain Bird Sales, Inc., Peoria, IL) placed at 92 m intervals. An irrigation hydrant uniformly dispenses OE to a distance of 46 m as it rotates through 360 degrees. During normal operating conditions, KACC alternates OE applications between the ESF and WSF site on a weekly basis. Typical applications average 25.4 l m^{-2} wk^{-1}, weather permitting. Both sprayfields are disced monthly to promote soil aeration, optimize OE infiltration, and to control growth of weeds. The fields also are plowed twice yearly to a depth of 70 cm to prevent the development of a hardpan. Chemical properties of the sprayfield and an unoiled Huntington silt loam soil located adjacent to the ESF soils (Table 1) were determined using standard procedures at the Cornell University Nutrient Analysis Laboratory (Cornell University, Ithaca, NY).

Soil samples were obtained from the ESF and WSF during November, 1986 and monthly during

Table 1

Chemical characteristics of Huntington silt loam soil used for land disposal of a dilute waste oil emulsion

Site	pH (in water)	exchangeable acidity (cmol (+) kg^{-1})	P	K	Mg	Ca	N	C
			(mg kg^{-1})				(%)	
ESF	5.9	11.3	0.5	169	199	1582	0.2	4.7
WSF	6.1	11.1	0.5	244	169	1398	0.2	4.3
Unoiled	5.7	11.0	0.5	204	149	1161	0.2	3.5

June through November, 1987. During summer 1987, the irrigation system in the ESF was under repair and the site received no OE applications after early June. Thus, 1987 soil samples from the ESF did not receive periodic exposure to OE, while samples obtained from the WSF were receiving higher than normal application rates of OE.

Extraction of hydrocarbons from the waste oil emulsion

Twenty liter samples of OE were obtained periodically from a valve in the pipeline connecting the waste irrigation system with the waste emulsion collection ponds. Total recoverable oil and grease (EPA method 413.1), chemical oxygen demand (EPA method 410.1), total dissolved solids (EPA method 160.1), and total suspended solids (EPA method 160.3) of selected OE samples are presented in Table 2. A modification of the oil and grease extraction procedure was used to obtain concentrated samples of hydrocarbon and fatty acid components of the OE. One liter aliquots of the OE were acidified with 50 ml of 12 N HCl and placed in a 90°C water bath for 5 to 10 h in order to completely break the emulsion. The aliquots were then cooled (23°C) and extracted twice with equal volumes of trichlorotrifluoroethane (TCTFE) in a glass separatory funnel. All solvents used were HPLC grade (Fisher Scientific, Inc., Fairlawn, NJ). The TCTFE fractions were filtered and dried by passage through # 1 Whatman filter paper containing 5 g anhydrous Na_2SO_4 and collected in preweighed 250 ml beakers. Extracts were pooled and the solvent evaporated for gravimetric analysis of residual hydrocarbons and fatty acids. Samples were then diluted to 500 $\mu g\ ml^{-1}$ in TCTFE prior to analysis by gas chromatography (GC) and gas chromatography/mass spectrometry (GC-MS). Portions of the original unextracted OE also were analyzed by a purge and trap procedure (EPA method 501.1) coupled with GC-MS analysis.

Table 2

Chemical characteristics of the waste oil emulsion collected at the influent to sprayfield

Sample date	pH	OG[a]	COD[b]	TDS[c]	TSS[d]
		($mg\ l^{-1}$)			
6/86	5.7	2029	12,300	1082	574
9/86	5.7	1738	9,700	1715	284
6/87	5.2	1540	N.D.[e]	5133	N.D.
8/87	5.3	1490	N.D.	3277	N.D.

[a] Oil and grease;
[b] Chemical oxygen demand;
[c] Total dissolved solids;
[d] Total suspended solids;
[e] Not determined.

Extraction of the waste oil emulsion from soil

Bulked samples were obtained from the waste disposal sites by removing six soil cores (2 × 24 cm) at each of four points 34 m from two designated irrigation hydrants in both the ESF and WSF. Cores from each spray field were sieved (< 5 mm), combined in plastic bags, then refrigerated at 5°C until solvent extraction or use in biodegradation studies. Larger cores (7.5 × 30 cm) were removed from selected areas in the ESF and WSF. First, one such core was used to sample soil 0–30 cm in depth. A second core was then placed in the same spot and used to sample soil from 30–50 cm. These samples were used to determine OE distribution in the soil profile. Cores were returned to the laboratory, extruded, then divided into 8 cm sections from the 0–48 cm depth.

Soil samples were air dried for 24 h, sieved (< 5 mm), mixed, and divided into replicate 10 g subsamples. Subsamples were placed in 250 ml Erlenmeyer flasks and extracted on a rotary shaker (140 rpm, 14 min) with two 20 ml portions of TCTFE. The TCTFE fractions were filtered, dried, and weighed as previously described. Dried extracts were redissolved in 10 ml of TCTFE and further diluted (1:15) for GC and GC-MS analyses. Shaking was used as an extraction technique in order to more conveniently process a large number of samples. TCTFE was a convenient solvent for use with this procedure because of its lower volatility compared with hexane or pentane. Extraction efficiency with TCTFE from sterile control soils averaged

>99% for hexadecane and pristane, and 85% for OEH.

Biodegradation of alkanes and waste oil hydrocarbons added to soil

In vitro hydrocarbon biodegradation assays were performed in replicate 250 ml Erlenmeyer flasks containing 10 g ESF or WSF soil. Soils collected in November, 1986 were amended with 10 mg each *n*-hexadecane and pristane (Aldrich Chemical, Inc., Milwaukee, WI). Soils collected in June and September, 1987 were amended with 6 and 7 g kg^{-1}. respectively, of extracted OE hydrocarbons and fatty acids (OEH). Unamended soils and amended sterilized soils (autoclaved at 121°C at 15 psi for 20 min on 2 consecutive days) were included in all experiments. Pristane and *n*-hexadecane were added directly to the soil via syringe. OEH amendments were first dissolved in 1 ml pentane prior to addition. The pentane then was allowed to evaporate for 30–60 minutes. Preliminary studies demonstrated that addition of pentane did not affect CO_2 production in amended soil compared to unamended control soils (data not shown). After hydrocarbon additions, the gravimetric soil moisture content of each sample was adjusted to approximately 25% by addition of sterile-distilled water. Flasks then were closed with stoppers fitted with a rubber septum and incubated at 23°C in the dark. The headspace of the flasks were analyzed weekly for CO_2 production by GC. All measurements were correct for dissolved CO_2. Each flask was unstoppered to permit reaeration subsequent to withdrawal of a gas sample. Four replicate flasks were sacrificed for analysis of residual hydrocarbon concentrations at day 0 and at 14 day intervals thereafter for 56 days. Unamended soils and amended sterilized soils were analyzed only on day 0 and 56. Microbial activity in the sacrificed flasks was inhibited prior to air drying of the soil by fumigation (2 h) with chloroform (2 ml flask-1). Soils in the flasks were air dried (24 h) and extracted with TCTFE as described previously.

Analytical measurements

Hydrocarbons and fatty acids were analyzed by GC using a Varian 3400 gas chromatograph (Varian Associates, Inc., Sunnydale, CA.) equipped with a flame ionization detector. Separations were achieved with a DB-1 megabore column (<0.5 μm film thickness, 20 m × 0.53 mm, J&W Scientific, Inc., Folsom, CA) using hydrogen as a carrier gas (7.5 ml min^{-1}). Samples (1 μl) were introduced by on-column injection using a Varian 8035 autosampler. Operating conditions were as follows: (i) Injector, 50°C for 0.1 min, 200°C min^{-1} to 250°C; (ii) Column, 75°C for 2 min, 10°C min^{-1} to 250°C, 6 min at 250°C; (iii) Detector, 300°C isothermal, 300 ml min^{-1} zero air, 20 ml min^{-1} zero nitrogen. Individual peaks were identified and quantified by comparison with authentic compounds (Aldrich Chemical, Inc., Milwaukee, WI) used as external and internal standards.

Hydrocarbons and fatty acids were further identified by GC-MS analyses using a Finnigan 9600 gas chromatograph/4500 mass spectrometer (Finnigan Corp., Cincinnati, OH) connected to INCOS data system equipped with a NBS internal library. Separations were achieved using a DB-1 capillary column (0.25 μm film thickness, 30 m × 0.25 mm) using helium as a carrier gas (3 ml min^{-1}). Samples (1 μl) were injected (12:1 split injection) via syringe (Hamilton Co., Reno, NV). A purge and trap method was used to introduce some samples: sample size, 5 ml; purge time, 11 min; purge flow 40 ml min^{-1} helium; desorb time, 4 min; desorb temperature, 180°C; bake temp, 250°C. GC operating conditions were: (i) Injector, 258°C; (ii) Column, 50°C for 2 min, 10°C min^{-1} to 300°C, 3 min at 300°C. All compounds identified by GC-MS matched NBS library spectra at greater than 95% similarity.

Headspace CO_2 samples were analyzed on a Carle 100 Series gas chromatograph (Hach Company, Loveland, CO) equipped with a thermal conductivity detector. Separations were achieved on a Poropak Q column (2 m × 3 mm, Waters Associates, Milford, MA) using helium as a carrier gas (30 ml min^{-1}). Samples (0.5 m l) were introduced via syringe. Injector, column oven, and detector were operated isothermally at 80°C.

RESULTS AND DISCUSSION

The main hydrocarbon-containing constituent of the oily waste generated by KACC is the oil emulsion used to cool and lubricate the aluminum rolling mills. Other oily materials are known to enter the waste collection system in small quantities such as hydraulic fluids and waste lubricating oils [24]. GC and GC-MS analyses of the OE demonstrated that the OE is a complex mixture of compounds resolvable by GC and also contained various unresolvable materials indicated by the 'envelope' of the GC chromatogram (Fig. 1). Thirteen of the resolvable compounds were *n*-alkanes (C_{12}-C_{25}) and 2 were iso-alkanes (pristane and phytane). Saturated (hexadecanoic and octadecanoic acid) and unsaturated (oleic acid + isomers) fatty acids also were identified. Oleic acid was a major constituent of the waste, consistent with its use as an additive to replenish depleted organic soaps in the rolling mill emulsion. Product specifications for the mineral oils used by KACC to formulate the rolling emulsion indicate a composition comprised of some cycloalkanes and aromatic hydrocarbons. Only one such compound was resolvable in the OE (1,2 benzenedicarboxylic acid dibutyl ester). Other compounds identified in low amounts by the purge and trap procedure included: methylbenzene; 4,7-dimethylundecane, 2,6,10,15-tetramethylheptadecane, and 1,6,7-tricyclo-2,2,5,5,8,8 hexamethylnonane. Hydrocarbon composition of the OE did not vary significantly among several samples analyzed during 1986 and 1987 (data not shown).

The potential for biodegradation of hexadecane and pristane was determined for ESF and WSF soil collected in November, 1986. An average 96% decrease in the concentration of both pristane and hexadecane occurred during the 56 day in vitro incubation (Fig. 2). No significant disappearance of either hydrocarbon was observed from sterilized soil during the same period. Pristane disappearance was linear, compared with an exponential decrease in hexadecane concentration with time. The biodegradation rate of pristane was estimated by linear regression analysis to be 10.7 and 11.0 mg kg^{-1} day^{-1} (r^2 = 0.94 and 0.99) in the ESF and WSF,

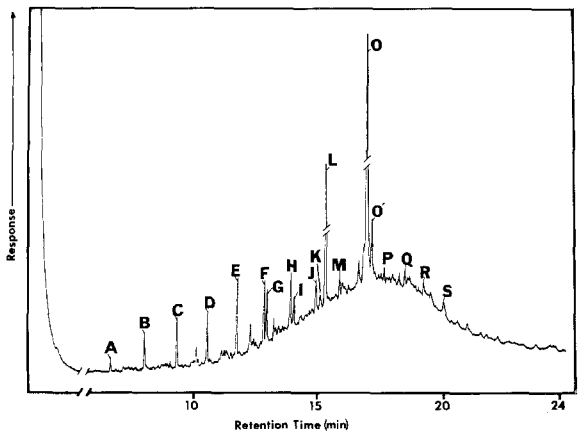

Fig. 1. A representative gas chromatogram illustrating resolvable components extracted from the waste oil emulsion: A, *n*-dodecane; B, *n*-tridecane; C, *n*-tetradecane; D, *n*-pentadecane; E, *n*-hexadecane; F, *n*-heptadecane; G, pristane; H, *n*-octadecane; I, phytane; J, *n*-nonadecane; K, 1,2 benzene-dicarboxylic acid-dibutylester; L, hexadecanoic acid; M, *n*-eicosane; O, oleic acid (and isomers); O', octadecanoic acid; P, *n*-docosane; Q *n*-tricosane; R, *n*-tetracosane; S, *n*-pentacosane. Compounds were identified by co-chromatography with authentic standards and by gas chromatography/mass spectrometry.

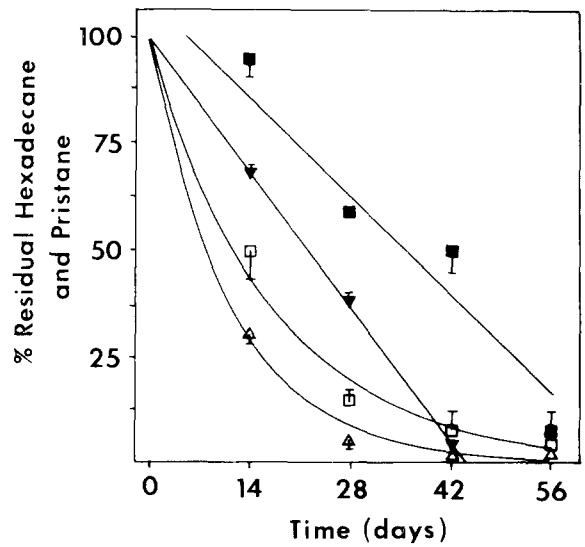

Fig. 2. In vitro disappearance of hexadecane and pristane from sprayfield soil collected in November, 1986. Disappearance curves are the best fit linear regression line for pristane, and the integrated first order velocity equation for hexadecane. Points are the mean and standard deviation of 3 replicates, hexadecane: ESF (□), WSF (△); pristane: ESF (■), WSF (▼). Recovery of both hydrocarbons from amended sterile soils averaged 99%.

respectively. Log transformation of the hexadecane data resulted in linearization of the rate of disappearance of this hydrocarbon with time (r^2 = 0.99 and 0.94, ESF and WSF, respectively). The apparent half-life of hexadecane in soil, estimated from the log transformed data as described by Segel [31], was 11.7 days in ESF compared with 7.7 days in the WSF.

The rate of net CO_2 production was 43.9 and 30.4 mg CO_2-C kg soil^{-1} day^{-1} in the WSF and ESF, respectively. Greater soil respiration in the WSF was consistent with the higher rate of hexadecane biodegradation observed in these samples. However, the amount of respired carbon was higher at both sites than could be accounted for by the added pristane and hexadecane (1 g each kg^{-1} soil). Soil from both sites contained background concentrations of TCTFE extractable material (16 and 11 g kg^{-1} soil, ESF and WSF, respectively) from previous OE applications. Addition of pristane and hexadecane in amounts greater than that normally received during OE application (approximately 150 mg each of pristane and hexadecane m^{-2} week^{-1}), may have enriched for a microbial population able to utilize this additional background carbon, contributing to the higher respiration rates measured in treated samples compared with nontreated controls.

Hexadecane is a linear alkane which has been used extensively as a substrate for the isolation and growth of hydrocarbon degrading microorganisms [22,25,27,35]. Pristane, a quaternary branched isoalkane, generally is considered to be a more recalcitrant hydrocarbon [13,17,27,30]. Pirnik observed no pristane biodegradation in the presence of hexadecane by a *Brevibacterium* sp. [27]. Various workers [19,32,33] have used the slower biodegradation of pristane as an internal standard against which to measure the more rapid biodegradation of linear alkanes in crude oils. In the present study, hexadecane and pristane were readily metabolized in soil collected from both sprayfield sites, demonstrating the presence of microbial populations with the potential of degrading both linear and branched alkanes in the OE.

Sprayfield soil collected in June and September, 1987 was amended in vitro with OEH. The amendment rates were 6 g kg^{-1} in June and 7 g kg^{-1} in September. On an areal basis these application levels correspond to 162 and 189 g m^{-2} wk^{-1}, which are comparable to actual in situ applications of OEH which range from 115 to 460 g m^{-2} wk^{-1}. Background concentration of TCTFE extractable material in soil samples ranged from 3.1 to 5.7 g kg^{-1}.

Disappearance of OEH was followed by GC analyses (Fig. 3). Fatty acids were removed from all

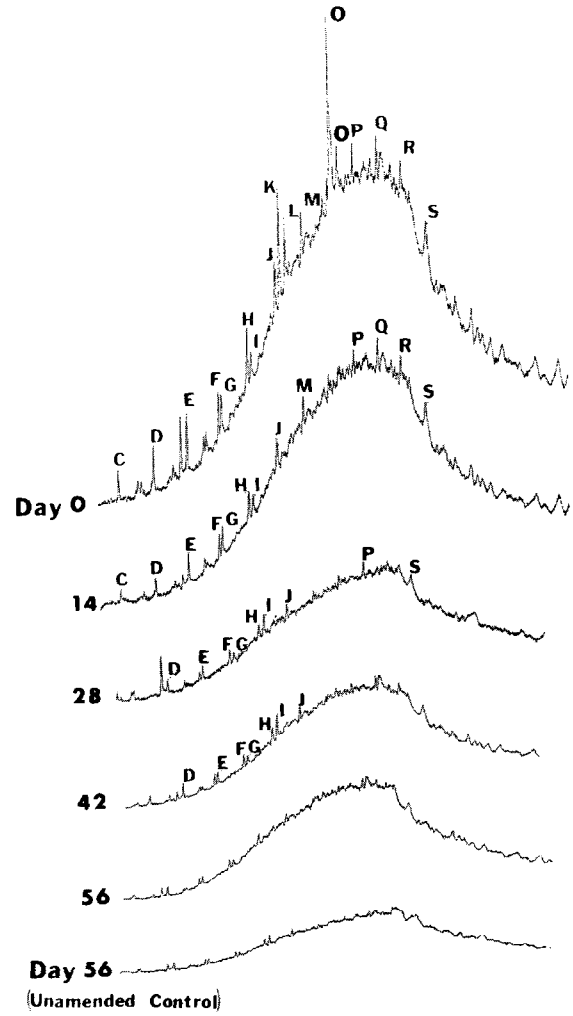

Fig. 3. Representative gas chromatograms illustrating in vitro disappearance of OEH added to ESF soil obtained during June, 1987.

samples within 28 days. However, September samples contained significant amounts of resolvable hydrocarbons at the end of the 56 day incubation, compared with nearly complete hydrocarbon biodegradation in June samples. In order to compare relative difference in OEH biodegradation, total resolvable peak heights of the chromatograms were summed. Their totals were used to determine the percentage of resolvable OEH remaining with time (Fig. 4). Log transformation of these data resulted in linear rates of OEH disappearance from all samples (ESF, $r^2 = 0.90$ and 0.94; WSF, $r^2 = 0.95$ and 0.99; June and September samples). The apparent half-lives of resolvable OEH estimated from the log transformed data were 9.5 and 9.2 days in June, and 60.3 and 28.1 days in September samples, from the ESF and WSF, respectively.

Decreased biodegradation rates in September samples could not be attributed to a decrease in total microbial activity since net CO_2 production was similar at both sampling dates (ESF, 5.8 and 8.5 mg CO_2-C kg^{-1} day^{-1}; WSF, 9.5 and 14.1 mg CO_2-C kg^{-1} day^{-1}; June and September samples).

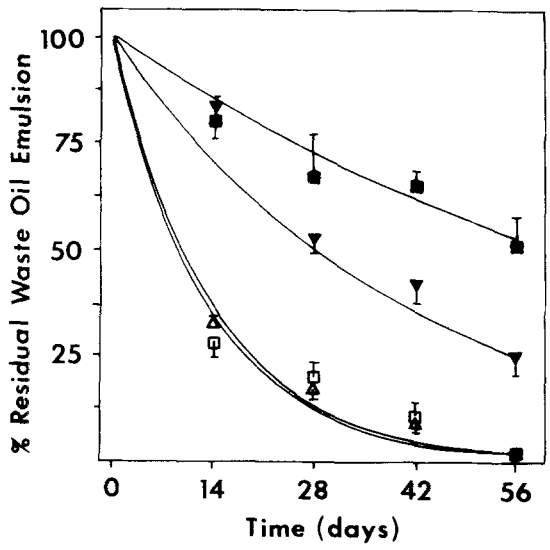

Fig. 4. In vitro disappearance of OEH from sprayfield soil collected in June and September, 1987. Curves are best fits to an integrated first order velocity equation. Points are the mean and standard deviation of 3 replicates: ESF, June (□), September (■); WSF, June (△), September (▼). Recovery of OEH from amended sterile soils averaged 85%.

Our present data do not explain the differences in the biodegradation rate between the two sampling times. However, several possibilities are suggested. The OE application regime may have contributed to rate differences observed. During 1987, the ESF and WSF received similar amounts of OE prior to collection of soil samples in June. The ESF received no additional OE after the June sampling, while the WSF received double the normal load of OE. Thus the WSF samples obtained in September were continuously exposed to OE, while ESF samples had not been exposed to waste for 3 months. Lack of waste exposure may have decreased populations of microorganisms capable of OEH biodegradation in the ESF. Previous studies have demonstrated that oil application to soil selects for increased populations of hydrocarbon degraders [16,18,21,25,26,28]. Slower biodegradation rates exhibited by September samples from the WSF, may suggest that OEH application rates in excess of 460 mg m^{-2} wk^{-1} should be avoided under the current sprayfield management regime. Other workers have recommended periodic additions of N and P fertilizers to stimulate hydrocarbon biodegradation in soil [1–3,7,9,12,17,20,29]. However, the efficacy of this treatment to enhance OEH biodegradation currently is unknown. Abundant weeds (primarily Johnson grass, *Sorghum halpense* (L.) Pers.) grew in the ESF after cessation of waste application in June. The plant material was disced into the soil prior to the September sampling, providing a readily utilizable source of carbon and nutrients in the soil. Availability of this plant material may have limited hydrocarbon biodegradation by favoring immobilization of N and P or provided competitive substrates for microbial growth [3]. Immediate plant growth after the cessation of OE application indicates that long term application of this waste had not created phytotoxic soils, as has been reported for land treatment sites receiving metal-containing oil sludges [5].

Cores were used to obtain soil profiles from the sprayfield sites during June through September, 1987. Gravimetric analyses indicated that the majority of extractable compounds were restricted to the upper 48 cm of the soil column (Table 3). Weights of extractable material were greatest within

Table 3

Weight of TCTFE extractable material from soil cores obtained from the east and west sprayfield during summer, 1987.

Soil depth (cm)	ESF 6/87	9/87	WSF 6/87	9/87
	(mg g^{-1})			
0– 8	2.2[a]	1.1	4.1	6.7
8–16	1.6	1.8	3.5	5.1
16–24	1.4	1.7	4.5	3.2
24–32	2.0	1.1	2.1	3.6
32–40	1.0	0.4	0.4	0.5
40–48	0.2	0.2	0.1	0.8

[a] Values are the mean of 3 replicate samples. Standard deviations for these determinations ranged from 0.1 to 0.6 mg g^{-1}.

the upper 24 cm and approached background (0.11 g kg^{-1}, unoiled soil) at the 40–48 cm depth. The majority of the gravimetric weight of the soil extract was comprised of compounds unresolvable by GC. Consistent with the spray regime, less total extractable material was obtained from the ESF compared with the WSF. However, the distribution with depth of extractable OEH was similar at both sites.

Resolvable hydrocarbons were normally detected in the upper 0-8 cm of the soil profile within 48 h after application of OE (Fig. 5). Samples obtained 14 days after cessation of waste application in June, 1987 indicated biodegradation of most resolvable hydrocarbons, but the retention of unresolvable compounds was indicated by the 'envelope' of the chromatogram. The chromatographic envelope of 104 day samples was reduced, suggesting further biodegradation of these unresolvable components.

Others have demonstrated that concentrated hydrocarbon wastes, such as oil sludges, are retained and degraded in upper soil horizons under conditions appropriate for land treatment [1,6–8,12,17,20,23]. In one such study [12], a concentrated waste machine coolant (20% oil) was mineralized at a rate of 320 mg m^{-2} day^{-1} during a one-year study. Land disposal of dilute waste coolant emulsions has received less attention [4,24]. Neal et al. [24] observed that dilute waste emulsions

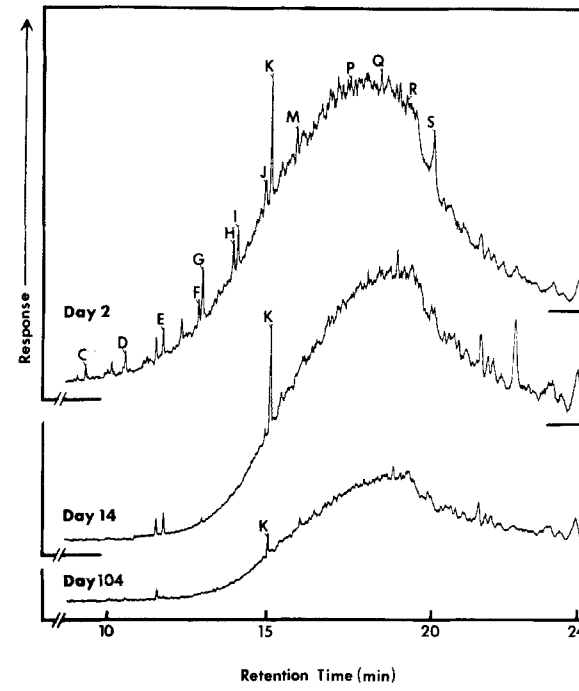

Fig. 5. Representative gas chromatograms of TCTFE extracts from the upper 8 cm of the ESF soil. Samples were obtained 14 and 104 days after cessation of waste application to the ESF in June 1987. The 48 hour sample was obtained after waste application was resumed to this site in November, 1987.

applied at rates of 115 to 1840 g OEH m^{-2} wk^{-1} were concentrated and retained by soil binding. Our data confirm the retention of OEH and further suggest that biodegradation of the oily waste occurs in the upper soil horizons. Like other land treatment studies [9,12,17,28], biodegradation appears to be incomplete and results in an accumulation of hydrocarbons in the soil. Significant concentrations of oil and grease were not detected during routine quarterly monitoring of groundwater collection wells located on the sprayfield site (KACC, unpublished data), however, suggesting that the nondegraded material is effectively retained by the soil.

Land treatment appears to be an appropriate treatment for the waste oil emulsion generated by KACC. The waste is readily immobilized in the silt loam soil of the sprayfield and evidence of OE biodegradation is apparent. Application of OE since 1972 has not inhibited hydrocarbon biodegradation in the soil and does not appear to have created phy-

totoxic conditions. The level of OE applicated to the site may effect the rate at which OE is degraded. Continuous low level exposure to the waste may be beneficial in maintenance of a microbial population with the capacity to biodegrade the OE, while overexposure to OE or exposure to other competitive carbon substrates may decrease the biodegradation rate. Currently, the sprayfield is not fertilized, a treatment found to be effective in enhancing biodegradation of other oily wastes in soil [3]. Studies are currently underway to achieve optimum management of the site in order to enhance biodegradation of the waste oil emulsion.

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