

Biodegradation of Petroleum Hydrocarbons in a Soil Containing Polyacrylamide

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Abstract

The objective of this study was to evaluate the fate and toxicity of total petroleum hydrocarbons (TPH), polyacrylamide and acrylamide monomer in soil under aerobic conditions for mixtures of commercially available products that have application as an anti traction material (ATM) (Southwest Research Institute patent pending for ATM).

The aerobic biodegradability of petroleum hydrocarbons in several formulations was determined using a simple microcosm/respirometric method based on carbon dioxide production and TPH depletion. The microcosms consisted of 1L mason jars fitted with sealed rubber caps that allowed headspace gas samples to be collected in a sealed system. The analytical procedure included the detection of peaks for the compounds in TPH by gas chromatography and identification of peaks with a mass spectrometer (GCMS). Mole fractions of the major components in TPH (undecane, dodecane, tridecane and tetradecane) were calculated from the detected peaks. The extracted soil was analyzed for total organic carbon (TOC) content in order to examine the carbon balance. The method described here provides a simple and inexpensive method for determining the aerobic biodegradability of organics in soil.

Results indicated that, for the polyacrylamide (PAM) treatments in soil, there was no significant CO₂ production in the headspace of the microcosm within the experimental time period. Total organic carbon values obtained for the initial and final soil showed no significant PAM biodegradation within a time period of 161 days. This confirms that PAM biodegradation is a slow process and may take several years.

Introduction

Total petroleum hydrocarbons (TPH) is a term used to describe a large family of several hundred chemical compounds that originally come from crude oil. The TPH in this study consists of mainly aliphatic hydrocarbons ranging from C₁₀-C₂₅ with undecane, dodecane, tridecane and tetradecane being present in larger percent. Many studies have been conducted that address the properties of organic compounds and their fate in the environment (1-37). For most hydrocarbons, biodegradation was not a significant removal process (15; 30; 31). For JP8 jet fuel, disappearance from soil appeared to be due to both evaporation and biodegradation (21).

In a study of the fate of JP-4 in soil (15), hydrocarbons with molecular weights equivalent to decane or lower disappeared from soil in both active and sterile treatments by the first sampling time, indicating that evaporation was the major removal process for these hydrocarbons. Hydrocarbons with molecular weights higher than decane like undecane, dodecane, tridecane and tetradecane were not removed as rapidly from soil as the more volatile hydrocarbons and traces of these hydrocarbons persisted until the end of the experimental period. It was also found from the same study that for undecane, dodecane and hexadecane, no significant differences in disappearance were noted between the active and sterile treatments.

Volatilization and biodegradation are the two major processes that determine the fate of TPH components in soil. While volatilization is expected to be the dominant fate process for these fuels from soil surfaces, biodegradation will become increasingly dominant as the soil depth increases. Some components of these fuels may migrate through the soil to groundwater.

When dodecane is released into the soil, it may biodegrade to a moderate extent. Because of sorption and low solubility in water, dodecane is not expected to leach into groundwater. When released into water, it may evaporate and/or biodegrade to a moderate extent. In the atmosphere, dodecane is expected to be readily degraded by reaction with photochemically produced hydroxyl radicals. When released into the air, it may be removed from the atmosphere to a moderate extent by sorption (26).

For mixtures of TPH, their movement in the environment is actually a function of the chemical and physical properties of the component hydrocarbons. Following release of TPH to air, water, or soil, the component hydrocarbons partition relatively independently of each other based on their respective vapor pressures, solubilities, and Henry's law and sorption constants. For TPH mixtures, these values are ranges based on the component hydrocarbons. Information on the specific physical and chemical properties of several of the component hydrocarbons (e.g. undecane, dodecane, tridecane, tetradecane, etc.) can be found in Material Safety Data Sheets (MSDS) obtained from Acros Organics (2) and Fisher Scientific (18) and other sources. These values and sources are presented in Table 1. Humphrey (20) has reviewed and addressed the solubility of these hydrocarbons with respect to their biodegradation. Erickson et al. (17) have reviewed the literature on microbial growth when two liquid phases are present.

In general, using carbon dioxide (CO₂) evolution to measure biodegradation is a reliable technique and actually provides data on the mineralization of a test chemical. Here we describe a simple microcosm method, based on CO₂ production and TPH depletion, for determining the aerobic biodegradability of organic chemicals in soils. The experiment involves extraction of TPH components from soil and subsequently identifying them using analytical techniques. The concentration of CO₂ in the gas phase is measured at regular time intervals using a gas

chromatograph (GC). Results demonstrate that the loss of TPH correlates well with the production of CO₂.

When petroleum or petroleum products enter the environment, they are subjected to various weathering processes that alter their chemical and physical nature. Biodegradation of petroleum pollutants by microorganisms is a major process mediating the fate of oil in the environment (4). The chemical nature of petroleum and refined hydrocarbons and compounds, such as naphthoic acids, phenols, thiols, and heterocyclic nitrogen, sulfur, and oxygen (NSO) compounds, as well as some metalloporphyrins (5) presents a challenge to microorganisms. Extensive degradation of a petroleum mixture generally requires the combined activities of several different microbial populations (4).

Fate of Polyacrylamide

A major constituent of many of the formulations for ATM is polyacrylamide (PAM), which has been used to control soil erosion and hold water in desert soils. Polyacrylamides are synthetic polymers made of acrylamide or acrylamide and acrylic acid (3).

Once exposed to the environment, polyacrylamide polymers are capable of translocating through different soil compositions under field conditions (32; 24). However, they can bind to particulate matter such as clay particles (33). Polyacrylamides may undergo biodegradation to mineralized forms such as CO₂ and NH₃. Degradation of PAMs in soil systems can be expected to occur with time as a result of mechanical degradation, chemical and biological hydrolysis, sunlight, salt and temperature effects (34; 36) at a rate that has been estimated to be about 10% per year (6). Release of the acrylamide monomer has not been observed in degradation studies (13). In the manufacture of polyacrylamides, maximum residual acrylamide levels range between 0.05-0.5% depending on the intended use of the product (13). Polyacrylamides are non-toxic because of their inability to pass biological membranes (27).

Fate and Toxicity of Acrylamide Monomer

One of the important components of polyacrylamide is acrylamide, which is a vinyl monomer with a solubility of 212 g/100 ml water (37). Acrylamide is a potential groundwater contaminant. It is a known neurotoxin to man (14; 29). Animal testing has demonstrated that acute exposure primarily affects the central nervous system and that chronic, subacute exposure can damage the peripheral, as well as the central, nervous system.

A major source of acrylamide in the environment is the release of residual acrylamide monomer from the polymers. Studies by Croll et al. (13) showed that industries employing polyacrylamide or acrylamide-acrylic acid copolymers as flocculating agents, without exception, discharged acrylamide into the environment in amounts far exceeding the maximum allowed levels for potable water, which is 0.5 ppb (35).

New information on acrylamide has been recently reported in food technology by Coughlin (12). Five international research groups have separately confirmed a major Maillard reaction pathway for acrylamide formation. Using elegant radiolabeling experiments, they conclusively

demonstrated in model systems that significant amounts of acrylamide are formed by the high-temperature reaction of glucose and the common amino acid asparagine. Since potato products are especially high in asparagines, it is now thought that this Maillard reaction is most likely responsible for the majority of the acrylamide found in potato chips and French fries (12).

Acrylamide in the environment has high mobility in soil (24). It may travel great distances in groundwater (10) and is biodegradable in water and soil (8; 13). It is not absorbed significantly by sediments or affected by conventional water treatment (7). Acrylamide is biodegradable and does not accumulate in soils. At ambient temperatures, half-lives range from 18 to 45 hours for 25 ppm acrylamide (25 mg AMD/kg soil) (24). Decreasing the temperature or increasing the acrylamide concentration increases half life. The half life was found to be longer under anaerobic soil conditions (24). Acrylamide is hydrolyzed in soils producing ammonium ions (NH_4) that are eventually oxidized to nitrite (NO_2) and nitrate (NO_3) under aerobic conditions (1). Croll et al. (13) has shown acrylamide to be biodegradable in the laboratory and in effluent in which PAM was used as a flocculent. Brown et al. (7) reported acrylamide to be biodegradable in all unsterilized natural and polluted waters. Degradation of acrylamide usually occurs within 100 to 700 hours in water under aerobic conditions.

Materials and Methods

Experiment 1: Disappearance of TPH in Open Soil Microcosms

Khaitan et al. (22) investigated the disappearance of TPH from open soil microcosms. The soil was taken from Department of Agronomy, Kansas State University. The soil contained 24% sand, 50% silt, 26% clay, 0.086% N, 0.95% C, and 1.4% organic matter (Soil Testing Lab, Dept. of Agronomy, Kansas State Univ.). Soil was ground, sieved and dried for 24 hours. Superfloc (solid crystal PAM) and Cydril (a mixture of PAM and TPH) were obtained from Cytec industries for the experimental work. Three replicates were made in open containers (four 120 ml bottles) with a mixture which contained 8.0 g of water, 0.27 g Cydril and 0.13 g Superfloc added to 20 g soil in each container. Extraction was performed at regular time intervals of $t = 0, 2, 4$ weeks. The whole bottle was taken for extraction at each time. After 60 ml of acetone was added for each extraction, the TPH was allowed to separate by shaking for approximately 2 hours so that hydrocarbon phase from soil moves into the acetone. After that, centrifuging at 500 rpm was done for 10 minutes. An empty (60 ml) bottle was taken and weighed with cap. Extract was poured into the bottle and whole bottle was weighed with cap. The difference of the final and initial weight gave the mass of extract in the bottle. The extract was subsampled with a plastic syringe capped with a filter. Finally, the filtered extract was transferred to a GC vial and capped tightly using a capper. The amount of TPH was determined using a HP GC 5890 Series II with Flame Ionization Detector (FID). Column specifications are 0.32 mm inside diameter, 30 m long, 0.00025 mm film thickness. The carrier gas was hydrogen; make-up gas was nitrogen and fuel gas was hydrogen and air. The temperature program was 40°C for 2 min followed by 10°C increase/min to 300°C. The detector temperature was 300°C while injector temperature was 200°C. Injection was set at 2 microliters per run and the vials were placed on an automatic sampler for analysis.

Experiment 2: Biodegradation of TPH and PAM

The soil was taken from Department of Agronomy, Kansas State University. The soil contained 24% sand, 50% silt, 26% clay, 0.086% N, 0.95% C, and 1.4% organic matter (Soil Testing Lab, Dept. of Agronomy, Kansas State). Superfloc (solid crystal PAM) and Cydril (a mixture of PAM and TPH) were obtained from Cytec industries for the experimental work. Soil moisture was calculated by drying 10 g of soil and reweighing it after the soil was dried. The difference in initial and final weights gave the amount of soil moisture. The value obtained for the soil moisture was about 1% for the soil as received. The whole soil was grounded, sieved and dried for 24 hours. About 200 grams of soil was sterilized in an autoclave with steam at 1 atm gauge pressure and a temperature of 120°C for 30 minutes.

Various formulations of Anti Traction Material (ATM) are being investigated, and some of the ingredients used in the formulations are used in this experimental work. Ten grams of soil was transferred to each of eighty-seven 120 ml bottles. The following type of treatments made were: A) sterilized soil with 8 g water, 0.27 g cydril, and 0.13 g superfloc, B) 8 g water, 0.27 g cydril, 0.13 g superfloc in soil, C) 4 g water, 0.135 g cydril, 0.065 g superfloc in soil, D) 0.27 g cydril and 8 g water in soil, E) 0.13 g superfloc and 8 g water in soil and F) control with no contaminant in the soil. Ten grams of dry soil was used in each sample. Eighteen replicates were made of the type B and D formulations in 120 ml bottles. Fifteen replicates were made of the type A, C, E and F in 120 ml bottles. All the 120 ml bottles with treatments inside were transferred to 1L mason jars. Approximately 100 ml water is added to each jar to create moisture inside the jars. All the jars had a rubber septum in the lid to allow the gas phase to be sampled.

Extraction of TPH in the soil was performed at regular time intervals using the entire mass of soil from a jar to get an estimate of amount of TPH present at any instant. At time $t=0$, six replicates of treatments - B, C, D, E and 3 replicates of treatment F were taken for extraction. Tetracosene was used as an extraction standard for the TPH and 500 μl of it was added to each treatment being extracted. After adding tetracosene, the treatments were left for 10-15 minutes for the sorption of tetracosene to soil. The procedure formulated for extraction employs mixing and shaking with acetone three times to extract the TPH sorbed from soil to acetone phase. Twenty ml of acetone was added in each extraction. After twenty ml of acetone was added for each extraction, the TPH was allowed to separate by shaking for approximately 2 hours so that the hydrocarbon phase from soil moves into the acetone. After that, centrifuging was done at 500 rpm for 10 minutes. Empty 60 ml bottles were taken and weighed with caps. Extract from a soil sample was poured into a 60 ml bottle and then the bottle was closed with a cap. After three extractions, approximately 60 ml of extractant was accumulated in each 60 ml bottle. All the bottles with extractant were weighed with caps. Total weight of extractant was calculated for each bottle after subtracting the final weight from the initial empty bottle weight with cap. Sub sampling of the extract was done with a plastic syringe capped with a filter. Next, filtered extract was placed in GC vial and was capped tightly using a capper. Hydrocarbon peaks were determined using the GC and temperature program as given in Experiment 1. This experimental method resulted in more than 95% recovery of the tetracosene (23).

The left over soil was left open to the environment for 1 week at room temperature to evaporate any trace of acetone. The acetone-dried soil was sent to soil testing laboratory for total organic carbon (TOC) analysis. At subsequent time intervals $t=3, 6, 13,$ and 23 weeks, the same procedure of extraction and GC analysis was repeated for three replicates of each treatment. The

left over soil at each time interval was air dried for 1 week at room temperature, and then sent for TOC analysis.

Carbon dioxide produced due to biodegradation of organics was measured in the headspace of the mason jars at 3, 6, 13 and 23 weeks. Five hundred μl of gas was collected from the headspace using a gas syringe and injected into a noncapillary GC (Varian/Becker) with porapak p column and thermal conductivity detector (TCD). All measurements were done at room temperature of 25° C.

Results and Discussion

Experiment 1

The weights of TPH at zero, 2 and 4 weeks can be observed from Table 2. It can be seen that for the first two weeks there is a significant decrease in TPH which is due to biodegradation and/or volatilization. Volatilization is expected to be an important factor when hydrocarbons are exposed to the open surroundings. Then in the subsequent two weeks, there is only a small reduction in TPH in Table 2. This shows that higher TPH concentration has a higher rate of disappearance and that the rate slows down as the concentration of TPH decreases.

Significant disappearance of TPH occurred within the first two weeks in an open environment; equilibrium was not reached when TPH was exposed to the surroundings in an open container. The same set of components was studied by Dean-Ross (16) in her 15 day study of fate of JP-4 in soil, which produced comparable results in terms of volatilization of undecane and dodecane.

Biodegradation of TPH is studied best in a closed container where losses due to volatilization are small. Experiment 2 studies the fate of TPH in a closed container where biodegradation of TPH occurs in soil. The fifteen day study by Dean-Ross (16) also provides evidence for the possibility of biodegradation of higher molecular weight organics like tridecane, tetradecane and pentadecane in soil as volatilization of these compounds was found to be slow. Modeling of TPH components is done to confirm that biodegradation and not volatilization is responsible for the disappearance of TPH from the soil in the closed microcosm studies.

Experiment 2

Discussion of TPH Disappearance With Time

The amount of TPH was obtained for the treatments A, B, C, D, E, and F by the summation of area under the peaks. The concentration of TPH is plotted with time for all treatments in Figure 1. The error bars in Figures 1 and 2 are for 1 standard deviation.

During the initial 3 weeks, the rate of disappearance of TPH is low with slight loss of TPH from soil. Then for next 3 weeks, there was a more significant loss of TPH as shown in Figure 1. The reason behind the increase in rate after 3 weeks can be due to microbial adaptation and a possible increase in number of microorganisms in soil leading to this enhanced rate of

disappearance. After 6 weeks, the rate of disappearance becomes low due to the decrease in concentration of TPH in soil. In Figure 1, treatments A and B, the activity is low for initial period and there is only slight loss of TPH during the initial 3 weeks. For treatment A, this may be due to the sterility of the environment inside the jar during the initial period. After 3 weeks, the rate of disappearance increases leading to TPH loss from the soil. The activity increases rapidly after 6 weeks for treatment A, which is due to increased growth of microorganisms. The increased growth of microorganisms for treatment A can be due to the contamination of soil when the containers were opened to allow all CO₂ to escape.

In Figure 1 for treatment B (the initial concentration of TPH is same as treatment A but not sterile), the activity is low for the initial period, i.e. rate of disappearance of TPH is low for the first 3 weeks. Hereafter, there is a sharp increase in rate of disappearance of TPH till 6 weeks. This may be due to an increase in number of microorganisms biodegrading TPH in the soil. After 6 weeks, a lower activity is displayed by the graph of treatment B. This may be due to the decrease in concentration of TPH in treatment B. It appears that a long time may be needed for the TPH to disappear from soil at this concentration of PAM and TPH in mixtures.

In Figure 1 for treatment C, it is seen that at the end of 13 weeks, most of TPH has disappeared. Extrapolation of the graph for treatment C appears to suggest complete disappearance of TPH.

In Figure 1 for treatment D, the rate of disappearance is low for the initial 3 weeks, and then the rate is slightly higher up to 6 weeks. Overall the rate is lower for treatment D, which may be due to the absence of superfloc (solid crystal PAM) in treatment D. Superfloc was added in all other treatments.

TPH Composition and Exposure Limits

The identity of peaks was determined using GC/MS. A vast array of compounds was found to be contained in TPH. The four prominent peaks detected were for undecane, dodecane, tridecane and tetradecane. Mole fractions of the individual components are estimated as a ratio of individual component counts to total TPH counts. The values obtained for mole fractions of these four components are tabulated in Table 3.

To confirm the mole fraction values obtained by ratio of counts, mole fraction of dodecane and tetradecane were also estimated by standard additions of the components to 10,000 ppm standard of TPH (from cydril) in acetone. The values of mole fractions obtained agreed well with those obtained by ratio method.

Using Raoult's Law, and the vapor pressure data in Table 1, the concentration of each component in head space was calculated. The recommended exposure limit (REL) value for dodecane was obtained using MSDS data from Chevron Phillips and Mallinckrodt Baker, Inc. The estimated equilibrium concentration obtained is far less than the REL value as given in Table 4. Thus, the dodecane in TPH in the air is not expected to cause any health concern for the safety of human beings in the environment. The other components REL values were not found but their use is not expected to cause any concern as they fall in the same range as dodecane.

Carbon Dioxide Produced by Biodegradation of TPH

Carbon dioxide was produced in the head space of the jars due to biodegradation of TPH, PAM and organic matter contained in the soil. Figure 2 shows the plot of CO₂ as a function of time for all treatments. The control treatments, F, have a low amount of CO₂ as shown in Figure 2. Biodegradation of TPH and PAM are responsible for most of the production of CO₂ in our contaminated soil. There was a slight disappearance of PAM as shown in Table 13 of Khaitan (23) for treatment E, so biodegradation of TPH was the primary source of CO₂ produced in the microcosms. The rate of CO₂ production was high initially and then the rate slows down gradually as can be seen from the slopes of the graphs in Figure 2. Treatment B produced the largest amount of CO₂ as it contained the largest amount of TPH. Initially, treatment C produced CO₂ at a high rate and then the rate became very low at t=13 weeks due to the decrease in concentration of TPH. From the TPH plot as a function of time in Figure 1, disappearance of TPH in treatment C is nearing completion, which results in a corresponding reduced rate of production of CO₂. Treatment D continued to produce CO₂ at almost the same rate as shown from the plot in Figure 2; there was a corresponding decrease in the TPH toward the end of the experimental time period of 23 weeks. Biodegradation of TPH in treatment D may be able to continue for a few more weeks as biodegradation does not appear to be near completion. The same reasoning applies for treatment B, the potential to produce CO₂ for several more weeks is indicated by the concentration of TPH at the end of 23 weeks as shown in Figure 1. Treatment A was sterilized and was not expected to produce CO₂, but insufficient sterilization and/or contamination of the treatment resulted in CO₂ production for all sterilized replicates.

Though treatment A had the same concentration of TPH as treatment B, the CO₂ production in treatment A was much less than in treatment B as can be seen from Figure 2. This may be due to the sterilization of treatment A, which reduced the microbial activity in the soil. In Figure 2, CO₂ produced by independent replicates of treatment A for a period of 23 weeks was less than the CO₂ produced by replicates for a period of 13 weeks. This may result from differences in the degree of sterilization and contamination of treatment A replicates. The largest losses of carbon were associated with treatment A. There may be some loss because of the sterilization process. Treatment E produced slightly higher quantities of CO₂ than that produced by treatment F (control) as shown in Figure 2. This is the only evidence for the biodegradation of PAM. The carbon dioxide produced by PAM is low compared to that produced by TPH. Biodegradation of PAM is expected to be slow and may take several years.

Conclusions

Some potential formulations of ATM material are composed of polyacrylamide, petroleum hydrocarbons and residual acrylamide that has not been removed. Biodegradation of polyacrylamide is a slow process and usually takes several years. Polyacrylamide has been shown to be nontoxic to humans, animals, fish and plants, but any residual acrylamide monomer content in PAM products is a neurotoxin to humans and is a major concern in regulation of this polymer. It is concluded that PAM itself, does not pose any environmental threat, and can be used in various applications such as those described in this work and to treat soils to effectively reduce irrigation-induced erosion.

Significant disappearance of petroleum hydrocarbons, of the range C₁₀ – C₁₄, in an open environment is due to volatilization. Hydrocarbons on the surface of soil and other surfaces are

more likely to evaporate than biodegrade. Hydrocarbons deep in the soil are likely to biodegrade to a larger extent than evaporate as they are not exposed to the open environment. Light weight hydrocarbons (undecane and dodecane) are more likely to volatilize from open soil microcosm than the heavier ones (tridecane and tetradecane). In an open soil microcosm, higher molecular weight organics are more likely to biodegrade than the lighter ones.

Based on the findings from microcosm studies, biodegradation of hydrocarbons is likely to occur in soil where there is less opportunity to volatilize. In a one liter headspace at standard conditions, hydrocarbons are not expected to volatilize significantly and thus, any disappearance of hydrocarbons may be due to biodegradation and/or any other source of degradation. TPH carbon is biodegraded to form carbon dioxide and soil organic matter (which includes microbial biomass). A decrease in the concentration of hydrocarbons may lead to lower rates of mineralization and production of carbon dioxide. Endogeneous metabolism in which microbes feed on the existing organic matter in soil also produces carbon dioxide.

Equilibrium values of the of major components of TPH in the formulations investigated are found to be below REL (Recommended Exposure Limit), which implies that these components do not pose a hazard for the indoor environment even if the equilibrium concentration is reached. The CO₂ evolution curves obtained provide support for the biodegradation of TPH in ATM.

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Table 1. Physical Properties of Selected Components of TPH.

Component	Mol. Formula	Mol. Weight (g/mol)	Vapor Pressure (T=25° C) mm Hg	Log K_{ow}^c	Solubility^d g/L
Undecane	C ₁₁ H ₂₄	156	0.5988 ^a	6.94	Sparingly soluble
Dodecane	C ₁₂ H ₂₆	170	0.12 ^b	7.24	3.75E-05
Tridecane	C ₁₃ H ₂₈	184	0.0375 ^b	7.57	Sparingly soluble
Tetradecane	C ₁₄ H ₃₀	198	0.0286 ^a	7.2	Sparingly soluble

^aPerry and Green (28).

^bLide (25).

^cGustafson et al. (19).

^dSafety Sheets from Acros Organics and Fisher Scientific (2; 18).

Table 2. Disappearance of Petroleum Hydrocarbons in Mixture of Organics From Open Soil Microcosm.

Time	t=0	t=2weeks	t=4weeks
Weight of TPH	0. 24 g	0. 015 g	0. 013 g

Table 3. Mole Fractions of Selected Components of TPH.

Component	Total TPH Counts	Component Counts	Mole Fraction^a
Undecane	10023700	214249	0.022
Dodecane	10023700	700273	0.069
Tridecane	10023700	962008	0.096
Tetradecane	10023700	221210	0.022

^aRatio: Component Counts/ Total TPH Counts.

Table 4. Exposure Limits for Some Hydrocarbon Components in Mixtures of Organics.

Component	Mole Fraction^a	Vapor Pressure (T=25° C) mm Hg	Partial Pressure Mm Hg	Mole Fraction in air	ppm in Air	REL in air ppm
Undecane	0.022	0.5988 ^b	0.013	1.70E-05	17.00	NA
Dodecane	0.069	0.12 ^c	0.0083	1.10E-05	11.00	500 ^d
Tridecane	0.096	0.0375 ^c	0.0036	4.70E-06	4.70	NA
Tetradecane	0.022	0.0286 ^b	0.00057	7.50E-07	0.75	NA

^aFrom Table 3.

^bPerry and Green (28).

^cLide (25).

^dMSDS (#28230) Dodecane: Chevron Phillips Chemical Company LP (9).

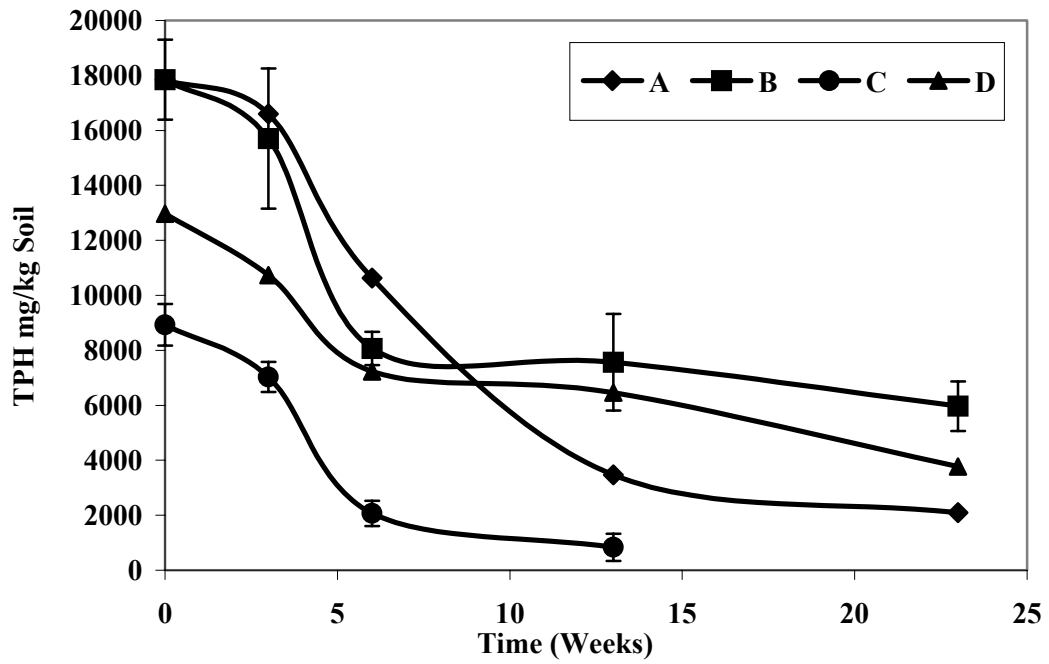


Figure 1. TPH Disappearance With Time in Closed Soil Microcosms. Error Bars for Mean Values are Shown for B and C.

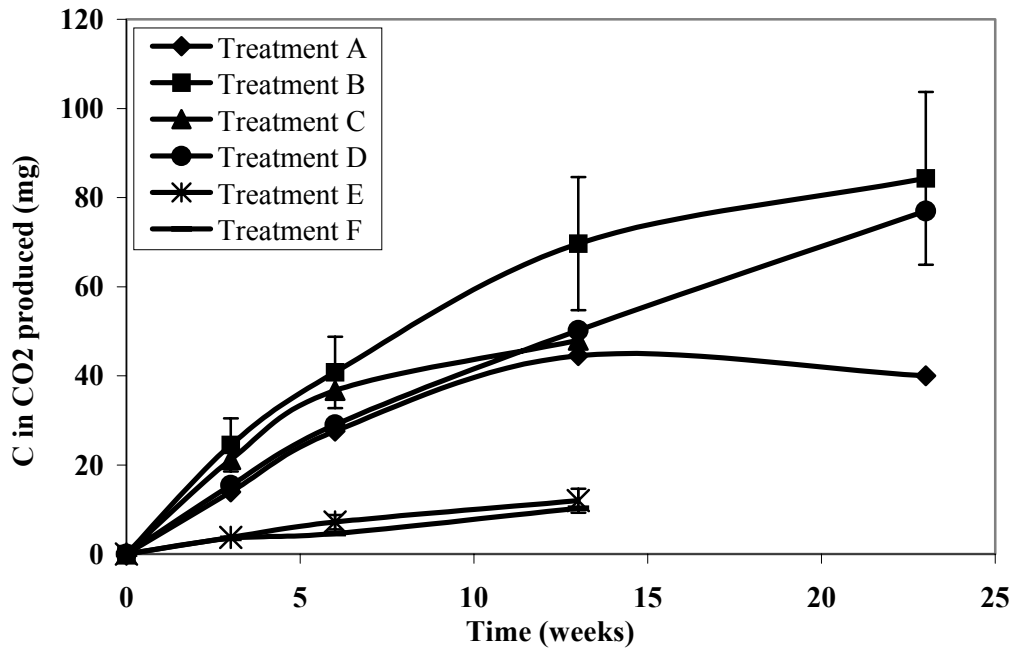


Figure 2. Carbon Dioxide Production in Soil Microcosm Over Time. Error Bars for Mean Values are Shown for B and E.