Mineral Insulating Oils Used in the Power Industry

Chemical Composition and Dissolution Characteristics

Technical Report

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Chemical Composition and Dissolution Characteristics

1000141

Final Report, September 2000

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CITATIONS

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This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Mineral Insulating Oils Used in the Power Industry: Chemical Composition and Dissolution Characteristics, EPRI, Palo Alto, CA: 2000. 1000141.

REPORT SUMMARY

Mineral insulating oil (MIO) is the most widely used fluid for electrical insulation and heat transfer in the power industry. EPRI has recognized the utility need for data on the chemical composition and physical properties of new and used MIOs. This final report presents the results of laboratory tests for 53 samples of MIO submitted by utilities throughout the USA. The report combines data from earlier EPRI reports with new data for 23 supplemental samples.

Background

In 1996, EPRI published two reports that presented data on the chemical composition, physical properties, and environmental characteristics of 18 samples of MIO. Most of those samples were produced from a single refiner and were collected from the system of a single utility. In order to expand the MIO database, EPRI initiated a follow-up study designed to analyze MIO samples from different refiners and collected from several utilities across the country. In this way, a more representative database of MIO characteristics would be available to utilities.

Objective

To generate certain chemical and physical property data on a diverse set of MIO samples.

Approach

Approximately 25 utilities throughout the country were contacted and asked to send two to five samples of new and used MIO to the laboratory. Guidance was provided to the utilities on the desired products, ages, and conditions of the samples. Six utilities responded by sending a total of 23 samples. These samples were analyzed for volatile and semivolatile organic compounds (VOCs and SVOCs), metals, volatile petroleum hydrocarbons (VPH), extractable petroleum hydrocarbons (EPH) and selected physical properties, including specific gravity, viscosity, liquid-water interfacial tension, liquid-air interfacial tension, average molecular weight, and vapor pressure. Also, the samples were equilibrated with water and the concentrations of VOCs and SVOCs in the aqueous phase were measured. The data were combined with data reported in previous EPRI reports.

Results

MIO is a complex mixture of hydrocarbons similar to certain lubricating oils. The amount of aliphatic and aromatic hydrocarbons comprising the various oils ranged from about 90:10 to 75:25 aliphatic to aromatic compounds, on a weight percent basis. However, one sample was found to be about 43% aromatic. Most of the compounds in MIO were unidentified alkanes, naphthenes, and alkylated aromatic compounds. However, small amounts of VOCs were detected in some of the samples. For example, benzene, toluene, ethylbenzene, and xylenes were

detected at concentrations ranging from non-detect to 270 mg/kg in the neat (pure) oil. SVOCs were detected at concentrations ranging from non-detect to 392 mg/kg.

In addition to VOCs and SVOCs, metals were detected at low concentrations in some MIO samples. While the new MIO appeared to be relatively free of metals, no trend in metals content was apparent among the used MIO samples.

Certain VOCs and SVOCs were detected at low concentrations in aqueous dissolution tests. For example, VOCs were detected from less than 0.5 µg/L to 90 µg/L of toluene in one sample. A few SVOCs were detected at concentrations ranging from less than about 0.5 µg/L to 48.7 µg/L of 3 and 4-methylphenol (m/p-cresol) in one sample. With consideration that the service histories of many samples were uncertain, it did appear that older MIOs produced higher concentrations of VOCs and SVOCs in water, generally.

Finally, some physical properties of MIO samples were similar to those of middle distillate fuel oils and light lubricating oils. In particular, the average specific gravity was 0.877 and the average kinematic viscosity (at 40°C) was 9.1 cSt. The liquid-water interfacial tension ranged from 16 to 38 dynes/cm, while the liquid-air interfacial tension ranged from 23 to 36 dynes/cm. Vapor pressure measurements indicated an average vapor pressure of 21 pascals at 79.4 ^{o}C. Finally, the mean molecular weight of MIO samples was 266 g/mole.

EPRI Perspective

Mineral insulating oil is in wide use in throughout the world as a dielectric fluid. Occasionally, leaks or spills of mineral insulating oil result in contamination of soil or water. Assessment and remediation of these leaks or spills can be very costly, yet they generally pose little risk to human health and the environment. Determining appropriate, cost-effective responses to leaks or spills requires careful estimate of risk, and that requires knowledge of the chemical composition of the fluid. EPRI’s TR-106898 reported the chemical constituents of mineral oil samples from one manufacturer, and TR-114129 provided interim results from this study of chemical characterizations of a wider variety of fluids. This final report summarizes all of the data developed by EPRI to characterize mineral insulating oils. EPRI’s Mineral Oil Spill Evaluation System, MOSES-MP, TR-106899, allows users to estimate the probability that a spill will reach surface water or groundwater and allows a company to consider abatement measures. TB-111083 considers the health risk of mineral oil spills.

Keywords

Mineral oil
Dielectric fluid
Groundwater quality
Transformers

ABSTRACT

This report presents the results of analyses of 53 samples of mineral insulating oil (MIO). The samples were analyzed for specific gravity, kinematic viscosity, liquid-water interfacial tension, liquid-air interfacial tension, vapor pressure, average molecular weight, VOCs, SVOCs, VPH, EPH, metals, and solubility. This report presents the data for 11 new MIO samples and combines the data for these new samples with that of the previously reported 42 MIO samples analyzed by EPRI. The data provided in this report can be used by environmental managers to estimate the impact of MIO releases, to design sampling and analysis programs, to estimate potential human health and ecological risks, and to design remedial measures.

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INTRODUCTION

More than one billion gallons (3.8 billion liters) of mineral insulating oil (MIO) are estimated to be in service in the United States (U.S.) power utility industry, primarily in transmission and distribution equipment [1]. MIO spills and leaks occur, and the assessment and remediation of those incidents are significant costs for utilities [2].

In 1996, EPRI generated chemical and physical property data on approximately 18 samples of MIO. The data included concentrations of some volatile and semivolatile organic compounds (VOCs, SVOCs), metals of regulatory importance, solubility in water, viscosity, surface tension, and specific gravity. The results of that study are contained in two EPRI reports [3,4]. Those data have been used extensively by EPRI members in support of environmental investigations and remedial designs. However, the sample results in the existing EPRI database include data from only two products, Shell Diala and Exxon Univolt from a limited geographic area and period of time, and may not encompass the full variability in MIO properties of environmental interest.

In response, EPRI initiated a supplemental program to analyze more samples of MIO. The samples were chosen to cover a range of product types, ages, service histories, and geographical areas. A summary of the results of the first set of 12 supplemental MIO samples was provided in an interim report [5]. This report combines all the supplemental sample data with the earlier data to provide a robust database that is representative of MIO properties generally.

Objectives

The objective of this study was to compile and present chemical composition, physical property values, and aqueous solubility data for samples of MIO provided by several utilities from various regions of the country. In all, 53 samples of MIO from 10 utilities in eight States were analyzed for selected chemical and/or physical properties. In addition, three samples of pharmaceutical mineral oil were analyzed for selected chemical parameters.

Approach

The work was conducted in three phases.

1. In the initial phase, 18 samples of MIO were collected by four utilities and sent to META Environmental, Inc. (META) for chemical and physical analyses. The 18 samples included MIO from two manufacturers supplying two regions of the country. The samples covered a range of ages from unused to more than 40 years old.

2. The next phase of the study was a survey of the historical and current uses of MIOs in the power industry. During this phase of the research, information was obtained regarding the changes in MIO refining processes over time, and the numbers and names of major producers. This information was used to identify producers and geographical regions for samples to augment the existing data.

3. In the third phase, twenty-three new and used MIOs were collected by utilities and shipped to META for chemical and physical characterization. The samples were chosen to cover a range of product types, in-service age, and geographical area. These samples have been coded as M01 to M23. Laboratory studies were conducted using U.S. Environmental Protection Agency (EPA) [6] methods or modifications of those methods, and American Society for Testing Materials (ASTM) methods.

History of Mineral Insulating Oil Use in the Power Industry

Background information on the production and nature of MIOs was summarized in the interim report [5]. Some of that information is repeated here for convenience.

Mineral Insulating Oil Sources and Refining

In general, mineral oils are highly refined fractions of crude oil from a group of products that includes lubricating oils, hydraulic oils, insulating and dielectric oils, white oils, pharmaceutic and food-grade oils, and others. However, this study focused on only those mineral oils used for insulation and heat transfer purposes in electrical equipment. These oils are sometimes referred to as transformer oils, electrical insulating oils, or mineral insulating oils.

In the U.S., MIOs are made from naphthenic crude oils. Selected crude oil compounds or classes of compounds are removed by a combination of distillation, acid treatment, solvent extraction, or hydrogenation methods. The compounds removed include water; volatile compounds; high boiling compounds and asphaltic materials; paraffinic hydrocarbons; some aromatic hydrocarbons; sulfur, nitrogen, and oxygen-containing compounds; and mineral matter. The resulting MIOs have a fairly narrow boiling point range and consist primarily of hundreds of saturated and unsaturated (including aromatic) hydrocarbons.

Usually, MIOs contain no chemical additives except in a few products where small amounts of antioxidants or stabilizers are added to improve long-term performance [7]. The two antioxidants most commonly used are 2,6-ditertiary-butyl-4-methylphenol, also called butylated hydroxytoluene or BHT, and 2,6-ditertiary-butylphenol. BHT is a common food additive.

A brief review of the history of MIO refining over the past 50 years showed that different companies were major producers at various times and that two distinct refining processes have been used. Specifically, prior to the mid-1970s, MIOs were mostly acid-refined and clay-finished, while after the mid-1970s, most MIOs were hydrotreated. In some cases, other refining steps were used, such as solvent extraction. Refiners changed to hydrotreating because they could control (reduce) the amount of aromatic hydrocarbons better.

Table 1-1 lists the major refiners for each time period, while Table 1-2 shows some of the products and processes used during those time periods. Brief definitions of the refining processes also are included here.

Table 1-1
Mineral Insulating Oil Suppliers over the Years

Pre-1970	1970 to 1980	Post-1980
Gulf	Gulf	Exxon
Texaco	Texaco	Shell
Mobil	Exxon	Chevron
Sun	Shell	Sun
Exxon	Sun	Pennzoil
Shell	Chevron	

Distillation

Initially, crude oil is separated into fractions by a combination of atmospheric pressure and vacuum distillation. This step generally isolates crude oil compounds by boiling point, a process that gives many petroleum products, including MIO, their “bell-shaped” profile when analyzed by gas chromatography (an instrumental technique that separates the hydrocarbons in complex mixtures by boiling point). However, the crude distillation “cut” that includes MIOs also contains compounds that hinder the electrical and heat transfer properties of the oil. Thus, these initial distillation products are subjected to additional refinement.

Acid Treatment

Acid treatment involves mixing the crude MIO with sulfuric acid. The reactions of sulfuric acid with crude MIO are complex and are somewhat dependent on the nature of the oil and amount of acid used. In general, acid treatment removes sulfur- and nitrogen-containing compounds, olefins, and phenols. Under typical conditions, acid treatment has no effect on the paraffinic, naphthenic, or aromatic hydrocarbon content [1,3,8].

Table 1-2
Selected Historical Mineral Insulating Oil Products

Refiner	Product Name	Principal Treatment
Pre-1972 - 1973 (Beginning of transition from acid refining to present processes)		
Gulf	Transcrest 60	acid refined
Texaco	Texaco 55	acid refined
Mobil	Mobilect[1]	acid refined
Sun	Sun D	acid refined
1973 - 1985		
Gulf	Transcrest H, HI, HI-30[2]	hydrotreated
Texaco	#600, 1515[3]	hydrotreated
Post-1980		
Chevron	Insulating Oil	hydrotreated
Sun	Suntrans II	hydrotreated
Pennzoil	Penreco	hydrotreated
Shell	Diala AX	hydrotreated
Exxon	Univolt 60	hydrotreated

[1] Mobilect is most often designated as Mobilect 24. For one year there was a designation of Mobilect A.

[2] Transcrest H - no inhibitor. Transcrest HI and HI-30 were the same as H but with different amounts of inhibitor.

[3] Texaco Code 1515 was made by acid refining and contained an inhibitor. Texaco Code #600 was the same as 1515 except it contained added inhibitor.

Solvent Extraction

Solvent extraction involves the use of a solvent to preferentially dissolve and extract polar and aromatic compounds from the crude MIO [1,3,8]. Solvent extraction has not been used extensively in MIO refining.

Hydrotreating

Hydrotreating involves heating the crude MIO with hydrogen gas in the presence of a catalyst. During mild hydrotreating, nitrogen, sulfur, and oxygen compounds undergo hydrogenolysis, producing ammonia, hydrogen sulfide, and water, respectively. These by-products are subsequently removed. Also, olefins are saturated, and some metals are selectively removed. With severe hydrotreating, aromatic compounds are converted into saturated hydrocarbons. Thus, by varying the degree of hydrotreating, MIOs with a range of chemical contents can be produced [1,3,8].

White mineral oils are examples of severely treated mineral oil. These oils are used for numerous food and pharmaceutical applications and are approved for ingestion. Because they are ingested or applied dermally, many of the compounds present in the original oil are removed, including organic acids, aromatic compounds, and heterocyclic compounds. The oils appear clear because the compounds that give mineral oil color are removed.

Clay Finishing

Some MIOs are passed through columns of clay material as a final step in the refining. This treatment with clay removes traces of asphaltic materials and other compounds that give the MIOs unwanted color and odor [8].

Environmental Issues and Challenges

As stated previously, leaks and spills of MIO occur with periodic release of the oil into the surrounding environment. The impact of a release of MIO is dependent on the extent of the release, the toxicity of the MIO, and the sensitivity of the affected area. Because the extent of release and toxicity of the MIO is dependent largely on the physical and chemical properties of the oils, appropriate data are needed to assess environmental impacts. For example, the density, viscosity, and interfacial tensions of MIO will determine its ability to move along the ground, within the soil, and with water. In addition, the presence and concentrations of chemicals toxic to humans or other organisms influence the results of risk assessments. Until recently, many of the physical and chemical properties of environmental interest were not available for a wide range of MIO types and ages. In response, regulators and environmental professionals treated MIOs like other more well characterized refined petroleum products, such as diesel fuel. However, MIOs are more highly refined than diesel fuels and contain far less concentrations of volatile organic compounds, such as benzene. Therefore, cleanup criteria based on assumed physical properties and chemical compositions were found to be very conservative. The data contained in this report address this deficiency by providing physical and chemical data on a large set of MIOs from diverse sources.

2

LABORATORY METHODS AND MATERIALS

MIO Samples

MIO samples were received by META in three general batches. The first batch, received in 1995, included the 18 samples that were reported in References 3 and 4. These samples were collected by four utilities, however most of the samples came from a single utility. Table 2-1 shows the laboratory codes and available service information for the samples received in 1995.

A second batch of 12 samples was received by META from one utility in 1997 and the results were summarized in Reference 9. Table 2-2 shows the laboratory codes and available service information for the samples received in 1997.

Twenty-three additional samples of MIO were shipped to META in 1999 from six utilities. Of the 23 samples received, two of the MIOs were new and 20 had been used in electric equipment. One additional sample was collected from a used transformer oil storage tank and represented a composite of recently reconditioned MIOs. Table 2-3 shows the laboratory codes and available service information for the samples received in 1999.

Most samples were shipped in 1 L amber glass bottles with Teflon®-lined screw caps maintained at 4°C. However, META also received smaller volumes (about 250 mL) of some samples. At META, the samples were stored in a refrigerator at 4°C.

Some “used” samples were received with information on their service histories, however, the details of the MIO source and history was not provided for many of the samples. This was expected since many transformers contain MIOs that have been reconditioned and/or mixed with other MIO sources. Thus, it is often impossible to determine the specific brand and age of MIO in a given transformer or capacitor even when the model and year of the equipment are known, and the MIO purchasing records are available. In response to this uncertainty, the objective of this EPRI study was to obtain approximately 50 samples of MIO from diverse sources having a range of geographic, product, and age characteristics.

Finally, META obtained one sample of white mineral oil from a local pharmacy (Squibb Intestinal Lube), and two samples of white mineral oil from Exxon Biomedical Sciences, Inc. (East Millstone, NJ). The samples were stored in the dark at 4°C until analyzed. Table 2-4 shows the laboratory codes and available information on the white mineral oil samples.

Table 2-1
Mineral Insulating Oil Samples from 1996 EPRI Study (3, 4)

Sample ID	Product	New or Used	Equipment Manufacture Date	Location
Sample 1	Shell Diala	New	NA	Northwest
Sample 2	Exxon Univolt	New	NA	Southeast
Sample 15	Shell Diala	Used	1951	Northwest
Sample 16	Shell Diala	Used	1958	Northwest
Sample 17	Shell Diala	Used	1958	Northwest
Sample 18	Shell Diala	Used	1966	Northwest
Sample 19	Shell Diala	Used	1949	Northwest
Sample 20	Shell Diala	Used	1978	Northwest
Sample 21	Shell Diala	Used	1985	Northwest
Sample 22	Exxon Univolt	Used	1951	Southeast
Sample 23	Exxon Univolt	Used	1976	Southeast
Sample 24	Exxon Univolt	Used	1989	Southeast
Sample 25	Shell Diala	Used	1984	Northwest
Sample 26	Shell Diala	Used	1984	Northwest
Sample 27	Shell Diala	Used	1984	Northwest
Sample 28	Shell Diala	Used	1978	Northwest
Sample 29	Shell Diala	Used	1958	Northwest
Sample 30	Shell Diala	Used	1958	Northwest

Sample ID numbering is as shown in Reference 9

NA - not applicable

Table 2-2
Mineral Insulating Oil Samples Received 1997 (10)

Sample ID	Product	New or Used	Equipment Manufacture Date	Location
Sample 3	Exxon Univolt	Used	Unknown	Southeast
Sample 4	Exxon Univolt	Used	Unknown	Southeast
Sample 5	Exxon Univolt	Used	Unknown	Southeast
Sample 6	Exxon Univolt	Used	Unknown	Southeast
Sample 7	Exxon Univolt	Used	Unknown	Southeast
Sample 8	Exxon Univolt	Used	Unknown	Southeast
Sample 9	Exxon Univolt	Used	Unknown	Southeast
Sample 10	Exxon Univolt	Used	Unknown	Southeast
Sample 11	Exxon Univolt	Used	Unknown	Southeast
Sample 12	Exxon Univolt	Used	Unknown	Southeast
Sample 13	Exxon Univolt	Used	Unknown	Southeast
Sample 14	Exxon Univolt	Used	Unknown	Southeast

Sample ID numbering is as shown in Reference 9

Table 2-3
Mineral Insulating Oil Samples Received in 1999

Sample ID	Product	New or Used	Equipment Manufacture Date	Location
M01	Unknown	Used	1997	Northeast
M02	Unknown	Used	1984	Northeast
M03	Unknown	Used	1958	Northeast
M04	Unknown	Used	Unknown	Southeast
M05	Unknown	Used	1963	Southeast
M06	Unknown	Used	1987	Southeast
M07	CrossTrans 106	New	NA	Southeast
M08	Unknown	Used	1979	Southeast
M09	Unknown	Used	1980	Southeast
M10	Unknown	Unknown	Unknown	Midwest
M11	Unknown	Unknown	Unknown	Midwest
M12	Unknown	Unknown	Unknown	Midwest
M13	Unknown	Used	1994	Northeast
M14	Unknown	Used	Various	Northeast
M15	Exxon Univolt 60	New	NA	Northeast
M16	Unknown	Used	1994	Northeast
M17	Unknown	Used	1960	Northeast
M18	Unknown	Used	Unknown	Northeast
M19	Unknown	Used	Unknown	Northeast
M20	Unknown	Used	Unknown	Northeast
M21	Unknown	Used	Unknown	Northeast
M22	Unknown	Used	Unknown	Northeast
M23	Unknown	Used	Unknown	Northeast

NA - not applicable

Table 2-4
White Mineral Oil Samples

Sample ID	Product	New or Used	Equipment Manufacture Date	Location
M24	Mineral Oil, Intestinal Lube	New	NA	NA
M25	MRD #96-746 Technical grade	New	NA	NA
M26	MRD #96-458 Technical grade	New	NA	NA

NA - Not applicable

Sample Preparation and Analysis

Most of the samples were analyzed for physical and chemical properties using the methods shown in Table 2-5. The target analyte lists for chemical analyses are provided in Appendix A. Some modifications were made to the published methods shown in Table 2-5 to minimize analytical interferences and to lower detection levels. Brief descriptions of the methods as applied to the MIO samples are provided in the following subsections.

Volatile Organic Compounds (VOCs) in MIO

The concentrations of VOCs in MIO were determined by one or both of two methods. For the principal method, a portion of each sample was diluted in methanol at a known concentration. Then, a portion of the methanolic solution was diluted in water in the purge unit of a standard purge and trap GC/MS instrument. The VOCs were determined according to EPA Method 8260B [6]. In the second method, MIO samples were diluted in methylene chloride (DCM) and directly analyzed by GC/MS using a modification of EPA Method 8270C [6]. The modification involved adjustment of the 8270C instrument conditions to calibrate and determine selected VOCs in the same GC run as the target semivolatile compounds. This secondary analysis of VOCs was used as a QC check of the principal method, EPA Method 8260B.

Table 2-5
Characterization Parameters and Methods

Parameter	Method
volatile organic compounds	EPA Method 8260B
semivolatile organic compounds	EPA Method 8270C
volatile petroleum hydrocarbons (VPH), extractable petroleum hydrocarbons (EPH), and total petroleum hydrocarbons (TPH)	VPH/EPH - Massachusetts methods
metals	UOP 391/GFAA (Sb, As, Pb, Se, Tl) UOP 391/ICP (Al, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Mn, Mg, Ni, K, Na, Ag, V, Zn) ASTM D 3684 (Hg)
liquid-water interfacial tension (@25°C)	ASTM D 971
liquid-air interfacial tension (@25°C)	ASTM D 971
density (@22°C)	ASTM D 1298
kinematic viscosity (@40°C)	ASTM D 445
vapor pressure	ASTM D 2879
average molecular weight	Vapor phase osmometry

Semivolatile Organic Compounds (SVOCs) in MIO

SVOCs were determined by EPA Method 8270C [6]. However, to better quantify the low concentrations of certain target compounds, principally PAHs, in the presence of the large amounts of non-target hydrocarbons, an analytical scheme that included class fractionation by acid/base partitioning (EPA Method 3650), on alumina (EPA Method 3611B), and/or on silica gel (EPA Method 3630C mod.) was utilized [6].

In summary, samples of MIO were diluted in pentane and directly analyzed by EPA Method 8270C. This analysis was used to quantify those compounds that were not subject to hydrocarbon interferences, principally low molecular weight and high molecular weight compounds. Then, several portions of each extract were separated on 10 cm columns packed with alumina [3,4] into aliphatic (recovered in pentane or hexane), aromatic (recovered in DCM), and polar (recovered in methanol) fractions. Later, 10 cm silica gel columns were used for this hydrocarbon class fractionation step [9]. The replicates of each fraction were combined and concentrated to 1.0 mL prior to analysis by EPA Method 8270C. In addition, the organic acids were isolated from another portion of each sample using the acid/base partitioning method. The various extracts were then analyzed by GC/MS.

Volatile Petroleum Hydrocarbons (VPH) and Extractable Petroleum Hydrocarbons (EPH)

The VPH and EPH content of each MIO was determined using the Massachusetts methods for those parameters [10,11].

Solubility Tests

The solubility test was a modification of the EPA method in 40 CFR 796.1840 as follows. Each sample was equilibrated with unbuffered, oxygen-free, deionized water at pH 4 and pH 7 in 2-liter glass separatory bottles. Three milliliters of MIO were carefully placed on the inside surface of the bottle; then the separatory bottle was righted and filled with water slowly from the bottom. Each separatory bottle was completely filled so that there was no headspace, placed on a rotary agitator, and rotated end-over-end for 18 hours at 30 revolutions per minute. The laboratory temperature was maintained at 19 to 20°C for the duration of the experiment.

After rotation, each sample was left to stand until the phases separated and the aqueous phase was clear and no suspended droplets were visible. Then, a small Teflon® tube was pushed through the stopcock into the center of the water phase. Sample bottles were then slowly filled through the Teflon® tube in the following order: 2 @ 40 mL-VOA vials for VOCs; 1 @ 1 liter-amber glass bottle for SVOCs; and 1 @ 0.5 liter-polyethylene bottles for metals. The samples were stored at 4°C prior to extraction and analysis.

The aqueous extracts were analyzed for VOCs by EPA Method 8260B; SVOCs were determined by EPA Methods 3510 and 8270C; and the metals were determined by EPA Methods 6000 and 7000. Because the concentrations of metals detected in neat MIO and in solubility studies conducted in 1995 to 1996 [3,4] were very low or not detectable, metals were not determined in the aqueous solutions of the supplemental study (Sample 3 to Sample 14 and M01 to M23).

Quality Assurance and Quality Control

The samples were received in 13 separate batches from many sources over several years. Most samples were shipped by overnight courier in 1 liter-amber glass bottles with Teflon-lined screw caps packed on ice. Upon receipt, the integrity of each sample bottle was checked, the sample was logged and stored in a refrigerator at 4°C dedicated to MIO samples and other similarly refined petroleum fluids. In some cases, samples were held for several weeks until analytical batches of 10 or more samples had been received.

The quality control procedures specified by the analytical methods were followed. These included such measures as regular instrument tuning and calibration, use of surrogate and internal standard compounds, and the preparation of method, equipment, and fractionation blanks, spiked blanks, duplicate samples, and matrix spikes.

3

RESULTS OF PHYSICAL AND CHEMICAL CHARACTERIZATION OF MIOS

This report presents the laboratory results obtained since the publication of the interim report [5] plus pooled data from all samples analyzed as part of EPRI's MIO research. The new results include: SVOCs in the 12 MIO samples (M01 to M12) that were the subject of the interim report [5]; physical properties, metals, VOCs, VPH/EPH, and SVOCs in the 11 MIO samples (M13 to M23) analyzed since the interim report; and dissolution test results for all 23 samples (M01 to M23). Tables 2-1 through 2-4 show the laboratory codes for the supplemental samples as well as the older sample batches.

Physical and Bulk Property Results

Table 3-1 contains the results for specific gravity, kinematic viscosity, liquid-water interfacial and liquid-air interfacial tension for the 11 MIO samples M13 to M23. The specific gravity values ranged from 0.855 to 0.883, which agree well with those reported on material safety data sheets (MSDSs) and in previous EPRI studies [3,5,9,12,13,14]. The data show that MIOs are less dense than water, and therefore will behave as LNAPLs (light non-aqueous phase liquids) when released into the environment. Table B-1 lists the specific gravity results for all samples analyzed. The average specific gravity for all samples was 0.877.

Table 3-1
Selected Physical Properties of Mineral Insulating Oils

Sample	Specific Gravity, 60/60	Viscosity, kinematic, cSt at 40°C	Liquid-water Interfacial tension, dynes/cm	Liquid-air interfacial tension, dynes/cm
M13	0.877	9.53	34	24
M14	0.856	7.75	46	28
M15	0.855	7.64	43	29
M16	0.881	9.83	37	30
M17	0.873	9.22	18	29
M18	0.871	8.89	37	25
M19	0.875	9.27	29	30
M20	0.883	9.14	38	26
M21	0.868	8.72	30	23
M22	na	na	na	na
M23	0.879	10.30	18	30

na – not analyzed; insufficient sample

The range of viscosities of the MIOs presented in Table 3-1 was 7.74 to 10.30 cSt at 40°C. These values were lower than those given in other EPRI reports [3,9] because the temperature at which the viscosities were measured for samples M13 to M23 was higher than in earlier analyses (40°C for this data set, 25°C for the previous data set). Regardless, the viscosity values are typical for MIOs, as reported previously [9], and are slightly more viscous than gasoline or diesel fuel.

The average viscosity for all samples measured at 40°C (M01 to M23) was 9.1 cSt and the median was 9.21 cSt. The viscosities at 40°C ranged from 7.64 to 10.3 cSt. The viscosities for Sample 1, Sample 2, and Samples 15 to 30 are shown in Table B-1.

Interfacial tension is a measure of the force acting at the boundary between two phases. If the phases are a liquid and air (liquid-air interfacial tension), the forces are referred to commonly as surface tension. The forces are referred to commonly as interfacial tension if the phases are two immiscible liquids (liquid-liquid interfacial tension). The liquid-air interfacial tension of an organic liquid is one of the important characteristics that determines the residual amounts of that liquid in the vadose zone and the forces needed to mobilize the residual liquid. Similarly, the liquid-water interfacial tension is one of the important characteristics of an organic liquid that influences its residual amounts and mobilization forces in the saturated zone [15].

Table 3-1 shows the liquid-water and liquid-air interfacial tensions for samples M13 to M23. The liquid-water interfacial tension values ranged from 18 to 46 dynes/cm, which is in the range for MIOs reported previously [3,5,9]. The liquid-air interfacial tension values ranged from 23 to 30 dynes/cm, which also is in the range for MIOs reported previously.

The liquid-water interfacial tension of MIOs has been shown to decrease with use. This effect is considered an indication of MIO deterioration with the associated increase in the amount of oxidized constituents [8,16]. The data for samples M13 to M23 appear to follow this trend, since the lowest liquid-water interfacial tensions were measured in samples M17 and M23 which appear to be the oldest samples in the data set (Table 2-3). For example, the liquid-water interfacial tension of sample M17 (about 40 years old) was 18 dynes/cm as compared to 43 dynes/cm for new Exxon Univolt 60 (sample M15). However, because the actual MIO product and the specific service histories for these samples were not well known, a relationship between in-service age and liquid-water interfacial tension could not be established for all the samples.

The range of liquid-water interfacial tensions for all samples analyzed (Sample 1, Sample 2, Samples 15 to 30, and Samples M01 to M23) was 16 to 46 dynes/cm. This range is similar to that observed for new and used MIOs [7].

The specific gravity, viscosity, liquid-water interfacial tension, and liquid-air interfacial tension values for all samples analyzed are listed in Table B-1.

Vapor pressure curves for samples M01 to M23 were measured using an isoteniscopic method (ASTM D2879). The data are shown in Table B-2. As expected, MIO vapor pressures are low, averaging 21 Pa (0.15 torr) at 79.4°C. The vapor pressures for the 23 samples ranged from 13 to 29 Pa (0.10 to 0.22 torr) at 79.4°C. These values are in contrast to vapor pressures for gasoline, 51,000 to 100,000 Pa at 37.8°C [17], and diesel, 2,000 Pa at 37.8°C [18]. It is clear that new or used MIOs will produce little or no chemical vapors in the environment, especially at the relatively low temperatures that exist in the subsurface (about 10 to 15°C).

The average molecular weight of hydrocarbon mixtures such as MIO is needed for estimating the mole fraction of individual constituents, and thus calculating the aqueous solubility of those constituents. The average molecular weights of samples M01 to M23 were determined by vapor phase osmometry and are listed in Table B-3. The molecular weights ranged from 233 to 335 g/mole with a mean of 270 g/mole and a median of 264 g/mole. These values are comparable to those reported previously by EPRI where the molecular weights of Sample 1, Sample 2, and Samples 15 to 30 ranged from 239 to 271 g/mole with a mean of 257 g/mole [3]. The greater range observed among samples M01 to M23 as compared to the earlier results may be a reflection of the greater diversity in types and sources of MIO in this most recent group of samples.

When the data from both studies are pooled the range is 233 to 335 g/mole, the mean is 266 g/mole with a median of 260 g/mole.

Chemical Characterization

MIOs are complex mixtures of hundreds of organic compounds, primarily hydrocarbons. Hydrocarbons are compounds comprised of carbon and hydrogen only, and are classified by their structures as alkanes, naphthenes, olefins, or aromatic compounds. It is recognized that it is technically impossible to separate, identify, and quantify all of the compounds in MIO or similar complex petroleum products. Thus, no attempt was made in this study to identify all of the compounds in MIO or to establish a mass balance. Instead, selected compounds of environmental regulatory importance were measured in the oils, including VOCs, SVOCs, and metals. The full lists of compounds analyzed in this study are provided in Appendix A.

Metals

Table 3-2 presents the concentrations of metals in neat MIO samples M13 to M23. Seven metals (calcium, copper, iron, lead, sodium, vanadium and zinc) were detected in one or more samples. The concentrations of metals found in the samples were very low, many close to the detection limits of the method. Of the metals found, copper, sodium, and zinc were detected in two samples. Calcium, iron, and vanadium were detected in three samples, and lead was detected in four samples. Of these metals, calcium, iron, copper, sodium, and zinc were found frequently in these samples and other MIO samples reported earlier [3,10,13]. Table 3-3 shows summary statistics for all of the MIO samples analyzed and Table B-4 provides the metals data for all of the samples analyzed.

It is important to note that the laboratory observed a positive interference in the analysis of mercury from the organic matrix. Therefore, the results for mercury near the mercury detection limit may be false positives and should be considered uncertain.

Table 3-2
Metals in MIOs (mg/kg)

Metal	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23
Calcium (0.5)								6.3	2.4	0.6	
Copper (0.5)							0.6	1.1			
Iron (0.5)								0.7	1.4		1.1
Lead (0.1)						0.2	0.5	3.6			0.9
Sodium (5)							36	42			
Vanadium (0.5)						0.5	1.4	1.5			
Zinc (0.5)								0.9	0.5		

A blank space denotes not detected at the reporting limit shown in parentheses. All other metals were not detected in any sample at the reporting limits shown in Appendix A.

Table 3-3
Summary of Metals Results in all MIO Samples (mg/kg)

	New Oil (n=4)			Aged Oil[3]	
	Mean	No. Detects[1]	Range[2]	Mean	Median
Aluminum	21	21/42	2.0 - 29	13.2	10
Antimony	0.2	0/42			
Barium	0.51	9/42	0.45 - 0.57	0.51	0.51
Cadmium		4/42	1.0 – 2.5	1.6	1.5
Calcium	20.7	33/42	0.6 - 74	15.2	7.0
Cobalt		4/42	1.0 - 1.0	1.0	1.0
Copper		16/42	0.5 - 43	9.5	7.0
Iron	7.1	29/42	0.7 - 50	7.5	4.4
Lead	0.1	13/42	0.1 - 3.7	1.7	0.9
Magnesium		17/42	3.0 – 36	13.9	6.0
Mercury	0.3	8/42	0.02 - 0.05	0.03	0.03
Nickel		3/42	3.0 - 14	9.7	12
Selenium	0.2	4/42	0.1- 0.3	0.2	0.1
Silver		1/42	1.6 – 1.6	1.6	1.6
Sodium	11	27/42	7 - 190	42	54
Vanadium		6/42	0.5 – 1.6	1.1	1.2
Zinc	7.5	21/42	0.5 - 38	8.1	4.0

[1] number of detects out of 42 samples of aged MIO.

[2] range, mean, and median are based on detects of aged MIO only. Non-detects are not included in the calculation.

[3] aged oils were collected from in-service transformers or used MIO storage tanks.

all other metals (As, Be, Cr, Mn, K, Tl) were non-detect in all samples.

Table 3-4 shows the concentrations of metals found in three samples of white mineral oil. As seen in the table, even these very highly refined oils contained detectable levels of metals, however the concentrations are relatively low. In fact, the concentrations of calcium, copper, iron, magnesium, nickel, and zinc were similar among Samples M24, M25, and M26 and the MIO samples. Also, the concentrations of aluminum and sodium were generally higher in the white mineral oils than in the MIOs.

Table 3-4
Metals in White Mineral Oils (mg/kg)

Metal	**M24**	**M25**	**M26**
Aluminum (5.0)	2	3	3
Calcium (0.5)	6	9	15
Copper (0.5)	1	2	3
Iron (0.5)	3	7	7
Magnesium (5)	4	3	5
Mercury (0.02)		0.02	0.05
Nickel			22
Sodium (5)	88	63	260
Zinc (0.5)			3

A blank space denotes not detected at the reporting limit shown in parentheses. All other metals were not detected in any sample at the reporting limits shown in Appendix A.

Volatile Organic Compounds

Previous analyses of MIO have shown that certain VOCs are present at low concentrations. The results of analyses of Samples M13 to M23 confirm that finding. However, as indicated in earlier reports, the volatilities and solubilities of VOCs are significantly greater than the more abundant higher-boiling hydrocarbons that comprise MIO. Therefore, their presence at low amounts could be important should the MIO enter the environment. In response, MIO Samples M13 to M23 were analyzed for the VOCs listed in Appendix A. Table 3-5 shows the concentrations of VOCs detected in neat MIO samples. Low concentrations of VOCs were found in every sample from this batch. Most of the VOCs detected were monocyclic aromatic hydrocarbons (MAHs), including benzene, toluene, ethylbenzene, xylenes, styrene, and other alkylated benzenes. These findings were consistent with both the refining history, and thus the expected composition of MIOs, and with previous EPRI results.

Table 3-6 summarizes the VOC data for all 43 samples analyzed. The full data set is given in Table B-5. In addition to MAHs, several other VOCs were detected in one or more MIO sample. These included acetone (6 samples), carbon disulfide (1 sample), 2-butanone (4 samples), 1,1,1-trichloroethane (3 samples), 2-hexanone (3 samples), tetrachloroethene (2 samples), 1,2,4-trichlorobenzene (4 samples), and chloroform (1 sample). The presence of these non-petroleum hydrocarbon compounds in MIO was sporadic. The sources of these compounds could not be determined with the available data.

Table 3-5
VOCs in MIOs (mg/kg)

VOCs	M13	M14	M16	M17	M18	M19	M20	M21	M22	M23
2-Butanone (MEK)			2.6				1.7		6.4	
Chloroform									**0.52**	
1,1,1-Trichloroethane									1.4	
Benzene				1.3				4.9	**0.82**	
Toluene		1.1	**0.79**	2.2	1.1		3	15	51	
2-Hexanone									1.8	
Ethylbenzene		**0.68**		2.1	**0.73**		1.5	2.9	2.5	
m/p-Xylene		2.4	2	5.7	1.3	1.4	8.1	8.4	15	
o-Xylene		**0.55**	1.1	2.8	**0.49**	**0.62**	5.3	2.9	6.6	
Styrene				**0.58**						
Isopropylbenzene		**0.5**		**0.74**	**0.71**			0.77	1.4	
n-Propylbenzene		**0.74**		1.5	1.1			1.3	2.4	
1,3,5-Trimethylbenzene		1.1	1.6	4.9	1.5	1.1	1.1	2.3	7.1	
tert-Butylbenzene									**0.52**	
1,2,4-Trimethylbenzene	**0.92**	3.7	5	15	5.5	3.7	2	9.9	19	0.85
p-Isopropyltoluene		1.5	**0.73**	2.6	2.5	1		3.3	3.6	
1,4-dichlorobenzene						**0.57**				
sec-Butylbenzene		7.1	**0.52**	4.5	8.9	2.5		7.2	2.6	
1,2,4-Trichlorobenzene							4.1			

A blank space denotes not detected. The reporting limits varied from about 0.5 to 1.0 mg/kg.
All other VOCs were non-detect in all samples.
Bold - denotes an estimated value below the calibrated range.

Table 3-6
Summary of VOCs Results in all MIO Samples (mg/kg)

	New Oil (n=4)	Aged Oil[3]			
	Mean	No. Detects[1]	Range[2]	Mean	Median
Acetone		6/41	0.81 – 0.79	2.69	1.05
Carbon disulfide		1/41	1.2 – 1.2	1.20	1.2
2-Butanone (MEK)		4/41	1.7 – 6.4	3.85	3.65
Chloroform		1/41	0.52 – 0.52	0.52	0.52
1,1,1-Trichloroethane		3/41	0.58 – 2	1.33	1.4
Benzene	0.58	13/41	0.22 – 5.5	1.43	0.82
Toluene	1.4	32/41	0.31 – 270	12.3	2
2-Hexanone		3/41	1.1 – 1.8	1.37	1.2
Tetrachloroethene		2/41	0.33 – 1.8	1.07	1.065
Ethylbenzene	0.91	27/41	0.21 – 20	1.89	0.88
m/p-Xylene	3.0	34/41	0.34 – 70	5.56	2.1
o-Xylene	1.2	32/41	0.2 – 40	3.03	0.905
Styrene		9/41	0.21 – 1.3	0.53	0.4
Isopropylbenzene	0.48	13/33	0.3 – 2.3	0.81	0.6
n-Propylbenzene	0.96	11/33	0.36 – 3.4	1.37	1.1
1,3,5-Trimethylbenzene	1.4	24/33	0.27 – 11	1.95	1.1
tert-Butylbenzene		2/33	0.5 – 0.52	0.51	0.51
1,2,4-Trimethylbenzene	5.8	31/33	0.41 – 23	4.27	2
p-Isopropyltoluene	1.3	20/33	0.34 – 3.9	1.67	1.15
1,4-dichlorobenzene		1/41	0.57 – 0.57	0.57	0.57
sec-Butylbenzene	6.8	21/33	0.25 – 8.9	2.88	2.2
1,2,4-Trichlorobenzene		4/41	1.2 – 4.1	3.15	3.65
Naphthalene	0.7	20/32	1.2 – 27	4.80	2.45

[1] number of detects out of the total number of samples of aged MIO analyzed.
[2] range, mean, and median are based on detects of aged MIO only. Non-detects were not included in the calculation.
[3] aged oils were collected from in-service transformers or used MIO storage tanks.
all other VOCs were non-detect in all samples.

The three white mineral oils, M24 to M26, were analyzed for selected VOCs, including benzene, toluene, ethylbenzene, and xylenes by waste dilution and GC/MS/SIM. One VOC was detected above 10 mg/kg in one sample. Styrene was detected at 17.2 mg/kg in sample M24. All other VOCs were below detection limits. The lack of VOCs in the white mineral oils is consistent with the severity of the refining of these oils.

Semivolatile Organic Compounds

The principal constituents of MIOs fall within the boiling point range considered to be semivolatile compounds. SVOCs is a general category of compounds that includes PAHs and many non-PAH compounds as shown in Table A-2. As stated previously, a full characterization of all of the SVOC compounds in refined petroleum oils is impossible. However, appropriate sample preparation and analysis methods were shown to be able to measure certain compounds of regulatory interest in MIO samples during previous EPRI research [3,9]. Both selected PAHs and non-PAH compounds were measured in MIO. In this section, PAHs and non-PAH compounds are discussed separately.

Table 3-7 provides the SVOCs found in the 23 supplemental samples of MIO (M01 to M23). Because the SVOC data for the Samples M01 to M12 were not included in the interim report [5], they have been included in Table 3-7 along with Samples M13 to M23.

Table 3-7
SVOCs in MIOs (mg/kg)

SVOCs	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12
Phenol		0.4	1.05	0.9	0.85	0.4				0.1		
2,4-Dimethylphenol		0.71			0.27	0.21		0.19		0.48		
2-Methylphenol		0.24		0.11	0.29					0.24		
3 and 4-Methylphenol		0.38	0.29	0.14	0.34	0.14				0.05		
Dibenzofuran												
Naphthalene	2.70	10.1	12.2	21	30.5	5.24	3.64	6.59	1.82	4.4	6.58	
2-Methylnaphthalene	66.0	46	71.2	80.6	36.2	38.8	21.2	39.9	3.45	18.3	24.8	
Fluorene		58.8					33.1					
Phenanthrene		232	33.3	112	204	282	55.2	243		30.6	18.9	
Anthracene						43.1	26.1	37.9				
Fluoranthene							13.8					
Pyrene							14.9					
Benz(a)anthracene							9.5					
Chrysene							9.01					

A blank space denotes not detected. The reporting limits varied from about 1.5 to 8 mg/kg for PAHs and from about 0.05 to 0.5 mg/kg for organic acids.

Table 3-7
SVOCs in MIOs (mg/kg) (Continued)

SVOCs	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23
Phenol				0.08	0.83				0.71	0.77	1.12
2,4-Dimethylphenol	0.16	0.31	0.31	0.13	1.8	0.59	0.25		0.32	0.35	0.11
2-Methylphenol	0.06	0.14	0.12		0.67	0.33	0.33		0.23	0.82	0.11
3 and 4-Methylphenol		0.05	0.04		0.46	0.26	0.26		0.08	0.98	0.11
Dibenzofuran					19.8						
Naphthalene	2.9	3.68	3.3	1.68	8.37	6.91	4.37	1.28	7.85	14.5	33.2
2-Methylnaphthalene		27.4	24.1	42	27.5	45.1	18.5	1.07	35.3	117	219
Fluorene		28.1	28.1								
Phenanthrene		19	19		39.1	40.8	49	50.6	25.7	243	178
Anthracene											
Fluoranthene											
Pyrene											
Chrysene								4.77		6	

A blank space denotes not detected. The reporting limits varied from about 1.5 to 8 mg/kg for PAHs and from about 0.05 to 0.5 mg/kg for organic acids.

Table B-6 lists the PAHs and Table B-7 lists the other SVOCs detected in all of the 46 MIO samples analyzed for SVOCs. SVOCs were not determined in Samples 15, 19, 23, 24, 27, 28, and 30. Also, Sample 3 through Sample 14 were analyzed for PAHs only. Nine of the 17 PAHs measured were found in one or more MIO sample. Of these nine, only four PAHs were detected in more than three samples. Table 3-8 shows summary statistics for PAHs in MIO. Naphthalene, 2-methylnaphthalene, fluorene, and phenanthrene were detected in 24 to 44 MIO samples analyzed. The concentrations of PAHs in MIO ranged from not detected at about 1 mg/kg to 392 mg/kg of phenanthrene in one sample. In contrast, only naphthalene at 15.5 mg/kg and fluoranthene at 26.5 mg/kg were detected in any of the three white mineral oil samples (the detection limit for the analysis of white mineral oils was about 10 mg/kg).

Four samples, Sample 22, M08, M20, and M22, contained one or more of the carcinogenic PAHs, benz(a)anthracene and chrysene. The available information indicates that two of those samples were from equipment that was 50 years old or more. One sample was from a 20 year-old piece of equipment, and no information was available on the fourth sample. Though sparce, the data suggests that modern refining produces MIOs with lower levels of high molecular weight PAHs than from past practices.

Table 3-8
Summary of PAHs Results in all MIO Samples (mg/kg)

	New Oil (n=4)	Aged Oil[3]			
	Mean	**No. Detects[1]**	**Range[2]**	**Mean**	**Median**
Naphthalene	2.52	45/49	0.82-33.2	6.39	4.23
2-Methylnaphthalene	10.3	44/49	1.07-219	34.9	26.1
Fluorene	16.4	24/49	0.92-77.1	25.1	21.1
Phenanthrene	16.9	40/49	1.18-392	98.1	44.9
Anthracene		3/49	26.1-43.1	35.7	37.9
Fluoranthene		1/49	13.8	13.8	13.8
Pyrene		1/49	14.9	14.9	14.9
Benz(a)anthracene		1/49	9.5	9.5	9.5
Chrysene		3/49	2.11-9.01	5.39	5.47

[1] number of detects out of 42 samples of aged MIO.

[2] range, mean, and median are based on detects of aged MIO only. Non-detects were not included in the calculation.

[3] aged oils were collected from in-service transformers or used MIO storage tanks.

all other PAHs were non-detect in all samples.

In addition to the 16 parent PAHs (unsubstituted) and one methylPAH determined by EPA Method 8270, MIOs contain many alkylated PAHs. The concentrations of 25 parent and alkylated PAHs were measured in 11 MIO samples (extended PAH profile) by GC/MS/SIM. Table B-8 shows the data for all 11 samples while Table 3-9 shows the average extended PAH profile for the 11 samples. The pattern of PAHs and alkylated PAHs follows the patterns of other refined petroleum products generally with the parent PAHs being less abundant than their alkylated homologs and with the C2- and C3-alkylated homolog groups as the most abundant in each series. No fluoranthene, pyrene, benz(a)anthracene, chrysene, or alkylated chrysenes were detected in these samples above a detection limit of about 1 mg/kg.

Table 3-9
Average Concentration (mg/kg) of PAHs and Alkylated PAHs in 11 MIO Samples

Compound	Mean	Standard Deviation
Naphthalene	4.6	2.3
C1-Naphthalene	29	19
C2-Naphthalene	350	240
C3-Naphthalene	790	670
C4-Naphthalene	2000	2600
Fluorene	37	22
C1-Fluorene	220	190
C2-Fluorene	520	410
C3-Fluorene	140	98
Dibenzothiophene	45	24
C1-Dibenzothiophene	330	120
C2-Dibenzothiophene	99	58
C3-Dibenzothiophene	150	110
Phenanthene/Anthracene	150	120
C1-Phenanthrene/Anthracene	260	210
C2-Phenanthrene/Anthracene	230	170
C3-Phenanthrene/Anthracene	150	85
Fluoranthene/Pyrene		
C1-Fluoranthene/Pyrene	37	13
C2-Fluoranthene/Pyrene	28	18
Chrysene		
C1-Chrysene		
C2-Chrysene		
C3-Chrysene		
C4-Chrysene		

A blank space denotes not detected above 0.5 mg/kg.

As previously stated, MIOs consist of hydrocarbons primarily. However, MIOs also contain small amounts of other types of organic compounds. Table 3-10 summarizes the results of analyses of 30 samples of MIO for SVOCs not including PAHs. It is clear that organic acids, including phenol, 2,4-dimethylphenol, 2-methylphenol, and 3 and 4-methylphenols are the most abundant non-PAH SVOCs in MIO. The concentrations of organic acid compounds ranged from not detectable to 44 mg/kg. However, the concentrations of organic acid compounds are mostly less than 1 mg/kg as indicated by the median values shown in Table 3-10.

In addition to organic acids, dibenzofuran was detected in seven of the 30 samples analyzed. The dibenzofuran concentrations also were very low, with a median value of 1.2 mg/kg. Finally, phthalates were detected in several samples from 0.07 to 223 mg/kg. Phthalates are common plasticizers and laboratory contaminants, and their actual presence in MIO is uncertain.

Table 3-10
Summary of SVOCs Results in all MIO Samples (mg/kg)

	New Oil (n=4)	Aged Oil[3]			
	Mean	**No. Detects[1]**	**Range[2]**	**Mean**	**Median**
Phenol	0.05	19/30	0.05-5.0	0.95	0.83
2,4-Dimethylphenol	0.35	22/30	0.09-5.08	0.57	0.28
2-Methylphenol	0.18	18/30	0.06-1.94	0.35	0.24
3 and 4-Methylphenol	0.07	22/30	0.05-44.1	2.28	0.2
Dibenzofuran	6.58[5]	7/30	0.95-19.8	4.64	1.2
Bis(2-ethylhexyl)phthalate	20.8	8/30	8.42-223	52.94	28.25
di-n-butylphthalate		5/30	0.07-1.94	1.12	1.53
di-n-octylphthalate	3.14[5]	0/30			
Dimethylphthalate		2/30	3.19-6.74	4.97	4.97

[1] number of detects out of 30 samples of aged MIO.

[2] range, mean, and median are based on detects of aged MIO only. Non-detects were not included in the calculation.

[3] aged oils were collected from in-service transformers or used MIO storage tanks.

[4] only 1 detect

all other non-PAHs SVOCs were non-detect in all samples.

Petroleum Hydrocarbon Fractions

Each of the 12 MIO samples was analyzed for VPH and EPH using the methods presented in Section 2. In VPH and EPH analyses, the samples are physically fractionated into aliphatic hydrocarbons and aromatic hydrocarbons and the total concentration of either aliphatic or aromatic hydrocarbons is determined for each of several selected chromatographic ranges. Total VPH results are equivalent to aliphatic hydrocarbons containing six through nine carbons (C_6-C_9) added to aromatic hydrocarbons with nine and ten carbons (C_9-C_{10}). Total EPH results are composed of aliphatic hydrocarbons containing nine through 36 carbons (C_9-C_{36}) plus aromatic hydrocarbons with 11 through 22 carbons (C_{11}-C_{22}). Because there is a slight overlap in C_9-C_{12} aliphatic hydrocarbons between VPH and EPH, when total VPH plus total EPH values are calculated, the aliphatics in the C_9-C_{12} range is subtracted from the total VPH plus total EPH values. The data for samples M13 to M23 are reported in Table 3-11. The data for all samples analyzed are provided in Table B-9.

Since MIOs are nearly pure hydrocarbons, and since the boiling point range of MIOs falls within the ranges specified by the VPH/EPH methods, then analysis by VPH and EPH should account for nearly all of the MIO composition. This is confirmed in Table 3-11 where the total VPH + EPH for each sample is about 100 percent. Similar results were obtained by EPRI for other MIOs [5,9]. The data in Table B-9 show that MIOs consist of from 57 to 92% aliphatic hydrocarbons, and from about 7.7 to 43% aromatic hydrocarbons, on a weight basis. However, one sample, M06, appears to be unusual in that the aromatic hydrocarbon content of most MIOs appears to be much lower, ranging from less than 10 to about 25%.

Table 3-11
VPH and EPH in MIO (g/kg)

	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23
Aliphatics (C6-C8)	0.2	0.46	1.4	1.1	1	1.3	1	1.1	0.37	0.36	0.51
Aliphatics (C9-C12)	2.4	2.5	3	3.2	4.4	4.1	1.9	0.58	4	11	8.8
Aliphatics (C13-C18)	330	347	325	369	299	212	250	334	283	338	250
Aliphatics (C19-C36)	343	352	326	341	332	431	414	368	393	281	303
Aromatics (C9-C10)	0	0	0.15	0	0.16	0	0	0	0	0	0
Aromatics (C11-C22)	230	215	203	190	235	240	244	217	222	250	193
Total VPH	2.6	3.1	4.5	4.4	5.5	5.5	3	1.7	4.4	11	9.4
Total EPH	904	917	857	903	870	888	911	920	903	881	754
Total VPH and EPH	905	917	858	904	872	889	912	921	903	881	755
TPH (unfractionated)	895	878	896	966	914	987	964	955	872	974	648
Percent Aliphatic	75	77	76	79	73	73	73	76	75	72	74
Percent Aromatic	25	23	24	21	27	27	27	24	25	28	26

Total VPH = Aliphatics (C6-C12) + Aromatics (C9-C10)
Total EPH = Aliphatics (C9-C36) + Aromatics (C11-C22)
Total VPH + EPH = Total VPH + Total EPH - Aliphatics (C9-C12), due to range overlap

It is important to recognize that the reported percentage of aliphatic and aromatic hydrocarbons in MIO samples is determined to some extent by the analytical method used. For example, the data in Tables 3-11 and B-9 were generated by fractionating the MIO into aliphatic and aromatic portions on silica gel columns. The results of this method are determined by the interaction of the various compounds in the MIO to silica gel. Other methods for determining the aromatic content of oils, such as those based on spectroscopy, may not give similar results [2].

Table 3-11 also shows that the overwhelming majority of MIO constituents fall in the EPH range (the C_9-C_{36} aliphatics and C_{11}-C_{22} aromatics) which consists of the semivolatile portion. This result corroborates that finding of very low concentrations of volatile organic compounds in MIO samples.

The differences between MIO and white mineral oils are clearly illustrated in Table 3-12. Both of the white mineral oil samples analyzed contained only trace amounts of aromatic compounds.

Also, the boiling point ranges of the white mineral oils and the fraction of the total sample amenable to the EPH method are different from MIOs.

Table 3-12
VPH and EPH in White Mineral Oil (g/kg)

	M24	M25	M26
Aliphatics (C6-C8)	NA	0.88	0.74
Aliphatics (C9-C12)	NA	0.24	0
Aliphatics (C13-C18)	NA	239	48
Aliphatics (C19-C36)	NA	393	295
Aromatics (C9-C10)	NA	0	0
Aromatics (C11-C22)	NA	1.8	1.2
Total VPH	NA	1.1	0.74
Total EPH	NA	635	344
Total VPH and EPH	NA	636	345
TPH (unfractionated)	NA	NA	NA
Percent Aliphatic	NA	100	100
Percent Aromatic	NA	0	0

NA – not analyzed

The VPH and EPH hydrocarbon fraction data are used in RBCA-type risk calculations to determine soil cleanup criteria. Previously, cleanup criteria for MIO-impacted soils were estimated [9]. For example, for the commercial exposure scenario, the maximum allowable soil concentration which could be left in the soil and not exceed the noncancer health risk using the State of Washington's Interim TPH Policy (January 1997), ranged from 14,600 mg/kg to 19,300 mg/kg of MIO. For residential exposures, the estimates ranged from 3,640 mg/kg to 4,839 mg/kg. Those estimates were made using the results of analyses of the 30 mineral oil samples received by EPRI in 1995 and 1997. When the mean concentrations of VPH and EPH hydrocarbon fractions for the 30-sample data set were compared to the mean concentrations for the full 53-sample data set, the differences for the three principal fractions (aliphatics C13-C18, aliphatics C19-C36, and aromatics C11-C22) were less than 20 percent. In fact, the differences for aliphatics C19-C36 and aromatics C11-C22 were less than 10 percent. Similarly, percent differences (%D) for the medians were aliphatics C13-C18, 20%, aliphatics C19-C36, 10%, and aromatics C11-C22, 40%. The minimum and maximum values were similar also.

The minimal change in the summary statistics with the addition of 23 samples indicated that the variability in MIO composition among the many sources of MIO is well defined by the EPRI data set. Further, because the estimated average compositions and ranges of MIOs are well characterized by the EPRI data set, risk estimates and soil cleanup criteria estimates based on these data are representative of MIO releases generally.

Tentatively Identified Compounds

As described in Section 2, eleven samples of MIO from the 1995 batch were subjected to fractionation on activated alumina and acid/base partitioning. This procedure produced four extracts from each sample: one containing aliphatic and non-polar compounds, one containing aromatic and slightly polar compounds, one containing moderately polar compounds, and one containing organic acids. Each of these extracts was analyzed by GC/MS for 68 selected SVOCs (Appendix A). However, as stated in Section 1, MIOs consist of hundreds of compounds in the semivolatile range.

Therefore, each of the GC/MS runs was carefully reviewed and the identities of prominent compounds, not on the list in Appendix A, were tentatively identified by mass spectral matching. There was some variability in the type of compounds found in each MIO. Table 3-13 summarizes the results by listing the compounds or compound groups commonly identified in most of the samples.

For example, the aliphatic or non-polar fraction contained numerous straight and branched alkanes and cyclic alkanes such as decane and decalin, respectively. The aliphatic fraction comprised the largest portion of MIO by weight and most of the compounds could not be identified with certainty. The aromatic or slightly polar fraction contained numerous alkyl-substituted benzenes and PAHs. As discussed previously in this report, alkylated benzenes and alkyated PAHs are known to be major constituent groups of crude oil and refined petroleum products. In addition, nitrogen and sulfur heterocyclic compounds such as carbazole and dibenzothiophene were likely present in the aromatic fraction based on published reports of petroleum distillate compositions and based on the identification of dibenzothiophene and alkylated dibenzothiophenes in MIO samples from this study. However, most of those compounds were present at concentrations too low to permit their identification. In fact, most of the compounds comprising the aromatic fraction could not be identified with certainty. The moderately polar fraction contained hydroxy- and ester-containing compounds such as BHA and BHT principally. However, as expected from the nature of the refining methods, the moderately polar fraction contained very few compounds above detection levels. Finally, the organic acid fraction contained mostly alkylated phenols and carboxylic acids. As seen in Appendix A, phenol and methylphenol isomers (cresols) are target compounds in EPA Method 8270. However, MIO additionally contained dimethyl phenols, trimethylphenols, ethylphenols, and other alkylated phenols. The organic acids comprised a very small portion of the total MIO mass.

Table 3-13
Tentatively Identified Compounds (TIC) in MIO

Fraction	Tentatively Identified Compounds[1]
Aliphatic and non-polar compounds	Various isomers of straight and branched alkanes Various isomers of cyclic alkanes (naphthenes)
Aromatic and slightly polar compounds	Biphenyl, alkyl-substituted biphenyls Alkyl-substituted benzenes, naphthalenes, fluorenes, and phenanthrenes
Moderately polar compounds	Methylcyclopentanol isomer Ethyl hexanol isomer Methyl ester of hexanoic acid Methyl ester of benzoic acid Butylated hydroxyanisole (BHA – antioxidant) Butylated hydroxytoluene (BHT – antioxidant) Methyl ester of hexadecanoic acid Methyl ester of decanoic acid Methyl ester of octadecanoic acid
Organic acids and bases	Dimethyl phenols, ethylphenols, trimethylphenols, tert-butyl phenol, Tetramethyl phenols Hexanoic acid, octanoic acid, nonanoic acid, alkyl carboxylic acids Thymol, oleic acid, hydroxybenzaldehyde, alkyl benzaldehydes Alkylbenzoic acid isomers

[1] includes only compounds or compound groups that gave fair or good matches in a computerized library search and appeared likely by the analyst

Dissolution of MIO Constituents in Water

Dissolution tests were done in two batches, one in 1995 to 1996 and one in 1999. Altogether, thirty-four samples of MIO were equilibrated with organic-free, deionized, deoxygenated water at pH 4 and pH 7 in the laboratory to simulate the dissolution of MIO in groundwater, surface water, or rainwater. After a 24 hour equilibration period, the water and oil phases were separated by gravity, and the water phase was analyzed for metals, VOCs, and/or SVOCs as described in Section 2.

Not all samples were subjected to dissolution testing and not all analytes were measured in each test. For example, metals concentrations were measured in water equilibrated with 11 of the MIO samples received in 1995 [3]. The data are provided in that report. Because the concentrations of metals in that initial EPRI study were very low or non-detect, dissolution tests for metals were not done with any of the samples from 1997 or 1999.

Also, no dissolution tests were done with any of the 12 MIO samples received in 1997.

The quantitation limits for VOCs and SVOCs in water for the 1996 sample batch were approximately 5 µg/L and the detection limits were about 1 µg/L. Few compounds were detected in those samples. For the supplemental set of tests (M01 to M23), the quantitation limits were about 1 µg/L and the detection limits were about 0.5 µg/L or less. The quantitation limits and detection limits varied from sample to sample and analyte to analyte depending on experimental factors such as actual sample size and instrumental response factors and linearity. The detection limits were set as low as practical because it was expected that MIO constituents would not be very soluble in water and therefore their concentrations would be very low.

Table 3-14 shows the dissolution test results at pH 4 and Table 3-15 shows the dissolution test results at pH 7 for VOCs and SVOCs. The results from the previous EPRI study [3] have been combined with those of the supplemental samples for calculating summary statistics. Table B-10 shows the results for all analytes in the individual samples M01 to M23 from the supplemental study.

The concentrations of both VOCs and SVOCs measured in water in equilibrium with MIO were in the low parts per billion or less range. These concentrations were comparable to those that are predicted by Raoult’s Law using the measured concentrations in neat MIO. For example, the average concentration of phenanthrene in MIO was 98.1 mg/kg. The average molecular weight was 266 g/mole and the supercooled liquid solubility was estimated at 2.14×10^{-5} moles/L. Using the equation for predicted aqueous solubility from reference [19], $C_w = (M_i)(MW_{MIO})(S_l)(0.001)$, and these values, a phenanthrene concentration in water at equilibrium of 0.56 µg/L is predicted. The average phenanthrene concentration measured in samples for which phenanthrene was above the detection limit was 1.4 µg/L.

Similar results were obtained for toluene. For example, the predicted equilibrium toluene concentration in water using an average MIO concentration of 12.3 mg/kg was 19 µg/L. By comparison, the average measured toluene concentration in water was 10 µg/L. For toluene and other VOCs, measured concentrations that were lower than predicted may have occurred because of compound loss during handling and storage of the aqueous samples.

Thus, the comparability between predicted and observed concentrations is very good indicating that Raoult’s Law calculations can be used to estimate the concentration in water of MIO constituents for any sample for which concentrations in the neat oil are known.

The measured concentrations VOCs and SVOCs in the dissolution tests conducted in this study measure the maximum aqueous concentrations possible when MIO contacts water. Site-specific factors such as dilution and attenuation will substantially lower the concentrations of VOCs and SVOCs found in groundwater and surface water environments.

Table 3-14
Summary of VOC and SVOC Results in Water Equilibrated with MIO at pH 4 (µg/L)

Compound	No. Detects[1]	Range[2]	Mean	Median
Acetone	0/34			
Carbon disulfide	0/34			
2-Butanone (MEK)	0/34			
1,1,1-Trichloroethane	0/34			
Benzene	3/34	2 – 2	2	2
Toluene	7/34	1 – 89	19	4
Ethylbenzene	2/34	2 – 5	3.5	3.5
m/p-Xylene	7/34	1 – 17	4	1
o-Xylene	4/34	1 – 11	4	1.5
Styrene	1/34	1 – 1	1	1
1,3,5-Trimethylbenzene	2/34	1 – 1	1	1
1,2,4-Trimethylbenzene	4/34	2 – 3	2	2
1,2-dichlorobenzene	0/34			
1,2,4-Trichlorobenzene	1/34	2 – 2	2	2
Naphthalene (8260)	8/34	1 – 6	3	3.5
1,2,3-Trichlorobenzene	0/34			
Phenol	8/34	0.42 – 2.6	0.91	0.74
2,4-Dimethylphenol	8/34	0.2 – 4.5	1.0	0.36
2-Methylphenol (o-cresol)	7/34	0.25 – 0.88	0.42	0.3
3 and 4-Methylphenol (m/p-cresol)	9/34	0.24 - 48.7	5.8	0.38
Dibenzofuran	19/34	0.11 – 0.95	0.46	0.34
di-n-butylphthalate	0/34			
Dimethylphthalate	1/34	0.33 – 0.33	0.33	0.33
Naphthalene (8270)	7/34	0.52 – 5.6	3.2	2.7
2-Methylnaphthalene	24/34	0.09 – 13.6	2.4	1.5
Acenaphthylene	2/34	0.11 – 0.21	0.16	0.16
Acenaphthene	9/34	0.14 – 0.41	0.24	0.19
Fluorene	24/34	0.09 – 1.8	0.79	0.78
Phenanthrene	21/34	0.11 – 5.36	1.5	1.04
Anthracene	6/34	0.05 – 0.17	0.11	0.12
Fluoranthene	0/34			
Pyrene	0/34			
Benz(a)anthracene	0/34			
Chrysene	0/34			

[1] number of detects out of 34 samples of new and aged MIO tested.

[2] range, mean, and median are based on detects of MIO compounds only. Non-detects were not included in the calculation.

all other VOCs and SVOCs were non-detect in all samples.

Table 3-15
Summary of VOC and SVOC Results in Water Equilibrated with MIO at pH 7 (µg/L)

Compound	No. Detects[1]	Range[2]	Mean	Median
Acetone	2/34	85 – 110	97	97
Carbon disulfide	1/34	2 – 2	2	2
2-Butanone (MEK)	1/34	3 – 3	3	3
1,1,1-Trichloroethane	2/34	2 – 3	2	2.5
Benzene	3/34	1 – 2	2	2
Toluene	13/34	1 – 90	10	2
Ethylbenzene	3/34	1 – 6	3	2
m/p-Xylene	9/34	1 – 22	4	2
o-Xylene	6/34	1 – 14	4	2
Styrene	1/34	1 – 1	1	1
1,3,5-Trimethylbenzene	2/34	1 – 2	1.5	1.5
1,2,4-Trimethylbenzene	5/34	1 – 4	2	2
1,2-dichlorobenzene	1/34	1 – 1	1	1
1,2,4-Trichlorobenzene	1/34	2 – 2	2	2
Naphthalene (8260)	11/34	1 – 7	4	3
1,2,3-Trichlorobenzene	1/34	1 – 1	1	1
Phenol	9/34	0.67 – 4.2	1.6	0.94
2,4-Dimethylphenol	9/34	0.26 – 7.4	1.7	0.71
2-Methylphenol (o-cresol)	8/34	0.22 – 0.79	0.44	0.38
3 and 4-Methylphenol (m/p-cresol)	9/34	0.39 – 73.2	11	0.7
Dibenzofuran	16/34	0.2 – 1.1	0.44	0.36
di-n-butylphthalate	7/34	0.54 – 0.82	0.65	0.63
Dimethylphthalate				
Naphthalene (8270)	7/34	1.3 – 6.5	3.6	3.3
2-Methylnaphthalene	22/34	0.25 – 18	3.8	2.3
Acenaphthylene	1/34	0.13 – 0.13	0.13	0.13
Acenaphthene	12/34	0.17 – 1.5	0.41	0.24
Fluorene	21/34	0.24 – 1.6	0.77	0.63
Phenanthrene	24/34	0.19 – 3.9	1.4	1
Anthracene	7/34	0.1 – 2.4	0.62	0.2
Fluoranthene	1/34	0.49 – 0.49	0.49	0.49
Pyrene	1/34	0.68 – 0.68	0.68	0.68
Benz(a)anthracene	1/34	0.21 – 0.21	0.21	0.21
Chrysene	1/34	0.18 – 0.18	0.18	0.18

[1] number of detects out of 34 samples of new and aged MIO tested.

[2] range, mean, and median are based on detects of MIO compounds only. Non-detects were not included in the calculation.

all other VOCs and SVOCs were non-detect in all samples.

4

CONCLUSIONS

As part of on-going EPRI research on dielectric fluids in the environment, 23 samples of MIO from six utilities in five states were physically and chemically characterized. The data were combined with characterization results for 30 MIO samples analyzed previously. Based on these results, the following conclusions were reached.

1. MIOs are complex mixtures of nearly 100% hydrocarbons. The aliphatic and aromatic hydrocarbon contents of MIOs vary, but are approximately 75 to 90% aliphatic and 10 to 25% aromatic, as determined by a silica gel fractionation method with GC/FID analysis.

2. MIOs contain low concentrations of some VOCs, primarily MAHs, some SVOCs, primarily PAHs, and metals. Soil cleanup criteria vary greatly from State to State and among land uses. However, the data indicate that MIO-containing soil will not exceed most cleanup criteria for individual compounds and metals.

3. Some VOCs and SVOCs will partition into water that is in contact with MIO. The concentrations of VOCs in water at equilibrium will be in the low parts per billion range or less. However, dilution, dispersion, and degradation are expected to rapidly and significantly decrease the concentrations of VOCs from equilibrium conditions in groundwater or surface water environments.

4. Only four PAHs of regulatory concern were detected frequently in dissolution tests: naphthalene, 2-methylnaphthalene, fluorene, and phenanthrene. The concentrations of those compounds in water at equilibrium will be in the low parts per billion range or less. However, dilution, dispersion, and degradation are expected to rapidly and significantly decrease the concentrations of PAHs from equilibrium conditions in groundwater or surface water environments.

5. Raoult’s Law can be used to estimate the expected equilibrium concentrations of MAHs and PAHs in water in contact with MIO. The predicted and experimental concentrations compare well.

6. MIOs are less dense than water and have relatively low viscosities and interfacial tensions. Therefore, they are LNAPLs and have some mobility as an organic phase when released to the environment in sufficient quantities. The vapor pressures of MIO are very low. Consequently, the concentrations of VOCs and SVOCs in air or soil gas in the vicinity of MIO releases will be very low or not detectable.

7. The ranges of observed concentrations of detected compounds in MIO were not great for the 53 samples in this study. Therefore, it is expected that the average or median values will

provide a good approximation to MIO sources generally. While there does appear to be a correlation between the age of the MIO and higher concentrations of VOCs and SVOCs, the correlation was not strong and was based on uncertain product age information.

5
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A

APPENDIX A - TARGET ANALYTE LISTS

Table A-1
VOCs by EPA Method 8260B

dichlorodifluoromethane
chloromethane
vinylchloride
bromomethane
chloroethane
trichlorofluoromethane
acetone
1,1-dichloroethene
carbon disulfide
methylene chloride
methyl tert-butyl ether
trans-1,2-dichloroethene
1,1-dichloroethane
vinyl acetate
2-butanone
cis-1,2-dichloroethane
2,2-dichloropropane
chloroform
1,1,1-trichloroethane
1,1-dichloropropene
carbon tetrachloride
benzene
1,2-dichloroethane
trichloroethene
1,2-dichloropropane
dibromomethane
bromodichloromethane
2-chloroethylvinyl ether
methyl isobutyl ketone
cis-1,3-dichloropropene
toluene
trans-1,3-dichloropropene
1,1,2-trichloroethane
2-hexanone
tetrachloroethene
1,3-dichloropropane
dibromochloromethane
1,2-dibromomethane
chlorobenzene
1,1,1,2-tetrachloroethane
ethylbenzene
m/p-xylene
o-xylene
styrene
bromoform
isopropylbenzene
1,1,2,2-tetrachloroethane
bromobenzene
1,2,3-trichloropropane
n-propylbenzene
2-chlorotoluene
1,3,5-trimethylbenzene
4-chlorotoluene
tert-butylbenzene
1,2,4-trimethylbenzene
sec-butylbenzene
1,3-dichlorobenzene
p-isopropyltoluene
1,4-dichlorobenzene
n-butylbenzene
1,2-dichlorobenzene
1,2-dibromo-3-chlorobenzene
1,2,4-trichlorobenzene
hexachlorobutadiene
naphthalene
1,2,3-trichlorobenzene

Table A-2
SVOCs by EPA Method 8270C

pentachloroethane
phenol
bis(2-chloroethyl)ether
aniline
2-chlorophenol
benzy alcohol
2-methylphenol
4-methylphenol
bis(2-chloroisopropyl)ether
3-methylphenol
N-nitrosopyrolidine
N-nitroso-di-n-propylamine
N-nitrosomorpholine
hexachloroethane
N-nitrosopiperidine
2-nitrophenol
2,4-dimethylphenol
bis(2-chloroethoxy)methane
2,6-dichlorophenol
1,2,4-trichlorobenzene
naphthalene
4-chloroaniline
2,4-dichlorophenol
hexachloropropene
hexachlorobutadiene
1,2,3-trichlorobenzene
N-nitrosodi-n-butylamine
4-chloro-3-methylphenol
2-methylnaphthalene
1,2,4,5-tetrachlorobenzene
hexachlorocyclopentadiene
2,4,6-trichlorophenol
2,4,5-trichlorophenol
2-nitroaniline
dimethylphthalate
acenaphthylene
4-nitrophenol
dibenzofuran
pentachlorobenzene
2,3,4,6-tetrachlorophenol
diethylphthalate
4-chlorophenyl-phenylether
fluorene
4-nitroaniline
4,6-dinitro-2-methylphenol
N-nitrosodiphenylamine
4-bromophenyl-phenylether
hexachlorobenzene
pentachlorophenol
phenanthrene
dinoseb (DNBP)
anthracene
di-n-butylphthalate
fluoranthene
pyrene
butylbenzylphthalate
benz(a)anthracene
chrysene
bis(2-ethylhexyl)phthalate
di-n-octylphthalate
benzo(b)fluoranthene
benzo(k)fluoranthene
benzo(a)pyrene
indeno(1,2,3-cd)pyrene
dibenz(a,h)anthracene
benzo(g,h,i)perylene
2-chloronaphthalene

Table A-3
Metals

	Reporting Limit as mg/kg in oil
aluminum	5
antimony	0.1
arsenic	0.1
barium	0.5
beryllium	0.5
cadmium	0.5
calcium	0.5
chromium	0.5
cobalt	0.5
copper	0.5
iron	0.5
lead	0.1
magnesium	0.5
manganese	0.5
mercury	0.02
nickel	0.5
potassium	5
selenium	0.1
silver	0.5
sodium	5
thallium	0.1
vanadium	0.5
zinc	0.5

Table A-4
Volatile Petroleum Hydrocarbons (VPH) and Extractable Petroleum Hydrocarbons (EPH)

Aliphatics (C6-C8)
Aliphatics (C9-C12)
Aliphatics (C13-C18)
Aliphatics (C19-C36)
Aromatics (C9-C10)
Aromatics (C11-C22)

Total VPH
Total EPH
Total VPH + EPH

B

APPENDIX B - DATA TABLES

Table B-1
Physical Properties of MIO

Sample ID	Specific Gravity, 60/60	Viscosity, kinematic, cSt at 40°C	Liquid-water Interfacial tension, dynes/cm	Liquid-air interfacial tension, dynes/cm
M01	0.884	9.53	38	30
M02	0.889	8.93	32	29
M03	0.897	9.2	16	30
M04	0.885	8.83	17	29
M05	0.883	9.22	20	29
M06	0.892	9.45	29	28
M07	0.888	8.53	30	28
M08	0.853	8.53	30	28
M09	0.89	9.54	36	29
M10	0.881	9.43	32	28
M11	0.874	9.23	25	26
M12	0.875	9.16	36	29
M13	0.877	9.53	34	24
M14	0.856	7.75	46	28
M15	0.855	7.64	43	29
M16	0.881	9.83	37	30
M17	0.873	9.22	18	29
M18	0.871	8.89	37	25
M19	0.875	9.27	29	30
M20	0.883	9.14	38	26
M21	0.868	8.72	30	23
M22	na	na	na	na
M23	0.879	10.3	18	30
Sample 1	0.898	*17.61*	39.9	34.6
Sample 2	0.869	*14.67*	37	32.5
Sample 15	0.874	*14.38*	24.4	34.5
Sample 16	0.874	*14.51*	26.8	33.7
Sample 17	0.874	*14.6*	25.3	33.4
Sample 18	0.873	*14.62*	37.7	32.2
Sample 19	0.872	*16.06*	42.5	33.6
Sample 20	0.873	*14.18*	34.1	33.6
Sample 21	0.881	*15.63*	31.7	34.9
Sample 22	0.886	*15.15*	16.6	27.1
Sample 23	0.879	*15.33*	33.2	34.2
Sample 24	0.872	*15.41*	38.8	35.5
Sample 25	0.882	*16.11*	40.6	33.1
Sample 26	0.881	*16.03*	39.1	33.3
Sample 27	0.874	*14.99*	29.3	33.6
Sample 28	0.872	*15.71*	41.3	32.1
Sample 29	0.871	*13.38*	36.7	33.2
Sample 30	0.87	*13.25*	37.6	33.3

italic indicates viscosity at 25°C
na - not analyzed, insufficient sample

Table B-2
MIO Vapor Pressure (Pascals) at each temperature °C

	79.4	93.3	121	149	177	204	232	260	288	316
Sample ID										
M01	21	47	190	670	2100	5500	12000	26000	56000	
M02	25	56	210	720	2100	5200	11000	23000	47000	90000
M03		83	330	1200	3500	8900	20000	42000	88000	
M04		120	430	1300	3600	8700	18000	36000	71000	
M05	17	40	170	610	1900	5200	12000	25000	55000	
M06	15	35	130	480	1500	3900	8500	18000	37000	68000
M07	16	37	160	570	1800	4800	11000	23000	51000	92000
M08	24	53	210	710	2200	5300	12000	23000	49000	87000
M09		17	87	350	1200	3500	8800	20000	45000	64000
M10		29	125	480	1500	4300	9900	22000	48000	90000
M11	17	37	160	560	1700	4700	10000	22000	47000	88000
M12	17	40	160	600	1800	4900	11000	23000	51000	92000
M13	23	49	200	690	2100	5300	12000	25000	51000	93000
M14	16	37	160	560	1700	4400	10000	21000	44000	81000
M15	16	36	150	530	1600	4300	9900	21000	44000	81000
M16	28	61	240	800	2400	6000	13000	27000	55000	96000
M17	29	63	240	750	2100	5100	11000	22000	44000	76000
M18	24	51	200	650	1900	4800	10000	21000	43000	77000
M19	16	37	160	560	1700	4500	10000	22000	47000	85000
M20	13	32	150	550	1800	5100	12000	27000	59000	81000
M21	20	44	170	600	1800	4500	10000	21000	44000	78000
M22	27	120	400	1200	3200	7600	16000	30000	57000	76000
M23	27	57	230	790	2300	5700	13000	27000	56000	75000

a blank space denotes a measurement couldn't be obtained

Table B-3
Average Molecular Weights (g/mole) by Vapor Phase Osmometry

Sample ID	Ave. MW
M01	270
M02	243
M03	264
M04	236
M05	233
M06	241
M07	242
M08	240
M09	245
M10	253
M11	237
M12	257
M13	307
M14	335
M15	310
M16	316
M17	306
M18	301
M19	308
M20	264
M21	284
M22	250
M23	268
Sample 1	255
Sample 2	296
Sample 15	260
Sample 16	257
Sample 17	271
Sample 18	239
Sample 19	256
Sample 20	266
Sample 21	268
Sample 22	269
Sample 23	269
Sample 24	257
Sample 25	246
Sample 26	248
Sample 27	250
Sample 28	259
Sample 29	266
Sample 30	261

Table B-4
Concentrations of metals in neat MIO (mg/kg)

Sample ID	aluminum	antimony	arsenic	Barium	beryllium	cadmium	calcium	chromium	cobalt	copper	iron	lead
M01	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1
M02	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1
M03	<5	<0.1	<0.1	<0.5	<0.5	2.5	2.5	<0.5	<0.5	0.5	<0.5	3.6
M04	<5	<0.1	<0.1	<0.5	<0.5	<0.5	4.6	<0.5	<0.5	<0.5	4.7	<0.1
M05	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1
M06	<5	<0.1	<0.1	<0.5	<0.5	<0.5	1.3	<0.5	<0.5	<0.5	<0.5	3.7
M07	<5	<0.1	<0.1	<0.5	<0.5	<0.5	0.7	<0.5	<0.5	<0.5	<0.5	<0.1
M08	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.9
M09	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.1
M10	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2.1
M11	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1
M12	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1
M13	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.1
M14	<5	<0.1	<0.1	<0.5	<0.5	<0.5	2.2	<0.5	<0.5	<0.5	1.3	0.2
M15	<5	0.2	<0.1	<0.5	<0.5	<0.5	5.0	<0.5	<0.5	<0.5	0.6	0.1
M16	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.6	<0.1
M17	<5	<0.1	<0.1	<0.5	<0.5	<0.5	1.7	<0.5	<0.5	1.0	1.1	0.2
M18	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.2
M19	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.6	<0.5	0.5
M20	<5	<0.1	<0.1	<0.5	<0.5	<0.5	6.3	<0.5	<0.5	1.1	0.7	3.6
M21	<5	<0.1	<0.1	<0.5	<0.5	<0.5	2.4	<0.5	<0.5	<0.5	1.4	<0.1
M22	<5	<0.1	<0.1	<0.5	<0.5	<0.5	0.6	<0.5	<0.5	<0.5	<0.5	<0.1
M23	<5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.1	0.9

Table B-4
Concentrations of metals in neat MIO (mg/kg) (Continued)

Sample ID	magnesium	manganese	mercury	nickel	potassium	selenium	silver	sodium	thallium	vanadium	zinc
M01	<0.5	<0.5	0.05	<0.5	<5	<0.1	<0.5	46.0	<0.1	<0.5	<0.5
M02	<0.5	<0.5	<0.02	<0.5	<5	<0.1	1.6	26.0	<0.1	<0.5	<0.5
M03	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	38.0	<0.1	<0.5	2.9
M04	<0.5	<0.5	<0.02	<0.5	<5	0.1	<0.5	19.0	<0.1	<0.5	<0.5
M05	<0.5	<0.5	0.03	<0.5	<5	0.1	<0.5	7.0	<0.1	<0.5	<0.5
M06	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	12.0	<0.1	<0.5	1.2
M07	<0.5	<0.5	0.03	<0.5	<5	<0.1	<0.5	6.0	<0.1	<0.5	<0.5
M08	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	42.0	<0.1	<0.5	<0.5
M09	<0.5	<0.5	<0.02	<0.5	<5	0.1	<0.5	56.0	<0.1	<0.5	<0.5
M10	<0.5	<0.5	0.03	<0.5	<5	<0.1	<0.5	17.0	<0.1	<0.5	<0.5
M11	<0.5	<0.5	<0.02	<0.5	<5	0.3	<0.5	<0.5	<0.1	<0.5	<0.5
M12	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	7.0	<0.1	<0.5	<0.5
M13	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	16.0	<0.1	0.6	<0.5
M14	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	15.0	<0.1	<0.5	<0.5
M15	<0.5	<0.5	<0.02	<0.5	<5	0.2	<0.5	16.0	<0.1	<0.5	<0.5
M16	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	<0.5	<0.1	1.6	<0.5
M17	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	23.0	<0.1	1.0	<0.5
M18	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	<0.5	<0.1	0.5	<0.5
M19	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	36.0	<0.1	1.4	<0.5
M20	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	42.0	<0.1	1.5	0.9
M21	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	<0.5	<0.1	<0.5	0.5
M22	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	<0.5	<0.1	<0.5	<0.5
M23	<0.5	<0.5	<0.02	<0.5	<5	<0.1	<0.5	<0.5	<0.1	<0.5	<0.5

Table B-4
Concentrations of metals in neat MIO (mg/kg) (Continued)

Sample ID	aluminum	antimony	arsenic	barium	beryllium	cadmium	calcium	chromium	cobalt	copper	iron	lead
Sample 1	<20	<1	<1	<0.45	<1	<1	23	<1	<3.75	<1.8	4.6	<1
Sample 2	21	<1	<1	0.51	<1	<1	54	<1	<3.75	<1.8	16	<1
Sample 3	3.0	< 1	< 1	< 1	< 1	< 1	6.0	< 1	1.0	3.0	3.0	< 5
Sample 4	4.0	< 1	< 1	< 1	< 1	2.0	6.0	< 1	1.0	4.0	6.0	< 5
Sample 5	17.0	< 1	< 1	< 1	< 1	< 1	5.0	< 1	< 1	5.0	5.0	< 5
Sample 6	3.0	< 1	< 1	< 1	< 1	< 1	6.0	< 1	< 1	6.0	2.0	< 5
Sample 7	3.0	< 1	< 1	< 1	< 1	< 1	9.0	< 1	< 1	8.0	4.0	< 5
Sample 8	3.0	< 1	< 1	< 1	< 1	< 1	10.0	< 1	1.0	9.0	< 1	< 5
Sample 9	3.0	< 1	< 1	< 1	< 1	< 1	5.0	< 1	1.0	14.0	2.0	< 5
Sample 10	3.0	< 1	< 1	< 1	< 1	1.0	7.0	< 1	< 1	9.0	4.0	< 5
Sample 11	3.0	< 1	< 1	< 1	< 1	< 1	11.0	< 1	< 1	9.0	5.0	< 5
Sample 12	3.0	< 1	< 1	< 1	< 1	1.0	7.0	< 1	< 1	16.0	3.0	< 5
Sample 13	2.0	< 1	< 1	< 1	< 1	< 1	12.0	< 1	< 1	23.0	7.0	< 5
Sample 14	16.0	< 1	< 1	< 1	< 1	< 1	13.0	< 1	< 1	43.0	12.0	< 5
Sample 15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 16	27	<1	<1	0.51	<1	<1	31	<1	<3.75	<1.8	14	3.6
Sample 17	25	<1	<1	0.45	<1	<1	28	<1	<3.75	<1.8	4.4	2.2
Sample 18	25	<1	<1	0.51	<1	<1	74	<1	<3.75	<1.8	6.8	<1
Sample 19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 20	<20	<1	<1	<0.45	<1	<1	16	<1	<3.75	<1.8	17	<1
Sample 21	25	<1	<1	0.53	<1	<1	27	<1	<3.75	<1.8	50	<1
Sample 22	24	<1	<1	0.57	<1	<1	43	<1	<3.75	<1.8	30	<1
Sample 23	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 24	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 25	24	<1	<1	0.50	<1	<1	20	<1	<3.75	<1.8	3.7	<1
Sample 26	22	<1	<1	0.46	<1	<1	60	<1	<3.75	<1.8	4.9	<1
Sample 27	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 28	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 29	29	<1	<1	0.57	<1	<1	22	<1	<3.75	<1.8	7.1	<1
Sample 30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA – denotes not analyzed

Table B-4
Concentrations of metals in neat MIO (mg/kg) (Continued)

Sample ID	magnesium	manganese	mercury	nickel	potassium	selenium	silver	sodium	thallium	vanadium	zinc
Sample 1	<30	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	<3
Sample 2	<30	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	7.5
Sample 3	5.0	< 1	0.03	< 1	< 5	< 1	< 1	100.0	< 1	< 1	1.0
Sample 4	5.0	< 1	0.02	< 1	< 5	< 1	< 1	120.0	< 1	< 1	3.0
Sample 5	4.0	< 1	< 0.02	< 1	< 5	< 1	< 1	64.0	< 1	< 1	3.0
Sample 6	3.0	< 1	< 0.02	< 1	< 5	< 1	< 1	22.0	< 1	< 1	4.0
Sample 7	3.0	< 1	< 0.02	12.0	< 5	< 1	< 1	190.0	< 1	< 1	5.0
Sample 8	8.0	< 1	0.03	< 1	< 5	< 1	< 1	78.0	< 1	< 1	8.0
Sample 9	6.0	< 1	0.02	< 1	< 5	< 1	< 1	38.0	< 1	< 1	9.0
Sample 10	6.0	< 1	< 0.02	< 1	< 5	< 1	< 1	73.0	< 1	< 1	9.0
Sample 11	5.0	< 1	0.02	14.0	< 5	< 1	< 1	140.0	< 1	< 1	7.0
Sample 12	5.0	< 1	< 0.02	3.0	< 5	< 1	< 1	78.0	< 1	< 1	10.0
Sample 13	5.0	< 1	< 0.02	<1	< 5	< 1	< 1	120.0	< 1	< 1	15.0
Sample 14	7.0	< 1	< 0.02	<1	< 5	< 1	< 1	43.0	< 1	< 1	38.0
Sample 15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 16	36	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	<3
Sample 17	36	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	<3
Sample 18	36	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	3.7
Sample 19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 20	36	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	4.1
Sample 21	<30	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	<3
Sample 22	31	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	33
Sample 23	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 24	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 25	<30	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	3.2
Sample 26	<30	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	<3
Sample 27	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 28	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sample 29	<30	<0.45	<0.1	<1	<150	<1	<1	NA	<1	<1.7	<3
Sample 30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA – denotes not analyzed.

Table B-5
Concentrations of VOCs in neat MIO (mg/kg)

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10
Acetone		1	7.9	1.1	4.5	**0.81**			0.85	
Carbon disulfide						1.2				
2-Butanone (MEK)			4.7							
Chloroform										
1,1,1-Trichloroethane										
Benzene					5.5	1.2				
Toluene	3.8	**0.47**	1.6	2.2	5.4		0.94	1.9	1.8	
2-Hexanone			1.1	1.2						
Tetrachloroethene					1.8					
Ethylbenzene		**0.48**		20	1.9		**0.89**	1.6	**0.55**	
m/p-Xylene		3		70	6.1		4.2	1.9	2.2	
o-Xylene		1.3		40	3.1		2	0.98	**0.75**	
Styrene					1.3					
Isopropylbenzene				2.3				1.5		
n-Propylbenzene		**0.73**		3.4	**0.81**		1.2	2.1		
1,3,5-Trimethylbenzene		2.6	**0.71**	11	2.4		1.9	**0.53**		
tert-Butylbenzene				**0.5**						
1,2,4-Trimethylbenzene	**0.72**	5.4	1.9	23	5.3	1.4	8.1	2.9	1.1	
p-Isopropyltoluene		1.6	**0.5**	3.4	1.1		1.1	3.9		
1,4-dichlorobenzene										
sec-Butylbenzene		**0.56**		1.9	**0.67**			8.3		
1,2,4-Trichlorobenzene								3.9		
Naphthalene	1.5	7	7.7	14	27	4.7	**0.7**	2.9	5.7	

A blank space denotes not detected.

Bold denotes a value below the calibrated range.

Table B-5
Concentrations of VOCs in neat MIO (mg/kg) (Continued)

	M11	M12	M13	M14	M15	M16	M17	M18	M19
Acetone									
Carbon disulfide									
2-Butanone (MEK)						2.6			
Chloroform									
1,1,1-Trichloroethane	**0.58**								
Benzene							1.3		
Toluene	2.1			1.1	1.1	**0.79**	2.2	1.1	
2-Hexanone									
Tetrachloroethene									
Ethylbenzene	**0.79**			**0.68**	**0.65**		2.1	**0.73**	
m/p-Xylene	1.9			2.4	2.3	2	5.7	1.3	1.4
o-Xylene	**0.72**			**0.55**	**0.51**	1.1	2.8	**0.49**	**0.62**
Styrene							**0.58**		
Isopropylbenzene				**0.5**	**0.48**		**0.74**	**0.71**	
n-Propylbenzene	**0.58**			**0.74**	**0.71**		1.5	1.1	
1,3,5-Trimethylbenzene	1.5			1.1	1	1.6	4.9	1.5	1.1
tert-Butylbenzene									
1,2,4-Trimethylbenzene	5		**0.92**	3.7	3.5	5	15	5.5	3.7
p-Isopropyltoluene	1.2			1.5	1.5	**0.73**	2.6	2.5	1
1,4-dichlorobenzene									**0.57**
sec-Butylbenzene	2.7			7.1	6.8	**0.52**	4.5	8.9	2.5
1,2,4-Trichlorobenzene									
Naphthalene	2.3		*	*	*	*	*	*	*

A blank space denotes not detected.

Bold denotes a value below the calibrated range.

* - denotes rejected during QC review.

Table B-5
Concentrations of VOCs in neat MIO (mg/kg) (Continued)

	M20	M21	M22	M23
Acetone				
Carbon disulfide				
2-Butanone (MEK)	1.7		6.4	
Chloroform			**0.52**	
1,1,1-Trichloroethane			1.4	
Benzene		4.9	**0.82**	
Toluene	3	15	51	
2-Hexanone			1.8	
Tetrachloroethene				
Ethylbenzene	1.5	2.9	2.5	
m/p-Xylene	8.1	8.4	15	
o-Xylene	5.3	2.9	6.6	
Styrene				
Isopropylbenzene		0.77	1.4	
n-Propylbenzene		1.3	2.4	
1,3,5-Trimethylbenzene	1.1	2.3	7.1	
tert-Butylbenzene			**0.52**	
1,2,4-Trimethylbenzene	2	9.9	19	0.85
p-Isopropyltoluene		3.3	3.6	
1,4-dichlorobenzene				
sec-Butylbenzene		7.2	2.6	
1,2,4-Trichlorobenzene	4.1			
Naphthalene	*	*	*	

A blank space denotes not detected.

Bold denotes a value below the calibrated range.

* - denotes rejected during QC review.

Table B-5
Concentrations of VOCs in neat MIO (mg/kg) (Continued)

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
Acetone										
Carbon disulfide										
2-Butanone (MEK)										
Chloroform										
1,1,1-Trichloroethane										
Benzene		**0.58**	0.44		0.84				0.22	
Toluene		**2.3**	1.7	0.4	3	0.31	0.77	0.35	3.5	
2-Hexanone										
Tetrachloroethene									0.33	
Ethylbenzene		**1.2**	0.5		1.2	0.31	0.41	0.21	1.1	
m/p-Xylene		**2.4**	2.1	0.34	2.4	1.2	1	0.38	2.7	0.39
o-Xylene		**0.95**	0.86		0.75	0.55	0.42	0.2	2.9	
Styrene					0.57		0.37	0.25	0.38	
Isopropylbenzene					0.36		0.3		0.48	
n-Propylbenzene										
1,3,5-Trimethylbenzene			0.54		0.71	0.53	0.79	0.27	1.2	
tert-Butylbenzene										
1,2,4-Trimethylbenzene			1.8	0.44	2.2	1.2	2.5	1.4	1.9	0.41
p-Isopropyltoluene						0.37		0.75	0.77	
1,4-dichlorobenzene										
sec-Butylbenzene			0.25		2.2	0.33	1.5	0.89	0.4	
1,2,4-Trichlorobenzene			3.4							
Naphthalene			1.2	5.1	1.2	2.2	1.4	2.9	1.9	

A blank space denotes not detected.

Bold denotes a value below the calibrated range.

Table B-5
Concentrations of VOCs in neat MIO (mg/kg) (Continued)

	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19
Acetone			NA	NA	NA				NA
Carbon disulfide			NA	NA	NA				NA
2-Butanone (MEK)			NA	NA	NA				NA
Chloroform			NA	NA	NA				NA
1,1,1-Trichloroethane			NA	NA	NA				NA
Benzene		0.31	NA	NA	NA	**0.63**	**0.92**		NA
Toluene	4.7	1.5	NA	NA	NA	2.9	3		NA
2-Hexanone			NA	NA	NA			**1.1**	NA
Tetrachloroethene			NA	NA	NA				NA
Ethylbenzene	1.7	0.84	NA	NA	NA	**1.2**	**1.3**		NA
m/p-Xylene	4.2	1.6	NA	NA	NA	4.4	4.8		NA
o-Xylene	3.2	0.7	NA	NA	NA	**1.8**	**2**	**0.6**	NA
Styrene		0.75	NA	NA	NA				NA
Isopropylbenzene	0.45	0.6	NA	NA	NA				NA
n-Propylbenzene	0.36		NA	NA	NA				NA
1,3,5-Trimethylbenzene	1.2	0.99	NA	NA	NA				NA
tert-Butylbenzene			NA	NA	NA				NA
1,2,4-Trimethylbenzene	1.7	3.9	NA	NA	NA				NA
p-Isopropyltoluene	0.61	2.6	NA	NA	NA				NA
1,4-dichlorobenzene			NA	NA	NA				NA
sec-Butylbenzene	0.31	4.6	NA	NA	NA				NA
1,2,4-Trichlorobenzene			NA	NA	NA				NA
Naphthalene	1.8	2.6	NA	NA	NA				NA

A blank space denotes not detected.

Bold denotes a value below the calibrated range.

NA – not analyzed

Table B-5
Concentrations of VOCs in neat MIO (mg/kg) (Continued)

	Sample 20	**Sample 21**	**Sample 22**	**Sample 23**	**Sample 24**	**Sample 25**	**Sample 26**	**Sample 27**	**Sample 28**	**Sample 29**	**Sample 30**
Acetone		NA		NA	NA			NA	NA		NA
Carbon disulfide		NA		NA	NA			NA	NA		NA
2-Butanone (MEK)	**0.82**	NA		NA	NA			NA	NA		NA
Chloroform	**0.95**	NA	270	NA	NA		**0.5**	NA	NA	3	NA
1,1,1-Trichloroethane		NA		NA	NA			NA	NA		NA
Benzene		NA		NA	NA			NA	NA		NA
Toluene	**0.85**	NA	**3.8**	NA	NA			NA	NA	**0.6**	NA
2-Hexanone	**2.2**	NA	22	NA	NA	**1.4**	**1.6**	NA	NA	**2.1**	NA
Tetrachloroethene		NA		NA	NA			NA	NA		NA
Ethylbenzene		NA		NA	NA			NA	NA		NA
m/p-Xylene		NA		NA	NA			NA	NA		NA
o-Xylene	**2**	NA	**10**	NA	NA	**0.7**	**0.75**	NA	NA	**0.95**	NA
Styrene		NA		NA	NA			NA	NA		NA
Isopropylbenzene		NA		NA	NA			NA	NA		NA
n-Propylbenzene		NA		NA	NA			NA	NA		NA
1,3,5-Trimethylbenzene		NA		NA	NA			NA	NA		NA
tert-Butylbenzene		NA		NA	NA			NA	NA		NA
1,2,4-Trimethylbenzene		NA		NA	NA			NA	NA		NA
p-Isopropyltoluene		NA		NA	NA			NA	NA		NA
1,4-dichlorobenzene		NA		NA	NA			NA	NA		NA
sec-Butylbenzene		NA		NA	NA			NA	NA		NA
1,2,4-Trichlorobenzene		NA		NA	NA			NA	NA		NA
Naphthalene		NA		NA	NA			NA	NA		NA

A blank space denotes not detected.

Bold denotes a value below the calibrated range.

NA – not analyzed

Table B-6
Polycyclic Aromatic Hydrocarbons (PAHs) in MIO in mg/kg

Sample ID	Naphthalene	2-Methylnaphthalene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Chrysene	Reporting Limit
Sample 1	**0.65**	**0.84**	**0.82**						<1.66
Sample 2	2.33	11.0	20.2	17.6					<1.67
Sample 3	2.21	15.80	**21.10**	177.00					<23.6
Sample 4	9.18	34.4	77.1	236					< 24.3
Sample 5	2.96	**16**	**14.2**	35.3					< 23.8
Sample 6	5.86	59.1	57.1	297					< 24.5
Sample 7	3.78	**17.5**	**17.2**	**20.2**					< 24.5
Sample 8		45.8	**17.2**	**18.6**					<24.2
Sample 9	4.23	**18.8**		118					< 24.6
Sample 10	6.58								< 24.1
Sample 11	4.79	**18.5**		119					< 23.9
Sample 12	3.95	38.8	30	68.7					< 24.9
Sample 13		33.7	46.4	392					< 24.0
Sample 14		**23.7**	31.5	44.9					< 23.8
Sample 15									<23.9
Sample 16	2.31	5.36	3.59	12.2					<1.66
Sample 17	2.05	4.48	3.01	10.5					<1.66
Sample 18	1.78	5.46	2.87	11.0					<1.67
Sample 19									<23.4
Sample 20	1.96	13.3	45.8	44.7					<1.67
Sample 21	1.68	6.74	3.06	17.1					<1.67
Sample 22	7.84	50.2	31.6	141				2.11	<1.67
Sample 23									<23.6
Sample 24									<24.1
Sample 25	**0.87**	**1.55**	**0.92**	**1.18**					<1.67
Sample 26	**1.16**	1.95	**1.15**	2.35					<1.67
Sample 27									<24.4
Sample 28									< 23.9
Sample 29	1.94	6.39	2.61	8.12					<1.67
Sample 30									<23.7

A blank space denotes not detected. The reporting limits varied by batch as shown in the table.
All other PAHs were non-detect in all samples.
Bold - denotes an estimated value below the calibration range.

Table B-6
Polycyclic Aromatic Hydrocarbons (PAHs) in MIO in mg/kg (Continued)

Sample ID	Naphthalene	2-Methylnaphthalene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Chrysene	Reporting Limit
M01	2.70	66.00							<1.85
M02	10.1	46	58.8	232					<1.9
M03	12.2	71.2		33.3					<1.83
M04	21	80.6		112					<1.93
M05	30.5	36.2		204					<1.92
M06	5.24	38.8		282	43.1				<1.9
M07	3.81	5.4		14					<1.94
M08	3.64	21.2	33.1	55.2	26.1	13.8	14.9	9.01	<1.91
M09	6.59	39.9		243	37.9				<1.89
M10	1.82	3.45							<1.93
M11	4.4	18.3		30.6					<1.89
M12	6.58	24.8		18.9					<1.89
M13	2.9								<1.95
M14	3.68	27.4	28.1	19					<2.3
M15	3.3	24.1	28.1	19					<1.95
M16	1.68	42							<1.95
M17	8.37	27.5		39.1					<1.95
M18	6.91	45.1		40.8					<1.95
M19	4.37	18.5		49					<1.95
M20	1.28	1.07		50.6				4.77	<1.95
M21	7.85	35.3		25.7					<1.95
M22	14.5	117		243				6	<1.95
M23	33.2	219		178					<1.95

A blank space denotes not detected. The reporting limits varied by batch as shown in the table.
All other PAHs were non-detect in all samples.
Bold - denotes an estimated value below the calibration range.

Table B-7
Concentrations of SVOCs in MIO (mg/kg)

Sample ID	Phenol	2,4-Dimethylphenol	2-Methylphenol	3 and 4-Methylphenol	Dibenzofuran	bis(2-Ethyl hexyl) phthalate	di-n-Butyl phthalate	di-n-Octyl phthalate	Dimethyl phthalate	Detection Limit
Sample 1	**0.04**	0.40				31.20		3.14		<1.66
Sample 2	**0.06**	0.34	**0.23**	**0.10**	6.58	10.50				<1.67
Sample 3	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 4	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 5	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 6	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 7	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 8	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 9	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 10	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 11	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 12	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 13	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 14	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 15	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 16	**1.06**	0.28	0.26	0.64	**1.20**	36.00	1.94			<1.66
Sample 17	**1.23**	0.40	0.30	0.82	**1.04**	69.00	1.83			<1.66
Sample 18		0.11		**0.14**	**0.95**	15.00				<1.67
Sample 19	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 20	1.35		**0.13**	**0.11**	6.95	10.70				<1.67
Sample 21	**0.05**	**0.09**		**0.12**	**1.43**	8.42				<1.67
Sample 22	**5.00**	5.08	1.94	**44.10**			**0.24**		6.74	<1.67
Sample 23	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 24	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 25	**0.14**	**0.16**	**0.08**	**0.05**		223.00	**0.07**			<1.67
Sample 26	**1.53**	**0.14**	**0.09**	**0.07**		40.90	**1.53**		3.19	<1.67
Sample 27	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 28	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Sample 29	**0.47**	0.36		0.64	**1.08**	20.50				<1.67
Sample 30	NA	NA	NA	NA	NA	NA	NA	NA	NA	

A blank space denotes not detected. The reporting limits varied by batch as shown in the table.

All other SVOCs were non-detect in all samples.

Bold - denotes an estimated value below the calibration range.

Table B-7
Concentrations of SVOCs in MIO (mg/kg) (Continued)

Sample ID	Phenol	2,4-Dimethylphenol	2-Methylphenol	3 and 4-Methylphenol	Dibenzofuran	bis(2-Ethyl hexyl) phthalate	di-n-Butyl phthalate	di-n-Octyl phthalate	Dimethyl phthalate	Detection Limit
M01										<1.85
M02	0.4	0.71	0.24	0.38						<1.9
M03	1.05			0.29						<1.83
M04	0.9		0.11	0.14						<1.93
M05	0.85	0.27	0.29	0.34						<1.92
M06	0.4	0.21		0.14						<1.9
M07										<1.94
M08										<1.91
M09		0.19								<1.89
M10										<1.93
M11	0.1	0.48	0.24	0.05						<1.89
M12										<1.89
M13		0.16	0.06							<1.95
M14		0.31	0.14	0.05						<2.3
M15		0.31	0.12	0.04						<1.95
M16	0.08	0.13								<1.95
M17	0.83	1.8	0.67	0.46	19.8					<1.95
M18		0.59	0.33	0.26						<1.95
M19		0.25	0.33	0.26						<1.95
M20										<1.95
M21	0.71	0.32	0.23	0.08						<1.95
M22	0.77	0.35	0.82	0.98						<1.95
M23	1.12	0.11	0.11	0.11						<1.95

A blank space denotes not detected. The reporting limits varied by batch as shown in the table.
All other SVOCs were non-detect in all samples.
Bold - denotes an estimated value below the calibration range.

Table B-8
Concentrations of PAHs and Alkylated PAHs in MIO (mg/kg)

	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14
Naphthalene	2.21	9.18	2.97	5.86	3.78	6.46	0.82	4.23	6.58	4.79	3.95
C1-Naphthalene	21.4	50.2	24.5	74.4	27.2	15.5	3.27	14.3	36.9	30.3	25.2
C2-Naphthalene	382	853	173	1130	170	168	15.4	185	220	243	278
C3-Naphthalene	852	1590	389	2060	375	334	38.8	334	439	1660	589
C4-Naphthalene	1140	1840	9510	3050	765	828	163	626	774	2700	1070
Fluorene	21.1	77.1	14.2	57.1	17.2				30	46.4	31.5
C1-Fluorene	211	710	132	400	123	70.8	97.2	70.6	201	267	124
C2-Fluorene	520	1550	449	830	338	202	127	180	512	768	293
C3-Fluorene		153	375	140		151	34.5	138	102	96.6	61.8
Dibenzothiophene	28.1	26.8	51.9	57.3	32.5	18.4		16.5	93.5	65.9	57.6
C1-Dibenzothiophene	220	294	376	358	259	291	110	266	472	558	387
C2-Dibenzothiophene	48.2	67.9	182	68.8	105	45.1	106	19	204	107	140
C3-Dibenzothiophene	99.5	52.9	299	114	216	30.5	83.9	28.3	304	183	289
Phenanthene/Anthracene	177	236	35.3	297	20.2	118		119	68.7	392	44.9
C1-Phenanthrene/Anthracene	296	518	126	465	91.7	166	20.2	178	161	703	127
C2-Phenanthrene/Anthracene	242	436	112	359	72	127		153	117	572	103
C3-Phenanthrene/Anthracene	152	272	94.9	201	56.7	114		119	82.7	301	72.9
Fluoranthene/Pyrene											
C1-Fluoranthene/Pyrene	29.8	27.8		49.7		24.1		34.3		57.6	
C2-Fluoranthene/Pyrene	12.3	48.7		37.5				14.6			
Chrysene											
C1-Chrysene											
C2-Chrysene											
C3-Chrysene											
C4-Chrysene											

a blank space denotes not detected

Table B-9
VPH and EPH Concentrations in MIO (g/kg)

	Aliphatics (C6-C8)	Aliphatics (C9-C12)	Aliphatics (C13-C18)	Aliphatics (C19-C36)	Aromatics (C9-C10)	Aromatics (C11-C22)	Total VPH	Total EPH	Total VPH + EPH	TPH	Percent Aliphatic	Percent Aromatic
Sample 1	1.5	3.9	330	260	0.19	120	5.6	710	720	NA	83	17
Sample 2	3	7.2	440	440	0.57	150	11	1000	1000	NA	85	15
Sample 3	3.3	4	426	445	3.9	163	11	1040	1040	1030	84	16
Sample 4	5	4.4	353	415	4	232	13	1000	1010	1060	77	23
Sample 5	4.8	2.3	394	488	4.5	151	12	1040	1040	1030	85	15
Sample 6	0.83	5.8	378	405	3.8	108	10	997	1000	1050	79	21
Sample 7	3.6	4.6	370	524	3.8	151	12	1050	1060	1050	85	15
Sample 8	3.9	11	351	522	3.1	161	18	1040	1050	1060	84	16
Sample 9	4.2	11.6	405	486	4.6	157	20	1060	1070	1050	85	15
Sample 10	5	4.4	430	492	1.5	141	11	1070	1070	1050	87	13
Sample 11	5.3	8.8	351	471	3.7	153	17	984	993	1030	84	16
Sample 12	5	6.1	343	500	3.9	165	15	1010	1020	1040	83	17
Sample 13	3.4	4.3	373	429	3.9	223	12	1030	1040	1050	78	22
Sample 14	5.6	4.8	349	530	3.7	172	14	1060	1060	1050	84	16
Sample 15	1.4	7.2	480	370	0.25	90	8.9	950	950	NA	90	9.5
Sample 16	2.2	7.2	460	350	0.17	82	9.6	900	900	NA	91	9.1
Sample 17	2.8	8.9	450	350	0.19	95	12	900	910	NA	90	10
Sample 18	2.6	6.7	490	370	0.21	110	9.5	970	970	NA	89	11
Sample 19	2.5	7.7	420	390	0.26	68	10	890	890	NA	92	7.7
Sample 20	2.7	4.1	440	330	0.17	160	7	930	940	NA	83	17
Sample 21	2.5	11	440	350	0.16	120	14	920	930	NA	87	13
Sample 22	2.1	6.5	370	500	0.23	130	8.8	1000	1000	NA	87	13
Sample 23	2.3	6.61	410	420	0.24	140	9.2	970	970	NA	86	14
Sample 24	2.1	6.5	370	500	0.23	130	8.8	1000	1000	NA	87	13
Sample 25	1.3	3.8	310	250	0.31	110	5.4	670	670	NA	84	16
Sample 26	1.9	4.7	340	260	0.23	130	6.8	720	720	NA	82	18
Sample 27	2	6.5	350	280	0.19	94	8.7	730	730	NA	87	13
Sample 28	1.2	4.6	300	280	0.19	83	6	670	670	NA	88	12
Sample 29	1.9	11	370	260	0.26	110	13	750	750	NA	85	15
Sample 30	1.1	9.8	420	290	0.19	99	11	820	820	NA	88	12

NA – not analyzed

Table B-9
VPH and EPH Concentrations in MIO (g/kg) (Continued)

	Aliphatics (C6-C8)	**Aliphatics (C9-C12)**	**Aliphatics (C13-C18)**	**Aliphatics (C19-C36)**	**Aromatics (C9-C10)**	**Aromatics (C11-C22)**	**Total VPH**	**Total EPH**	**Total VPH + EPH**	**TPH**	**Percent Aliphatic**	**Percent Aromatic**
M01	1.6	1.68	525	445	0.14	126	3.42	1090	1090	1020	89	11
M02	1.6	8.37	395	372	0.36	293	10.3	1070	1070	1020	73	27
M03	1.59	11.5	412	310	0.25	277	13.4	1010	1010	999	73	27
M04	1.49	23.9	417	355	0.62	220	26	1020	1020	1040	78	22
M05	1.2	7.54	419	405	0.3	242	9.04	1070	1070	1040	77	23
M06	1.34	1	190	352	0.32	408	2.66	950	952	932	57	43
M07	1.17	2.62	389	344	0.37	249	4.16	982	984	991	75	25
M08	0.47	1.43	365	522	0.62	160	2.52	1050	1050	900	85	15
M09	1.43	4.24	383	399	0.36	263	6.03	1050	1050	988	75	25
M10	1.22	3.48	512	413	0.26	167	4.96	1090	1090	966	85	15
M11	1.07	2.8	373	420	0.79	228	4.66	1020	1020	932	78	22
M12	0.43	5.44	448	448	0.47	214	6.34	1110	1110	951	81	19
M13	0.2	2.4	330	343	0	230	2.6	904	905	895	75	25
M14	0.46	2.5	347	352	0	215	3.1	917	917	878	77	23
M15	1.4	3	325	326	0.15	203	4.5	857	858	896	76	24
M16	1.1	3.2	369	341	0	190	4.4	903	904	966	79	21
M17	1	4.4	299	332	0.16	235	5.5	870	872	914	73	27
M18	1.3	4.1	212	431	0	240	5.5	888	889	987	73	27
M19	1	1.9	250	414	0	244	3	911	912	964	73	27
M20	1.1	0.58	334	368	0	217	1.7	920	921	955	76	24
M21	0.37	4	283	393	0	222	4.4	903	903	872	75	25
M22	0.36	11	338	281	0	250	11	881	881	974	72	28
M23	0.51	8.8	250	303	0	193	9.4	754	755	648	74	26

Table B-10
Concentrations of VOCs in water in MIO dissolution tests at pH 7 (ug/L)

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23
Acetone																							
Carbon disulfide																							
2-Butanone (MEK)			3																				
1,1,1-Trichloroethane																							
Benzene					**1**																2		2
Toluene	2			**1**	2												1			1	6	21	90
Ethylbenzene				6																			2
m/p-Xylene				22	**1**												2			2	2	4	5
o-Xylene				14																1		2	2
Styrene	**1**																						
1,3,5-Trimethylbenzene				1																			2
1,2,4-Trimethylbenzene				3													2				1	2	4
1,2-dichlorobenzene	**1**																						
1,2,4-Trichlorobenzene	2																						
Naphthalene (8260)	7	4	3	5	7	2											2	1			1	2	6
1,2,3-Trichlorobenzene	**1**																						

A blank space denotes not detected.

All other VOCs were non-detect in all samples.

Bold - denotes an estimated value below the calibration range.

Table B-10
Concentrations of VOCs in water in MIO dissolution tests at pH 4 (ug/L) (Continued)

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23
Acetone																							
Carbon disulfide																							
2-Butanone (MEK)																							
1,1,1-Trichloroethane																							
Benzene					2																2		2
Toluene	2			1	2																4	20	89
Ethylbenzene				5																			2
m/p-Xylene				17	**1**															1	**1**	3	4
o-Xylene				11																		1	2
Styrene	**1**																						
1,3,5-Trimethylbenzene				1																			1
1,2,4-Trimethylbenzene				2													2					2	3
1,2-dichlorobenzene																							
1,2,4-Trichlorobenzene	2																						
Naphthalene (8260)	6		3	4	6	2											1					1	4
1,2,3-Trichlorobenzene																							

A blank space denotes not detected.
All other VOCs were non-detect in all samples.
Bold - denotes an estimated value below the calibration range.

Table B-10
Concentrations of SVOCs in water in MIO dissolution tests at pH 4 (ug/L) (Continued)

	M01	**M02**	**M03**	**M04**	**M05**	**M06**	**M07**	**M08**	**M09**	**M10**	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**M19**	**M20**	**M21**	**M22**	**M23**
Phenol		0.64		0.86		0.83											0.42				0.49	0.58	0.85
2,4-Dimethylphenol		0.79		**0.36**	**0.28**												1.52	**0.31**			**0.35**	**0.2**	
2-Methylphenol		**0.37**		**0.25**	**0.3**												0.56		**0.3**		**0.25**	0.88	
3 and 4-Methylphenol		0.65	0.39	0.38	**0.33**	**0.28**											**0.34**		**0.24**			1.04	
Dibenzofuran		0.27		0.26	0.84		0.2	0.69	0.27	**0.11**	0.24	0.55	0.3	0.34	0.44	0.31	0.32	0.57	0.86	0.38	0.83		0.95
di-n-butylphthalate																							
dimethylphthalate				**0.33**																			
Naphthalene (8270)				3.22	5.47																1.02	2.22	5.62
2-Methylnaphthalene	4.22	2.72	3.78	4.64	2.56	1.97	0.24	1.22	1.4	0.12	0.77	0.35	**0.09**	0.5	0.63	1.5	1.51	2.06	1.21	0.42	2.18	7.44	13.55
Acenaphthylene		0.21																**0.11**					
Acenaphthene	0.4	0.31	0.41	**0.17**		**0.14**			**0.19**		**0.15**	0.26						**0.16**					
Fluorene	**0.09**	1.33	0.84	0.39	1.82	0.94	0.73	0.9	1.41	0.24	0.49	0.58	0.41	0.42	0.54		0.45	0.85	0.91	0.38	0.75	1.57	1.02
Phenanthrene		2.86		1.32	5.36	3.09	0.28	1.13	1.96		0.35	0.2	0.11	0.25	0.28		0.58	0.68	1.04	1.84	0.53	4.08	2.23
Anthracene		**0.09**				0.12			0.17		**0.05**							0.13					0.12
Fluoranthene																							
Pyrene																							
Benz(a)anthracene																							
Chrysene																							

A blank space denotes not detected.

All other SVOCs were non-detect in all samples.

Bold - denotes an estimated value below the calibration range.

Table B-10
Concentrations of SVOCs in water in MIO dissolution tests at pH 7 (ug/L) (Continued)

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23
Phenol		0.67	2.85	1.67	0.85	0.94											0.73						0.9
2,4-Dimethylphenol		0.9	0.71		**0.35**	0.4											1.73	0.54			**0.26**		
2-Methylphenol		**0.39**	0.47		**0.38**												0.79	**0.28**	**0.22**		**0.25**	0.74	
3 and 4-Methylphenol		0.7	0.77	0.54	0.4	0.39											0.5					0.83	
Dibenzofuran		0.24					0.2	0.38	0.3		0.24	0.52	0.2	0.42	0.48	0.21	0.34	0.64		0.36	0.37	1	1.11
di-n-butylphthalate																							
dimethylphthalate																							
Naphthalene (8270)			4.14	3.31	6.33																1.32	2.19	6.49
2-Methylnaphthalene	4.28	2.13	9.36	5.74	2.39	2.47	0.25	1.26	1.5				**0.7**	0.65	0.74	1.38	18.48	2.61	1.1	0.39	2.4	6.45	14.88
Acenaphthylene																	**0.13**						
Acenaphthene	0.36	0.54	0.81		1.5	**0.18**	0.21	0.2	0.2		0.31	0.26							**0.17**		0.23		
Fluorene		1.12	1.57		1.32	1.18	0.69	0.71	1.45	0.24	0.46	0.63	0.29	0.52	0.59	0.29	0.56	0.91	0.57	0.29	0.53	1.15	1.11
Phenanthrene		2.63		2.35	2.85	3.7	0.27	0.77	2.6		0.33	0.19	**0.8**	0.26	0.3	**0.9**	0.65	0.57	1.3	1.34	0.42	3.9	2.6
Anthracene		0.1				**0.9**	**0.5**	0.16	0.2										2.38	0.1			
Fluoranthene																			0.49				
Pyrene																			0.68				
Benz(a)anthracene																			0.21				
Chrysene																			**0.18**				

A blank space denotes not detected.

All other SVOCs were non-detect in all samples.

Bold - denotes an estimated value below the calibration range.

Target:

Transmission and Distribution Soil and Water Issues

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