A REVIEW ON PETROLEUM HYDROCARBON SUBSURFACE CONTAMINATION AND A GUIDELINE TOWARD THAILAND SITUATION

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ABSTRACT: Soil and groundwater contamination is the degrading of the natural quality of the subsurface system. Such contamination is usually thought of in the context of human activities. One of the main sources of contaminants comes from petroleum hydrocarbon materials and products in a variety of industries. Oil accounts for a large percentage of the world's energy consumption, ranging from a low of 32% for Europe and Asia, up to a high of 53% for the Middle East. More than 50% of petroleum is used for transportation (e.g. gasoline, diesel, and jet fuel). Contaminations are found widely spread everywhere and these should be case studies for other parts of the world.

Currently, Thailand consumes a larger amount of fuels than ever. The main proportion of petroleum products consumption is diesel, followed by gasoline (including gasohol), fuel oil, jet fuel, LPG, and kerosene. Past practices of fuel handling, storage, and disposal, along with leaks and spills, may have resulted in extensive underground soil and groundwater contamination. However, little is known for this kind of subsurface contamination in Thailand. This work reviews various case studies, in-situ and laboratory analysis methods for petroleum hydrocarbon contamination, remediation techniques, and different guidelines which are enforced elsewhere. Moreover, the current situation of petroleum hydrocarbon handling and storage in Thailand are explored. These components will be beneficial to a draft guideline for detecting petroleum hydrocarbon contamination in Thailand. The preventive and remedial phases need to be followed, including feasibility study, remedial design, remedial operation and maintenance.

INTRODUCTION

Soil and groundwater contamination is the degrading of the natural quality of the subsurface system. Such contamination is usually thought of in the context of human activities. Oil accounts for a large percentage of the world's energy consumption, ranging from a low of 32% for Europe and Asia, up to a high of 53% for the Middle East. More than 50% of petroleum is used for transportation (e.g. gasoline, diesel, and jet fuel). Airport is one of the main point sources of the petroleum hydrocarbon contaminants and is usually overlooked. A consortium of airlines, fuel companies, truck companies, petroleum products production, storage, and distribution centers, oil and gas pipelines, and gasoline service stations are contributing to the contamination of the subsurface underlying an airport area. A characteristic feature of airport operation is the long-term continuous handling of large volumes of fuels including their transport and storage. Inadequate technical conditions of storage, distribution facilities, the safety equipment and safety measures can cause leakage from the underground storage tanks (UST). The fuel leaking from UST seeps into underground soil and contaminates the subsurface waters including groundwater. The soil in these areas is consequently contaminated with petroleum products such as diesel fuel, aviation gas, lubricants, and chlorinated solvents that are known to persist in the environment and could be components of concern. Several of these organic compounds may produce liver injury and probable human carcinogens via ingestion. Many major airports in the United States are found contaminated with the petroleum hydrocarbon compounds.

Currently, Thailand consumes a larger amount of fuels than ever. The main proportion of petroleum products consumption is diesel, followed by gasoline (including gasohol), fuel oil, jet fuel, LPG, and kerosene. Major portion of this petroleum is consumed in Bangkok particularly near the airport areas. Bangkok is underlain by a thick clay layer and hydrocarbon contamination in the underlying soil layers has not much been done and reported. Past practices of fuel handling, storage, and disposal, along with leaks and spills, may have resulted in extensive underground soil and groundwater contamination. The preventive and remedial phases need to be followed, including feasibility study, remedial design, remedial operation and maintenance.

Figure 1 petroleum hydrocarbon storage tanks and leakages to surrounding area.

Past practices of fuel handling, storage, and disposal, along with leaks and spills, may have resulted in extensive underground soil and groundwater contamination. However, little is known for this kind of subsurface contamination in Thailand. This work reviews various case studies, in-situ and laboratory analysis methods for petroleum hydrocarbon contamination, remediation techniques, and different guidelines which are enforced elsewhere. Moreover, the current situation of petroleum hydrocarbon handling and storage in Thailand are explored. These components will be beneficial to a draft guideline for detecting petroleum hydrocarbon contamination in Thailand. The preventive and remedial phases need to be followed, including feasibility study, remedial design, remedial operation and maintenance.

TOTAL PETROLEUM HYDROCARBON

Petroleum is crude oil, natural gas, liquid natural gas, and other hydrocarbon mixture compounds that occurred naturally. They can be solid, liquid, or gas at the natural stage. In general, any petroleum compounds are composed of carbon ranging between 82-87%, hydrogen ranging between 11-15%, sulfur ranging between 0.1-6% and nitrogen ranging between 0.01-3%. (Maerah, 1998)

(ATSDR, 1999) Total petroleum hydrocarbon (TPH) is a term used to describe a large family of several hundred chemical compounds that originally come from crude oil. Crude oil is used to make petroleum hydrocarbon products, which can contaminate the environment. Because there are so many different chemicals in crude oil, it is not practical to measure each one separately. However, it is useful to measure the total amount of TPH at a site.

TPH is a mixture of chemicals, but they are all made mainly from hydrogen and carbon, called hydrocarbon. Scientists divide TPH into groups of petroleum hydrocarbons that act alike in soil or water. These groups are called petroleum hydrocarbon fractions. Each fraction contains many individual chemicals.

Some chemicals that may be found in TPH are hexane, jet fuels, mineral oils, benzene, toluene, xylenes, naphthalene and fluorene, as well as other petroleum products and gasoline compounds. However, it is likely that samples of TPH will contain only some, or a mixture, of these chemicals. Table 1 shows some of the petroleum compounds mostly found in the environments.

Table 1 Total petroleum hydrocarbon compounds and properties (ATSDR, 1999)

Representative Compounds	Properties
Hexane	Hexane isomers are mostly unreactive, and are frequently used as an inert solvent in organic reactions because they are very non-polar. They are also common constituents of gasoline and glues used for shoes, leather products, and roofing.
Jet fuel	Jet fuel is a type of aviation fuel designed for use in aircraft powered by gas-turbine engines. It is clear to straw colored. The most common fuels are Jet A and Jet A-1. Kerosene-type jet fuel (including Jet A and Jet A-1) has a carbon number distribution between about 8 and 16 carbon numbers.
Mineral oil	Mineral oil or liquid petroleum is a by-product in the distillation of petroleum to produce gasoline and other petroleum based products from crude oil. It is transparent, colorless oil composed mainly of alkanes (typically 15 to 40 carbons) and cyclic paraffins.
Benzene	Benzene, C6H6, is a colorless and highly flammable liquid with a sweet smell and a relatively high melting point. It is an important industrial solvent and precursor in the production of drugs, plastics, synthetic rubber, and dyes.
Toluene	Toluene is a clear water-insoluble liquid with the typical smell of paint thinners, redolent of the sweet smell of the related compound benzene. It is an aromatic hydrocarbon that is widely used as an industrial feedstock and as a solvent.
Xylene	It is used as a solvent in the printing, rubber, and leather industries. Xylene is a clear,

Representative Compounds	Properties
	colorless, sweet-smelling liquid that is very flammable.
Naphthalene	Naphthalene is a crystalline, aromatic, white, solid hydrocarbon with formula C10H8 and the structure of two fused benzene rings. It is best known as the primary ingredient of mothballs. It is volatile, forming an inflammable vapor, and readily sublimes at room temperature.
Gasoline	Gasoline or petrol is a petroleum-derived liquid mixture, primarily used as fuel in internal combustion engines. Small quantities of various additives are common.

TPH is therefore a mixture of chemicals that are mainly composed of hydrogen and carbon as their main components. Some of TPH can be clear and colorless to dark and heavily thick, while some of them can be unreactive as hexane and some can be responsive as gasoline. However, TPH should not be used as a direct indicator of risk to humans or to the environment. On the other hands, TPH values can suggest the relative potential for human exposure and hence for human effects.

THAILAND PETROLEUM CONSUMPTION

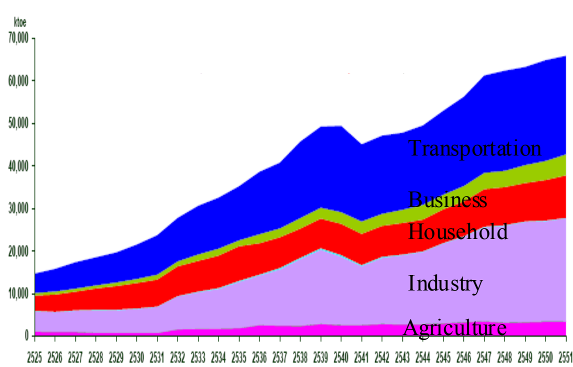

Figure 2 Energy consumption in different sections in Thailand (DEDE, 2009)

Energy is a factor of the well being of the people and is a production factor of the commercial and industrial sectors. As a result, energy is a prime mover of the country's competitive edge and economic development in the long term. In order to attain continuous and sustainable economic development, it is essential that energy supplies be adequate and secure, at reasonable prices, and that due consideration be given to the environment so as to enhance the country's competitiveness. In Thailand, the main energy consumptions are in transportation and industrial sections as shown in Figure 2.

In developed countries, such as Japan and England, the main transportation system in urban cities is the rail system, which is promoted by the governments due to its most energy efficiency. On the contrary, in Thailand, almost 80% of energy consumption in the transportation sector is used for land transportation; of this, 78.6% is for transportation by cars and light/heavy trucks and only 0.5% by rail. Transportation by waterway accounts for only 4.6%, and the remaining 16.3% is for air transportation. The major energy used in the transportation is gasoline with little amount of natural gas and electricity as shown in Figure 3. Gasoline typically is stored in underground and above ground storage tanks. Therefore, gasoline as the main energy source consumed in Thailand should be handled with care and cautiousness in order to avoid leakage from their storage tanks causing contaminations to the air, water, and soil environments.

Currently, Thailand has almost 3,500 of gasoline service stations distributed all over the country. Bangkok has 670 gasoline service stations, provinces around Bangkok have 262 service stations, Central Thailand has 228 service stations, and Upper North has 311 service stations while lower North has 277 service stations. Upper and lower Northeast has 369 and 336 service stations, respectively. While East has 348, 316 gasoline service stations are located in the West. The South has 188 service stations in the Upper and 148 service stations in the South. This data is obtained from Bureau of Fuel Trade and Stockpile, Department of Energy Business, Thailand.

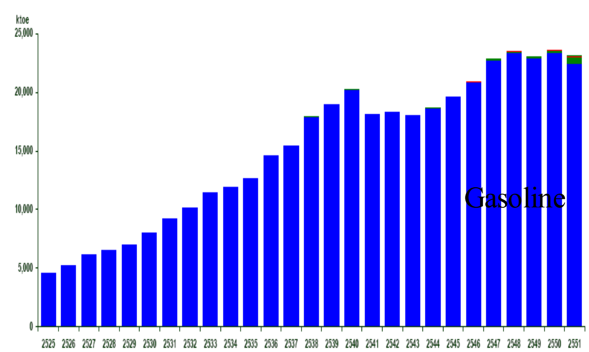

Figure 3 Energy compositions in transportation section between gasoline, natural gas, and electricity (DEDE, 2009)

CASE STUDIES OF PETROLEUM CONTAMINATION

It has been estimated that there are very likely more than 2.5 millions of underground storage tanks (USTs) that contain petroleum hydrocarbon compounds in the United States (Steen and Elton, 1996; Gangadharan et al., 1998).

In the US, BTEX (benzene, toluene, ethyl benzene, and xylene), which are the main components in the oil and gasoline for vehicles, are found to contaminate both soil and groundwater greatly. BTEX can significantly cause effects on human health and environment. The UST point sources may leak and BTEX compounds may seep into subsurface environment contaminating soil and groundwater. Because BTEX compounds are polarizing and can easily dissolve in the water, organic and inorganic byproducts of these BTEX compounds, when reach groundwater, can spread with groundwater flow through the mechanism of advection and dispersion and thus can pose risk and harm to human and environment in a larger scale.

Gangadharan et al. (1988) estimated that currently there are 100,000 UST leakages and there would be more than 350,000 UST leakages in the next 5 years. Statistically, approximately 90% of the leakages are because the tanks were made from steel, which could be eroded easily under little acidic and wet condition, and more than 65% of the leakages are from the USTs that have been used more than 17 years to store liquid underground.

In Thailand, there are some studies done on petroleum contaminations from gasoline service stations in water and subsurface environments. Among those, there are Suwanapichon (1996), Palaruck and Jandrapradith (1997), Sukhumavasi et al. (1999) and Watanasuthipong (2001). The studies found that most of wastewaters from the gasoline service stations contain oil and grease contents higher than the maximum standard allowable values even though there are oil and grease tanks implemented. The areas around lubricant release locations are found to be most contaminated by oil and grease contents.

As oil accounts for a large percentage of the world's energy consumption, more than 50% of petroleum is used for transportation (e.g. gasoline, diesel, and jet fuel). Airport is one of the main point sources of the petroleum hydrocarbon contaminants and is usually overlooked. A consortium of airlines, fuel companies, truck companies, petroleum products production, storage, and distribution centers, oil and gas pipelines, and gasoline service stations are contributing to the contamination of the subsurface underlying an airport area. A characteristic feature of airport operation is the long-term continuous handling of large volumes of fuels including their transport and storage. Inadequate technical conditions of storage, distribution facilities, the safety equipment and safety measures can cause leakage from the underground storage tanks (UST). Several of these organic compounds may produce liver injury and probable human carcinogens via ingestion. Many major airports in the United States are found contaminated with the petroleum hydrocarbon compounds. Table 1 shows some examples of subsurface petroleum hydrocarbon contaminations particularly at airports in the US.

Table 2 Examples of subsurface contaminations by petroleum hydrocarbons.

Location	COC	Sources	Note
International Airport in Delhi, India	PAH	Jet turbine exhaust	Sharmila et al. (2008)
Tucson International Airport	TCE, DCE, chloroform, benzene and chromium		
Phoenix-Goodyear Airport	TCE, chromium, PCE, DCE, chloroform, and carbon tetrachloride		Soil vapor extraction (SVE) system
JFC Airport, and La Guardia Airport, NY Airport	MTBE, benzene and other petroleum hydrocarbons	USTs, fuel piping	Several multiphase extraction systems
Seattle-Tacoma International Airport	Jet fuel, gasoline, solvents	USTs, fuel piping	
Fairbanks International Airport in AK	diesel fuel, aviation gas, lubricants, and chlorinated solvents		
Seattle-Tacoma International Airport	jet fuel, gasoline and solvents	USTs, fuel piping	
Juneau Airport Fueling Facility	Jet fuel, aviation gasoline	ASTs, USTs	Soil excavation, ozone injection remedial system
A petroleum-storage and pipe-line facility in Sioux Falls, SD	diesel fuel, fuel oil, gasoline, jet fuel, and pesticides		Pumping and treatment, in-place treatment, excavation and disposal with aeration and additives
Stapleton International Airport in CO	jet fuel, glycol aviation fuel		Visual analysis and smell, IR screening method, excavating and disposal
Tucson International Airport	TCE, dioxane, PCE, DCE, chloroform, benzene, and chromium		Soil vapor extraction (SVE) system

FATE AND TRANSPORT OF PETROLEUM CONTAMINATION

Groundwater serves as a medium to transport a chemical from its source to the point of exposure. With gasoline service stations and their underground storage tanks (USTs), there is more concern about petroleum hydrocarbon contaminations in our subsurface environment. Point-source contamination including leaking underground storage tanks, accidental spills, improper surface applications, etc. usually impacts the unsaturated zone before reaching the underlying aquifer. Although petroleum hydrocarbon can be attenuated in the unsaturated zone, they sometimes constitute health hazards. Non-biodegradable and non-volatile petroleum hydrocarbon can reach the water table through rapid vapor phase diffusion or transport in the aqueous phase. Depending on the petroleum density in comparison to water density, light contaminant fraction floats on the top of water table and dense fraction flows and disperses with groundwater flow. All the petroleum hydrocarbon phases also undergo natural attenuation or biodegradation by subsurface bacteria and other complex reactions as described following.

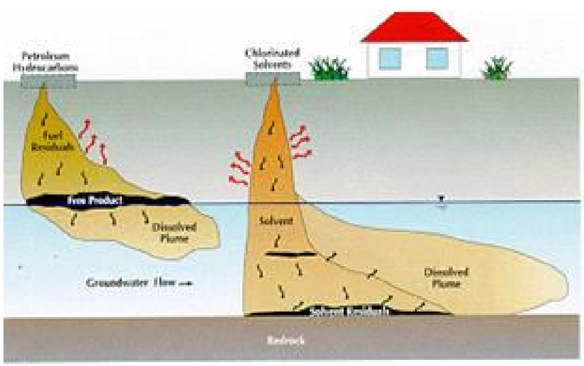

Figure 4 Fate of petroleum hydrocarbon contaminants in subsurface environment (FFRRO, 1999)

Non-aqueous phase liquid (NAPL) contamination may differentiate into at least four distinct bodies, each of which has unique chemical and geophysical characteristics. There is an immiscible phase, or free product, which is mobile or free to migrate under the influence of gravity. Secondly, the residual phase is that portion which is trapped or left behind after the free product has been removed by recovery wells or has migrated down the hydraulic gradient. Third, volatile NAPL may have a well-developed vapor plume in the region above free product and residual product. Finally, small amount of hydrocarbon enter the aquifer as a dissolved phase. The dissolved phase hydrocarbon plume is important for health reasons, but is not directly of consequence for geophysical methods because of the small quantities (ppm) and lack of charge carriers. (Sauck, 2000)

Natural subsurface microorganisms are capable of degrading petroleum hydrocarbons in groundwater, soil, and rocks. The results of such the biodegradation are CO2, H2O, energy and heat, and organic acids. The presence of acids causes the drop of pH and dissolution of salts from sediment grain coating. Therefore, the electrical conductivity of porewater in the zone of biodegradation is increasing.

The nature of free hydrocarbon phase plume is not a continuous phase. Hydrocarbon is generally lower than 50% of the saturation. For well-sorted coarse-grained sediments, the amount of hydrocarbon can be higher than in the fine-grained sediments. Hysteresis of hydrocarbon product may also occur; that a lowering water table leaves some residual hydrocarbon product stranded high, while conversely a rise in the water table elevation often leaves some hydrocarbon product trapped below the water table. Thus, smearing hydrocarbon product can be detected over a considerable vertical distance over a period of several years.

Some studies have found that the recent released hydrocarbon contamination results in high resistivity anomalies (Sauck, 1998). Several months after the leaks or spills, distinct low resistivity, which is corresponding to high conductivity, can be detected along the plume path (Atekwana et al., 2001; Sauck, 1998; 2000; Shevnin et al., 2003). According to Sauck (1998), the low resistivity anomaly is due to an increase of total dissolved solids (TDS) in the acid environment created by the bacterial action in the inferior part of the vadose zone or below groundwater table. However, the observed geophysical signatures are in response to many mixed complex physical and biochemical changes occurring within a dynamic system.

PETROLEUM HYDROCARBON ANALYSIS METHODS

(EPA 510-B-97-001) Analysis of soil, soil-gas, and groundwater samples in the field is an essential element of expedited site assessments (ESAs). Historically, the analysis of contaminated media during UST site assessments has been completed off-site in fixed laboratories that use certified analytical methods. While these methods provide a very high data quality level (DQL), their results may take days or weeks and their cost is relatively high. By combining field methods of different DQLs, ESA can improve the resolution of contaminant distribution and minimize analytical costs. Low DQL (i.e., screening) methods can be sued to provide a high density of data to determine source areas. Higher DQL methods can be used to identify low concentrations or specific chemicals of concern at select locations. Data from higher DQL methods can also be used as part of a quality control check for the field analytical program.

Table 3 Summary of data quality levels (EPA 510-B-97-001)

Data Quality Level	General Field Applications
1A: Qualitative screening	General presence of contamination (e.g. “Yes/no”, low/medium/high); health and safely
1B: Semiqualitative screening	Approximation of contaminated zone; provides order of magnitude estimations
2: Quantitative delineation	Delineation of specific contaminants
3: Quantitative clean zone	Regulatory monitoring, determining clean samples

Field screening tools

Field screening results are used to identify possible contamination in soil samples and to aid in selection of soil samples for chemical analysis. The field screening methods may also include visual examination, water sheen testing, and headspace vapor screening.

Visual screening typically involves inspecting the soil sample for visual indications of petroleum contamination, such as staining. Visual screening is typically more effective when soil samples are heavily contaminated, which generally results in staining.

Headspace vapor screening consists of placing a soil sample in a plastic bag and capturing air in the bag. The bag is then sealed and shaken to expose the atmosphere in the bag to volatile organic carbons (VOC) in the soil. The photoionization detector (PID) intake probe is then inserted into the bag to measure the concentration of VOCs in the bag headspace. Portable organic vapor analyzers such as flame ionization detectors (FID) and PID, and immunoassay field test kits are useful tools for on-site sample screening and sample selection for laboratory analysis. However, because of the lack of specificity, accuracy, precision, and quality assurance/quality control, field screening data will not be acceptable for confirming the presence, nature or extent of soil contamination; only laboratory results will be acceptable.

(ASTM, E2143-01) The test method using field-portable fiber optics synchronous fluorescence spectrometer is for quantification of field samples for aromatic and polycyclic aromatic hydrocarbons (AH and PAH). This technique is designed for on-site rapid screening and characterization of soil and water samples resulting in significant cost savings for remediation projects. Quantification of total AHs and PAHs in these environmental samples is accomplished by having a subset of the samples analyzed by an alternate technique and generating a site-specific calibration curve. Synchronous fluorescence provides sufficient spectral information to characterize AHs and PAHs present as BTEX, the aromatic portion of TPH.

Laboratory techniques

One of the difficulties with TPH analysis is that the scope of the methods varies greatly. Some methods are nonspecific while others provide results for hydrocarbons in a boiling point range. In order to quantify different hydrocarbon compounds for the purposes of delineation and regulatory monitoring, higher data quality levels for petroleum hydrocarbon detection must be achieved. Generally, this includes the methods conducted in laboratories as described below.

Conventional methods

EPA Method 418.1 (U.S. EPA, 1979) provides a value of TPH. The amount of TPH measured by this method depends on the ability of the solvent used to extract to hydrocarbon from the media and the absorption of infrared (IR) light by the hydrocarbons in the solvent extract. However, the method is not specific to hydrocarbons and doesn’t always indicate petroleum contamination (e.g., humic acid, a non-petroleum hydrocarbon, may be detected by this method).

EPA Method 418.1 has been one of the most widely used methods for the determination of TPH in soils. Freon-extractable material is reported as TOG. Polar components may be removed by treatment with silica gel, and the material remaining, as determined by infrared (IR) spectroscopy, is defined as Total Recoverable Petroleum Hydrocarbons (TPH, TRPH, or TPH-IR).

The important advantages of this approach are 1) the method is relatively inexpensive and 2) excellent sample reproducibility can be obtained. The disadvantages are 1) petroleum hydrocarbon composition varies among sources and over time, so results are not always comparable 2) more volatile compounds in gasoline and light fuel oil may be lost in the solvent concentration step 3) there are inherent inaccuracies in the method and 4) the method provides no information on the types of hydrocarbons present. Thus, this method, although they provide adequate screening information, do not provide sufficient information on the extent of the contamination and product type.

Gas chromatography (GC) methods do provide some information about the product type. Most methods involve a sample preparation procedure followed by analysis using GC techniques. GC determination is based on selected components or the sum of all components detected within a given range. Frequently, the approach is to use two methods, one for volatile range and another for semivolatile range. Volatiles are determined by purge-and-trap GC/FID (GRO). Semivolatile range is determined by analysis of extract by GC/FID (DRO). EPA Method 801.5 Modified reports the concentration of these GRO and DRO (U.S. EPA, 1983).

Methods for determining TPH in soils and sediments are used primarily for UST programs. Currently, many of the states have adopted EPA Method 418.1 or modified 801.5 or similar methods for analysis during remediation of contaminated sites. Thus, there is no standard for TPH analysis.

There is a trend toward use of GC techniques in analysis of soils and sediments. One aspect of these methods is that "volatiles" and "semivolatiles" are determined separately. The volatile or GRO components are recovered using purge and trap or other stripping techniques. Semivolatiles are separated from the solid matrix by solvent extraction (U.S. EPA, 1995). Other extraction techniques have been developed to reduce hazards and cost of solvent use and to automate the process. Capillary column techniques have largely replaced the use of packed columns for analysis, as they provide resolution of a greater number of hydrocarbon compounds.

Applications of geophysical tools

Typically, hydrocarbon compounds have very high specific resistivity of the order 10^6 Ωm up to 10^9 Ωm. This can be a meaningful signature in order to detect petroleum hydrocarbon contamination underground by a geophysical tool. However, a geoelectrical model of contaminated soil by hydrocarbon compounds is much more complex. Depending on the position of the groundwater level, the phase composition of the contaminant, as well as the geological content and structure of the soil in the contaminated volume, different reactions and processes may occur. As time goes by processes of biodegradation, migration, and diffusion of contaminants there develop.

Currently, there are some studies applying geophysical techniques in order to find petroleum contaminations by looking for the resistivity or electrical conductivity signatures in the subsurface environment. For examples, these are Batayneh (2005), Halihan et al. (2005), Coria et al. (2009), and Atekwana et al. (2000).

In the study of Batayneh (2005), short-term laboratory and controlled spill experiments using fresh hydrocarbon product support the model that organic contaminants generally have a high electrical resistivity on the order of 10^6 Ωm and low relative electrical permittivity between 2 and 3. Resistivity measurements were carried out utilizing the Wenner and dipole-dipole array configurations. Correlation between field results shows that dipole-dipole array is the most reliable. However, many geophysical field investigations of LNAPL at numerous sites with aged contamination show that the smear zone has low resistivity (Atekwana et al., 2000).

In Atekwana et al. (2000), three major layers can be observed; an upper medium grained sand; an oil-stained medium grained sand with strong gasoline odor; and black gravel saturated with free product. The results show higher resistivities (between 100-500 Ωm) in the upper vadose zone. The sudden decrease in resistivity to 15 Ωm is found in the middle layer with strong gasoline odor. Below this zone, the resistivity gradually decreases to 30-40 Ωm reflecting background saturate zone with free products. Throughout this investigation, geoelctric measurements consistently recorded low resistivities (high apparent conductivity) associate with zones containing the free/residual product plume.

However, it should be noted that the electrical resistivity imaging (ERI) images do not provide a signal such that the presence of hydrocarbon is the only explanation for any given anomaly. Some confirm technique is almost always required and for examples, these are direct drillings and measuring groundwater qualities. Halihan et al. (2005) applied two methods to monitor and test to determine if fugitive hydrocarbons had been removed. ERI and direct push sampling are applied and evaluated for TPH. The results of coring and testing were compared with the ERI images. The results of comparing the core analyses and electrical resistivity images indicated that ERI is a good technique for detecting hydrocarbons in the shallow subsurface. In Coria et al. (2009) study, a joint implementation of two geophysical non-invasive methods and chemical analysis of water and soil samples is applied to characterize an area affected by a hydrocarbon spill in Argentina. The geophysical prospecting was carried out through the resistivity and the electromagnetic induction methods. The chemical procedure consisted of water and soil analysis of PTH (Polinuclear total hydrocarbon) by EPA 418.1. The results between the geophysical interpretations and chemical data are established. The detection and characterization of the contaminated plume showed positive results even though a liquid phase was not preset at the site. Shallow intervals present increasing resistivity with the concentration of contaminant.

CURRENT GUIDELINES FOR PETROLEUM HYDROCARBON CONTAMINATION

Davis et al. (2006) reviewed significant numbers of protocols and techniques for characterizing sites with subsurface petroleum hydrocarbon. The document summarizes available guidance, protocol, and standards documentation from State government agencies and the NEPC, from industry, and from overseas (United States, United Kingdom, Europe, and New Zealand). This section briefs some of the guidance for site investigating and remedial acting.

1. Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand, August 1999, Published by the Ministry for the Environment, Wellington, New Zealand.

Purpose: The present guidelines have been designed to develop uniform and suitable methods of site investigation, contamination assessment, risk assessment, modeling and site management. They aim to provide details of methods for investigating potentially contaminated sites, and for identifying whether or not remediation or controls of the site are necessary in order to protect human health and the environment.

Approach taken: The guidelines take a risk-based approach to the assessment and management of petroleum hydrocarbon contaminated sites. A risk-based approach is flexible and allows decision-making to be appropriately tailored to site specific conditions and hazards. This leads to more cost-effective solutions and allows the greatest effort to be targeted to where it will be most beneficial. To provide for economical use of both small and large facilities, a three-tiered approach has been adopted, similar to that used in the United States and involving increasingly sophisticated levels of data collection and analysis. Generic soil and groundwater acceptance criteria are developed to help determine whether site management is required (Tier 1 assessment) or whether a more detailed assessment involving the development of site-specific criteria (Tier 2 or 3) is advisable. Sites contaminated by petroleum hydrocarbons differ widely in terms of their physical and chemical characteristics and the risk they pose to human health and the environment. The tiered approach provides a decision-making process whereby the site assessment and need for remediation are related to the conditions and risks specific to each site. This allows focused and cost-effective solutions.

2. Agency Guidelines for Petroleum Contaminated Soil and Debris, August 1996, Published by Vermont State Agency of Natural Resources, Waste Management Division (WMD)

Purpose: WMD has prepared this document to provide guidelines for the management, treatment, and disposal of petroleum contaminated soil and debris. These guidelines were developed as a common sense approach, for dealing with numerous large and small scale incidents in a cost effective manner that is protective of public health and the environment.

Approach taken: The WMD encourages the use of a photoionization detector (PID) for the direct screening of soil or debris contaminated with gasoline, fuel oils, and used oil. Soil or debris contaminated with waste oil or heavier petroleum products (e.g. - #4 and #6 fuel oil) will also need to be evaluated by analyzing samples in a laboratory.

The WMD has developed these guideline thresholds to help in the decision-making process concerning petroleum contaminated soils. The threshold is based on PID readings. When PID reading is small, only backfilling can be performed. However, when PID reading is higher, more sophisticated treatment and detail site investigation are required at the site. The on-site soil treatment options include polyencapsulation, vapor extraction, bioremediation and land-farming.

3. Environmental Guideline for Contaminated Site Remediation, November 2003, Published by the Environment Division (ED), Minister of Environment and Natural Resources (ENR), Canada

Purpose: The purpose of this guideline is to solve a contamination problem on a property by setting soil standards for site remediation. This guideline describes the process that is used to manage (e.g. identify, assess, remediate) contaminated or potentially contaminated sites on Commissioner's Land including private land within municipalities.

Procedure taken: Soil and groundwater effects must be assessed as well as potential effects on the surrounding population. A critical factor in a site assessment is completely defining and delineating the extent of the contamination in both soil and groundwater. Once the contamination plume is defined, it must remain defined.

Environmental Site Assessment (ESA) should identify the nature and extent of contaminants. There are three stages of phased investigation, depending on the size and complexity of the contaminated site, ranging from the general to the specific. The three phases of investigation are described below. Phase I is site information assessment identify actual and potential site contamination. In Phase I, the objective is to assemble all available historical and current information to help develop a field-testing program. Phase II is called reconnaissance testing program and it is to confirm the presence and characterize the substances of concern at the site. Characterization of the contamination and site conditions are necessary to develop a remedial action plan or to identify the need for more specific Phase III investigations. It also may be decided that no further action is required or that immediate action is needed. Phase III is the detailed testing program.

For remediation assessment, there are three basic approaches that may be utilized for the development of Site-Specific Remediation Objectives: Tier 1 Direct adoption of remediation criteria (Criteria-based Approach), Tier 2 Adoption of remediation criteria, with limited modifications (Modified Criteria Approach); and Tier 3 The use of risk assessment (Risk-based Approach).

The criteria-based approach is designed to require fewer resources while providing a scientifically defensible basis for protection that is sufficiently flexible to account for certain site-specific factors. The remediation criteria are presented in the context of four types of land use: agricultural, residential/parkland, commercial and industrial. The criteria are considered generally protective of human and environmental health for specified uses of soil at contaminated sites.

The risk-based approach can be more complex and more costly, and is generally utilized when a criteria-based approach is not suitable for a site (e.g., large, complex industrial site).

4. UST Section Guidelines for investigation and remediation of contamination from non UST petroleum releases, July 2007, published by State of North Carolina, Department of Natural and Environment and Natural Resources, Division of Waste Management.

Purpose and application: This document provides guidance for activities involving sources of contamination regulated by the UST Section. This volume contains guidance on methods, procedures and requirements for identifying the source of a discharge or release, determining the nature and extent of contamination, characterizing the risk posed to human health and the environment, and performing corrective action to reduce levels of contamination. The ESA has two processes and these are initial site assessment and comprehensive assessment. During the initial assessment, if soil and groundwater is clean and not contaminated, there is not need to perform the comprehensive assessment and the site can be close.

GUIDELINE IN THAILAND

Law and regulations in Thailand relating to subsurface contamination

According to the Thailand Ministerial Regulation regarding gasoline service stations issued in 2010, gasoline service stations can be classified into 6 classes according to service area and petroleum storage. For example, gasoline service station class A can store fuel less than 180 m^3 in dense populated areas and less than 360 m^3 in other areas. All the fuel must be stored in underground storage tanks, which must comply with UL58 Standard for Steel Underground Tanks for Flammable and Combustible Liquids and UL1746 Standard for External Corrosion Protection Systems for Steel Underground Storage Tanks. Tanks and other relating facilities more than 10 years old must be tested according to the testing guidance.

National Environmental Board Notice 25/2547 “Standard Specification for Soil Quality” set the standard for quality of soils used in for dwelling and agricultural land uses. For example, benzene must be less than 6.5 mg/kg and total xylene must be less than 210 mg/kg. Test methods of evaluating solid waste, physical/chemical methods (SW-846) published by the US Environmental Protection Agency must be applied to quantify the constituents. The method uses gas chromatography or gas chromatography/ mass spectrometer (GS/MC).

A draft guideline in Thailand

For Thailand, the guidance for petroleum hydrocarbon contaminations should be divided into 2 main sections. The first section will be mainly about the site investigation assessment in order to plan the remedial step or to project closure. The environmental site assessment will be separated into initial site investigation and detail site assessment. The second section will be on remedial strategy. The remedial assessment will be classified into different tier approaches. The first tier approach will be criteria-based and the last approach will be risk-based.

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