THE BEHAVIOUR OF LNAPL IN SAND DUE TO PRECIPITATION

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THE BEHAVIOUR OF LNAPL IN SAND DUE TO PRECIPITATION

By

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ABSTRAK

Kes penumpahan minyak telah menjadi semakin meningkat dan semakin serius. Penumpahan minyak boleh terjadi atas kebocoran paip, kemalangan semasa pengakutan, bencana alam atau letupan tangki minyak. Kerja pemulihan untuk membersihkan tanah yang tercemar memerlukan masa yang panjang sekiraya penumpahan minyak berlaku. Penumpahan minyak kebanyakannya berlaku atas darat dan laut. Minyak yang ringan daripada air terutamanya LNAPL akan mengapung atas laut dan juga air di bawah tanah. Kes ini membawa kesan kepada alam sekitar, binatang dan manusia. Minyak yang berapung atas laut melarang kemasukan oksigen dan sinaran matahari ke dalam laut telah mengancam kehidupan laut. Kesihatan manusia juga tergugat apabila kita menggunakan air di bawah tanah yang telah tercemar. Oleh itu, pengerakan minyak di dalam tanah perlu ditentukan sebelum mengadakan kerja pemulihan. Kajian tiang satu dimensi telah dijalankan untuk mengetahui tentang kadar pengerakan LNAPL disebabkan oleh air hujan kerana air hujan akan menjejas pengerakan LNAPL di dalam tanah. Kajian ini bermula dengan saliran air selama 4 jam, penyusupan diesel selama 24 jam, hujan selama sejam dan penyusupan air selama 24 jam. Kajian ini dijalankan sebagai situasi sebenar di dalam tanah. Titisan air daripada hujan akan menyusup ke dalam tanah dan menjadi air di bawah tanah. LNAPL menyusup dari kemukaan tanah dan mengambil ruang kosong antara particles tanah. Apabila hujan turun, diesel akan bergerak bersama air hujan ke bawah tanah sehingga mencapai zon kapilari yang bertepu. Titisan hujan mampu menolak diesel yang telah meduduki ruang kosong antara particle tanah ke bawah tanah yang lebih dalam. Kegunaan intensity air hujan dan isi padu diesel yang berbeza dalam kajian untuk mengetahui kesan yang berlaku atas pengerakan diesel.

ABSTRACT

The number of oil spill cases keeps increasing and turning serious. Any incidents can cause oil spill such as pipeline leakage, transportation accident, natural disasters or exploration of oil tanker. Once the oil spill happened, the remediation work may take long time to clean the contaminated soil completely. The oil spill happened on the ground and the sea. Oil has a density less than water, especially light non-aqueous phase liquid (LNAPL) will float on the sea surface and groundwater table. This will truly bring effect to the environment, animals and humans. Oil covered the sea surface, causing oxygen and sunlight difficult to go into the sea which threaten the aqua life. The pollution of groundwater will lead to health problems when human consumed the polluted groundwater as drinking water. However, before starting the remediation work, the movement of the oil in the ground needs to be determined. Hence, one dimensional (1-D) column tests were carried out to study the rate of migration of the LNAPL due to precipitation because the movement of oil may be affected by rain water percolation. The column test started with drainage for 4 hours, infiltration of diesel for 24 hours, precipitation for 1 hour and percolation of water for 24 hours. This test was conducted to simulate the real case scenario. When precipitation occurred, the droplets infiltrate into the ground and store as groundwater. The LNAPL infiltrate the ground surface and occupied the pore between the soil particles. During precipitation, diesel will migrate downwards together with rain water into the saturated capillary zone. The infiltrated water may occupy the pores by pushing diesel downward and entrapped in deeper soil. The different intensity of precipitation and volume of diesel was used to understand the effect on the saturation of diesel in height.

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LIST OF ABBREVIATIONS

AASHTO	**A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials
DNAPL	**D**ense **N**on-**A**queous **P**hase **L**iquid
LNAPL	**L**ight **N**on-**A**queous **P**hase **L**iquid
MIT	**M**assachusetts **I**nstitute of **T**echnology
NAPL	**N**on-**A**queous **P**hase **L**iquid
USCS	**U**nified **S**oil **C**lassification **S**ystem
USDA	**U. S. D**epartment of **A**griculture

NOMENCLATURES

C	Grain Shape Constant
C_c	Coefficient of Gradation
C_u	Uniformity Coefficient
D_{10}	Effective Particle Size of 10 Percent Fines
D_{30}	Average Particle Size
D_{60}	Effective Particle Size of 60 Percent Fines
e	Void Ratio
G_s	Specific gravity
$H_{c,\max}$	Maximum Capillary Height
k	Hydraulic Conductivity
γ_d	Unit Weight of Dry Soil
γ_w	Unit Weight of Water
w	Water Content
S	Saturation

CHAPTER 1

INTRODUCTION

1.1 Background

Oil is known as non-renewable energy and irreplaceable which will be used up one day. There are different types of oil, which will bring consequences to the environment when an oil spill happened. Oil is grouped into very light oil, light oil, medium oil and heavy oil.

NAPL is immiscible organic liquid and break up to two categories according their physical properties especially their density. LNAPL is light non-aqueous phase liquid where densities of liquid lower than water. Another category is dense non-aqueous phase liquid (DNAPL) which have greater specific gravities than water.

Nowadays, oil spill happened frequently either on the ground or sea because of human mistake, natural disaster or accident. There were number of crude oil spill incidents through shipping in the past 40 years, which caused impacts to the marine environment. Occurred of the small scale of oil spills may still affect the marine environment.

Beside shipping, oil storage tanks also contributed to the oil spill. Oil storage tanks contained a large amount of explosive, flammable and hazardous materials. So, the least amount of spilled oil will cause the contamination of soil and may pollute the groundwater too. Another case is about North American railroads. The railroads need to transport different chemicals, solutions and chemical mixtures in railroad tank cars which means those materials will spill into the surrounding and cause pollution to the environment in an accident event. Light non-aqueous phase liquid (LNAPL) is commonly transported through railroad tank cars among those chemicals. The clean ups

of spilled LNAPL into the soil and groundwater are very costly and time consuming (Yoon et al., 2009).

Besides, there were more than 24 incidents of gasoline and diesel fuel spilled at the Colomac mine site which located in Northwest Territories (NWT) between year 1990 to 2003. The causes of oil spill were due to fuel tanks leakage and overspill while transportation at the site. According to the record, the major oil spilled volume were around 18000 L and 273000 L in February 1990 and February 1997 respectively (Iwakun et al., 2010).

The accidental spills of oil and underground storage tanks leakage onto the ground surface, especially the NAPL which will cause serious contamination of soil. The low solubility of NAPL in water which tend to contaminate the subsurface of soil and groundwater become a concern to the environment. Since the density of LNAPL were lighter than water, they will migrate downward from the ground surface into the soil due to the influence of gravity forces, viscosity and capillary forces. Hence, they contaminated the subsurface region as well as the groundwater quality because they will float on the groundwater table. There are various factors influenced the migration of LNAPL in subsurface such as the types of fluids in the unsaturated and saturated zones and the percentages of occupied pores by each fluid. The solutes and vapours from LNAPL can lead to long-term contamination in groundwater (Sharma and Mohamed, 2003; Kim and Corapcioglu, 2003).

Oil leakage from transportation both sea and land, storage tanks or pipelines caused contamination to the soil and affected the environment too. For example, onshore pipelines convey of oil which contained chemical substances are toxic and hazardous to the environment. Once there is a pipeline leakage, the oil will contaminate the soil at unsaturated zone and saturated zone especially the groundwater.

Oil spill due to shipping accidents are serious issues which threaten tidal wetland habitats and mangrove forest. Oil affected the onshore soils, mangrove trees and marine life. Hence, the oil spilled will disturb the ecosystem because mangrove trees act as shoreline protection, habitat for specific animals, buffer of coastal water quality, recreation and ecotourism. Oil spilled on the sea surface will be brought to the coastal and washed ashore. Hence, the oil will damage the mangrove communities by coating their breathing system which is the roots of mangroves. Most of the flora and fauna died when exposed to oil. Fishing and collection of shellfish activities also will be restricted on an oil spill area which lead to the economic crisis on fish and shellfish supply. Recovery of damages mangrove forest is possible, but it may take at least a few years of time.

Besides impact to the environment, behaviour and geotechnical properties of oil-contaminated soil also affected. Hence, properties of soil are necessary to be determined because it may affect the nearby existing structures. Geotechnical properties such as strength of the soil, permeability, compressibility and compaction of soil will change on contaminated soil. The properties can be determined through carry out laboratory test such as triaxial test, consolidation test, compaction test, direct shear test and uniaxial compressive strength. Different types of soil will have different results on the effect of geotechnical properties.

Clean soil is very important before starting any development in an area to prevent any side effect which may cause any issue. If contaminated soil is found, remediation needs to be carried out to solve the contaminated soil problem. Remediation is categorised into few types such as biological remediation, physical-chemical remediation, chemical remediation and thermal remediation.

Every remediation technology has own advantages and limitations. Both time consuming and cost needed are the first two main factors for deciding which remediation methods to be applied to the contaminated land. For example, bioremediation is a natural method to treat the hydrocarbon which required bacteria to decompose the chemical substances. This method is low cost and the soil will be permanently without any side effect to the environment, but still it needed longer duration which may up to a few years for the treatment. Hence, any remediation treatment can be applied onto the oil contaminated soil, according the soil condition and the area nearby to make sure no or less side effect to the environment.

1.2 Problem Statement

The oil spill brought issues onto the soil, especially accident and leakage from pipeline or during transportation. The oil will infiltrate into the soil and affect the geotechnical properties of soil such as strength and permeability. Remediation work need to be carried out on oil contaminated soil. The land of oil and gas field normally faces pipeline leakage issues where the oil will contaminate the underground soil. The pattern of infiltration of oil into soil may be affected by the intensity of rain. Hence, the climate change which changed the rainfall pattern will divert the migration of oil in the soil. The effect of rainfall volume and intensity on migration of oil must be considered. The oil is released into the subsurface is then infiltrating through the pores within the soil due to capillary and gravitational forces. Hence, the migration of oil will become uneven. Thus, the depth of contamination need to be determined through physical experiment which is column test before carry out remediation. The purpose is to detect the exact location of oil in the soil to ease the remediation work. The problem of soil contamination can be solved through remediation work with known depth and location.

1.3 Objectives

The objectives of the final year project are stated as below:

1. To simulate precipitation based on common rainfall intensity for one dimensional physical model.
2. To analyse the effect of diesel spilled volume on the saturation changes due to precipitation.
3. To evaluate the changes of contaminant saturation due to infiltration of precipitation.

1.4 Scope of Works

In this study, diesel form LNAPL was used instead of other LNAPL due to limitation of because fuel viscosity may affect the permeability and safety consideration. The porous media used during testing was sand and its geotechnical properties assessment only focus on characteristic and hydraulic properties but not strength properties since this study is about the liquid flow in soil. Artificial precipitation was created for one dimensional column test to simulate the rainfall intensity in Malaysia using laboratory apparatus as this experiment was conducted in door because exposure to light will affect the images captured. Image analysis was done to obtained the results for physical modelling.

1.5 Expected Outcome

Understanding the migration of oil in contaminated soil very helpful in remediation work. Due to the dangerous pollution by oil contaminants, remediation needs to be carried out immediately to protect groundwater and living organisms. However, rainfall will affect the movement of oil. Hence, study of precipitation is

necessary because precipitation caused changes in the saturation of diesel and contaminated to the groundwater table. So, remediation work will become easier and shorter time consuming after knowing the area which contains higher saturation of diesel in the field.

1.6 Dissertation Outline

The thesis outline for chapter 1 is about introduction. Introduction include the background on oil, impacts, infiltration of oil and remediation, problem statement of this study and the objectives to carry out this study. Chapter 2 is about the literature review. By referring journals, the literature review is explaining more deeply on the background of the study. Chapter 3 is the methodology for the study. The flow chart of the study was drawn and the procedure and theory of all the laboratory tests need to be carried out to obtain results for the experiment to achieve the objectives of this study. Chapter 4 is about the results and discussion of results. After obtaining all the results from tests, discussion is required to explain on the results to fulfill the objectives. Last is the chapter 5 which is about conclusion. The conclusion is kind of closing for the study through summary out everything that's mentioned in chapter 1 to chapter 4.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Oil can be classified into LNAPL and DNAPL group. The difference between the physical properties is the density. LNAPL is lighter than water and DNAPL is heavier than water. By referring journals, there are many cases on oil spill happened, but this issue is not concerned by the government yet. Oil spill on the ground or on the sea bring impacts to human being and the environment too. Once the spilled oil contaminated the groundwater, the toxic and carcinogenic release from oil will affect human health and the ecosystem which may lead to death. Hence, remediation work is necessary to conduct after oil spill happened to reduce pollution to the environment. Before remediation work at the site, understanding on characteristic of the soil and characteristic of rainfall is needed. When rainfall happened, the saturation of contaminant in the ground will migrate vertically and horizontally as well. Different intensity of rainfall cause different effects on the migration pattern and the saturation of the diesel. The time taken for diesel and rainfall to infiltrate downward due to gravitational force and capillarity depends on the permeability of the soil. The higher the permeability, the faster the penetration of diesel and water in the soil. The oil migrates down and occupied the available pore spaces while water penetrate the soil to recharge the water table. Hence, when water moving deeper into the soil, it will encounter the oil and push it to go into the saturated zone, caused an increase of saturation of oil contamination in the saturated zone.

2.2 Types of Oil

Oil is immiscible organic liquids. NAPL is nonpolar compound and divided into two category base on their densities. According to Hwang et al. (2008), LNAPL is the liquid with specific gravity lower than water. Due to the buoyancy, these immiscible contaminants are normally restricted in the region above the water table. Examples for LNAPL are gasoline, jet fuel and diesel. Conversely, DNAPL will migrate downwards from the unsaturated zone to saturated zone due to their higher specific gravities than water. In my study, LNAPL is chosen because LNAPL is widely used which causes common soil contamination problems.

2.3 Oil Spill Cases

Oil spill is very common happening around the world due to the high demand of oil and gas exploration. Pipeline leakage, ship accidents, natural disasters, transportation and storage tanks accidents are the sources on oil spill which will contaminate the soil, groundwater and the sea water.

In Gong et al. (2014) study, oil may be released into the environment by routine or accidental releases because of human activities which included drilling, storing, manufacturing, waste management and transporting. For example, blowout of an offshore oil well or leakage from the pipeline will flow out higher amounts of oil and directly cause pollution to the marine environment. Other than that, oil tankers which carrying millions of oils also risky to the environment either in ship collisions or grounding. The number of cases of oil tank accidents happened in the world are shown in Figure 2.1 below. Hence, any activities related to oil firmly pose a significant threat to the environment and human life too.

Year	North America[a]	Asia and Australia[b]	Europe[c]	South America	Africa[d]	Total
1960–1969	3	7	6	1	0	17
1970–1979	18	9	6	1	2	36
1980–1989	26	9	9	5	4	53
1990–1999	36	33	12	2	2	85
2000–2003	31	14	5	0	1	51
Total	114	72	38	9	9	242

[a] South Africa:5.
[b] USA:105, Mexico:6, Canada:3.
[c] Taiwan:19, Japan:10, China:6.
[d] UK:6, Italy:4.

Figure 2.1: Number of tanks accidents occurred (Chang and Lin, 2006)

Since most of the oil exploitation activities are nearer or on the sea area, oil spill is turning the marine ecosystem in a dangerous condition. There are few bigger cases happened in the world such as the Deepwater Horizon oil gush in the Gulf of Mexico in April to July, 2010 and the oil leakage of Penglai oil rig platform in Bohai Sea China since June, 2011. The largest accidental marine oil spill in the history of the petroleum industry happened on April 20, 2010 at the Gulf of Mexico, shown in Figure 2.2. The spill has very seriously affected the nearby area, especially the marine ecosystem (Xing et al., 2015).

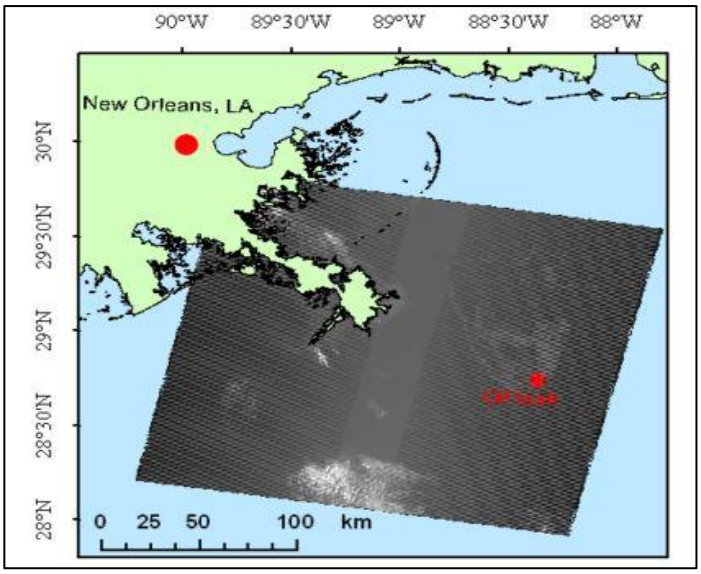

Figure 2.2: The location of oil rig platform with red*mark and oil spill nearby shown by grey patches (Xing et al., 2015)

Another factor cause oil spill is by natural disaster such as an earthquake. When the earthquake happened, oil storage tank or anything related to oil may face a crisis. According to Chang and Lin (2006), the damage of oil storage tank is a complex phenomenon because it involves the characteristic of seismic motions, structure of the tank, the physical properties of substances contained and the characteristics of the ground where all these are related to each other. In history, there are 4 earthquakes resulted in fires or catastrophic oil spills. Among these 4 accidents, the most serious big fire case happened in Niigata, Japan refinery in 1964 due to the ignition of hydrocarbon vapors with flash which generated during an earthquake. Another earthquake happened in 1978 at Shiogama, Japan refinery caused cracks in one light oil storage tank and two heavy oil storage tanks. From his study, unexpected earthquake will bring the largest crisis on oil refinery because earthquake is unavoidable.

In my study, the contamination of soil is assumed to be the leakage through transportation or storage tanks. The spilled oil will first land on the ground surface and slowly infiltrate into the ground which causes the soil contamination.

2.4 Impacts of Oil Spill

Since oil is immiscible liquid and contain hydrocarbon, oil spill will bring impact to the environment and living organism. Living organisms may face life threatening when in contact with oil.

2.4.1 Impact on Environment

The effects of oil spill on the environment are normally becoming long lasting disaster. Spilled oil contain chemical constituents which are poisonous. When the oil spill happened on marine, the oil will affect the offshore plants and animals such as sea turtles, coral reefs and mangroves. The oil coats breathing surfaces of mangrove roots, stems, seedlings and surrounding sediments as well as fauna present in burrows and root hallows (Duke, 2016). Mangroves are weak to oil spilling because oil will stay on sensitive plant surfaces. Hence, the oil disturbed the ecosystem services of mangroves for fisheries production and worldwide shoreline protection. Since the oils will float on the sea surfaces, seabirds are mostly killed in greater numbers.

2.4.2 Impact on Human Health

Oil spill can also affect human health. When human directly or indirectly contact with the oil spill, the oil brings impact on human health. People who involved in clean up the spill are risky because of the long-term effects. According to Y.-Z. Liu et al. (2016), there were more than 50000 workers involved in the cleanup process in the Gulf of Mexico oil spill. The spilled oil that can be inhaled created a significant health threat to those workers. Oil contains potential carcinogenic chemicals which include benzene, benzene derivatives and PAH. Hence, exposure to oil spills can easily cause skin and eye irritation, stress, breathing and neurological problems and even lung cancer as shown in Figure 2.3. When a human is directly exposed to oil spills, for example the oil spill occurs

near to where people work or live, the polluted air will contain chemical particles which damage people's respiratory system. Besides, skin infection also an impact if people touched the spilled material. For indirectly exposed such as consumption of contaminated water or food, especially groundwater and fish, human will intake the oil components and cause sickness because the oil components can accumulate in fish or drinking water.

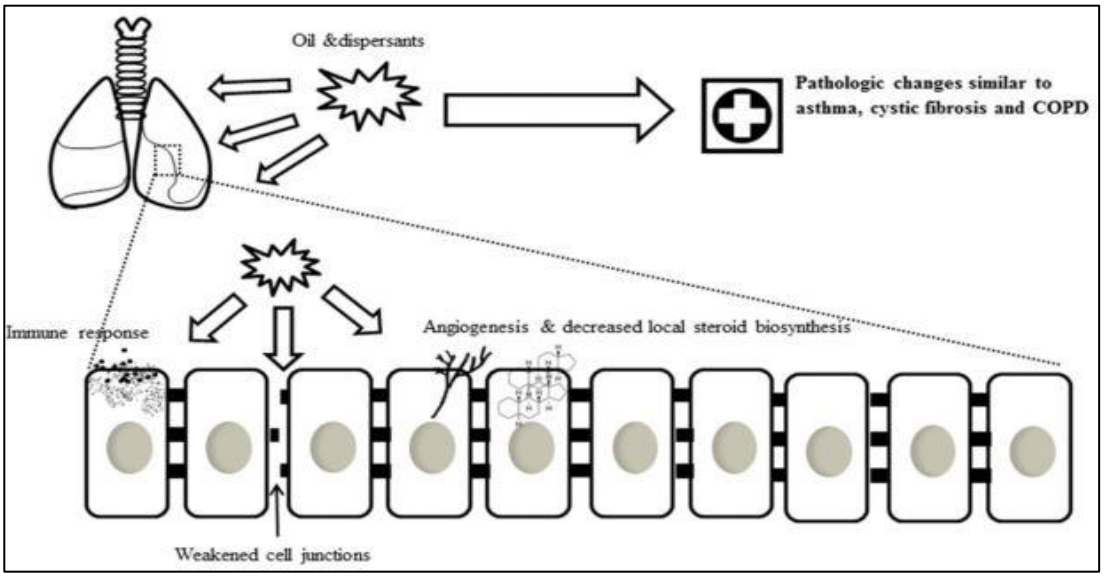

Figure 2.3: Potential impact on oil spill to lung (Y.-Z. Liu et al., 2016)

2.4.3 Impact on Geotechnical Properties

Oil spill might contaminate the soil whereby polluted soil will have different geotechnical properties such as Atterberg limits, permeability and strength parameters (uniaxial compressive strength and direct shear tests), and compaction characteristics compares with clean soil. According to Khamehchiyan et al. (2007), it is necessary to determine the effect of oil contamination on existing structures. Laboratory tests need to be carried out to determine the influence of oil contamination on the behaviour of soil and the geotechnical properties. Normally artificially contaminated sand which means added oil into the clean sand is used to determine the effect of oil on soil. The

contaminated sand will turn all geotechnical properties become weaker such as reducing the liquid limits and plastic limits, low permeability, decrease of maximum dry density and optimum moisture content when the oil content increases in contaminated soil.

2.5 Remediation

Soil contamination which leads to groundwater contamination become one of the serious environmental problems. According to Zhang et al. (2009), research efforts were operated to design remediation systems. When designing remediation systems, effectiveness of technologies not only the consideration, but also including economic, social and environmental factors. Hence, before carrying out remediation work, planning on time consume, total cost and mode of operation is required to minimize any loss on remediation work. There are different types of remediation which included biological, chemical, thermal, and physical-chemical remediation technologies.

2.5.1 Biological Remediation

In general, bioremediation is one of the remediation success in both in-situ and ex-situ for oil contaminated soil. Biological remediation is an environmental friendly remediation to clean up the oil contaminants in soil. The technologies are bioremediation such as bio-augmentation, bio-stimulation and bio-ventilation. According to Gogoi et al. (2003), bioremediation is one of an alternative technology which able to achieve permanent remediation at sites with minimum problems. It has the benefit of turning complex form reactants to carbon dioxide (CO_2) and hydrogen (H_2O) (Trindade et al., 2005). Few conditions are required to let biodegradation occur which are enough oxygen supply, pH, temperature, nutrients and water to supply to subsurface and mix together with bacteria to increase the efficiency of remediation work.

2.5.2 Chemical Remediation

Chemical remediation technologies are branched to two types which are chemical oxidation and electro-kinetic remediation. Chemical oxidation includes Fenton's reagent, ozone and other oxidants. It is useful as it does not affect by the toxicity of contaminant and help to minimise the dispersion of contaminant. The oxidants deliver through injection of gaseous chemical or liquid into the ground (Baciocchi et al., 2014). Electro-kinetic remediation is functioning well in low hydraulic permeability soils. In-situ remediation which gives respond in the fastest time and the operation cost is lower.

2.5.3 Thermal Remediation

Incineration, thermal desorption and microwave frequency heating are known as thermal remediation technologies. When heat is applied, these technologies are effective in clearing the oil contaminants. According to LI et al. (2009), thermal treatment is the most effective in the remediation of heavily contaminated soil. Microwave technology is rapidly in heating and can avoid over-heating the soil surface. Incineration is the easiest way among others because it can cope with large volumes of contaminated sites and effective in cleaning up hazardous materials.

2.5.4 Physical-Chemical Remediation

Physical-chemical remediation technologies included solvent extraction, soil vapour extraction, flotation and ultrasonication. Water/organic solvents, surfactant-aided extraction, subcritical fluid extraction and supercritical fluid extraction are under solvent extraction whereas air vapour, bioventing, thermally enhanced SVE are under part of soil vapour extraction.

Solvent extraction shows high efficiency on oil contaminated soil with lower energy consumption and obtain the results quickly. Soil vapour extraction can remove

large quantities of volatile contaminants in a short time. This method enhances the rate of biodegradation by stimulating the growth rate of microorganism with sufficient oxygen (Lim et al., 2016).

2.6 Infiltration of LNAPL in Sand

LNAPL has low water solubility, density less than water and are immiscible because of the differences in chemical and physical properties among LNAPL and water. Examples of LNAPL are jet fuel, gasoline and heating oils. The release of petroleum products is most commonly related with LNAPL which will cause groundwater contamination problems.

According to Kim and Corapcioglu (2003), when the NAPL leaked above an unconfined aquifer, the NAPL will start to migrate from the unsaturated zone under the influence of gravity forces, viscosity and capillary forces and leave some residual droplets in the unsaturated zone. The LNAPL form a mound which floats above the water table. Then the LNAPL spread and move with decreasing hydraulic gradient. The LNAPL, groundwater and soil gas are in contact with each other. Hence, LNAPL migrates on groundwater table is based on dissolution and volatilization. The contaminants divided from NAPL phase to soil gas phase through volatilization and move through the unsaturated zone. Then, contaminants divided from NAPL phase to water phase by dissolution in a saturated zone and move to groundwater, which shown in Figure 2.4. The vapours and solutes from LNAPL will contaminate the groundwater in the long-term.

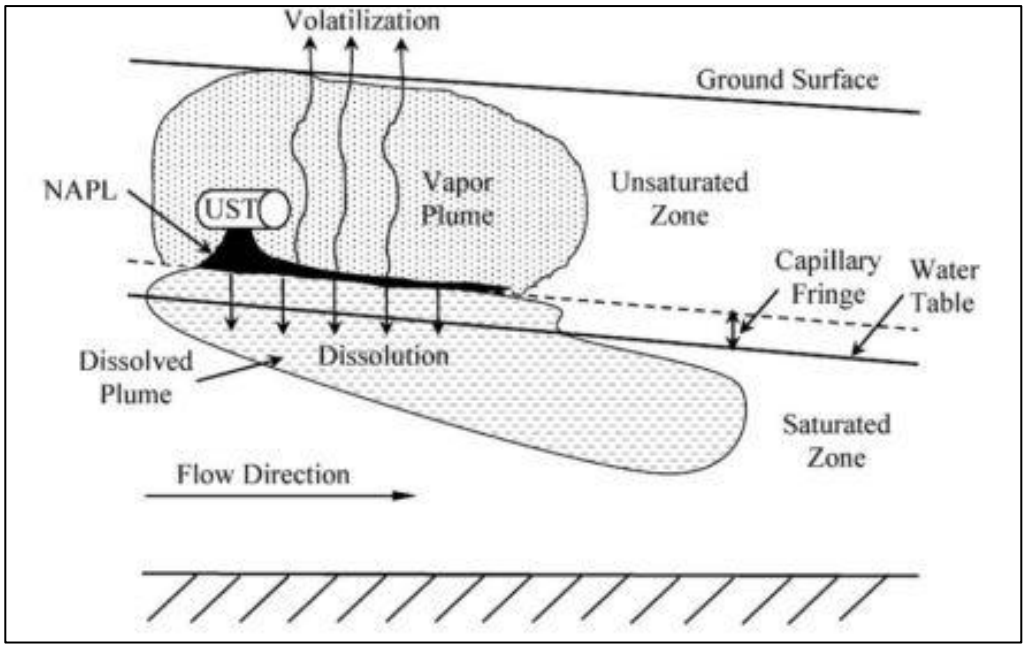

Figure 2.4: LNAPL migration and contamination of the subsurface (Kim and Corapcioglu, 2003)

2.7 Characteristics of Soil

Soil classification playing a role in sustainable land utilization and soil management. Different soils have their own physical and chemical properties such as colour, texture, structure, organic matter and pH value.

2.7.1 Composition

The soil basically contains organic matter, mineral particles, air and water. The composition of organic matter in soil is about 5%, for mineral particles are about 45%, for air is 25% and water is 25%. The organic matter is obtained through decayed plant residues, animal and microbial tissues, mineral particles are obtained from the decomposition and disintegration of rocks, air is obtained from the atmosphere and water is also from the atmosphere and the reaction in soil such as physical, chemical and microbial reaction. The composition of soil will be altered depending on few factors such as soil type, cultivation and water supply.

2.7.2 Colour

Different soil types are present in different colour and information of soil can be obtained through interpretation of soil colour such as some general properties of soil and the chemical process occurred in the soil profile. According to Aitkenhead et al. (2013), colour is used in the soil classification system, evidence of matching between specific soil types and unknown samples, and used to determine the environmental factors on soil composition. The minerals in the soil could cause colour range in soil due to the pH and redox potential. Besides, the impact on soil colour also came from the presence of clay minerals and organic matter. There are three main pigments where soil colour in black is due to high organic content, red in colour is the due to the presence of iron and aluminium oxides and white is due to salts and silicates.

2.7.3 Soil Texture

The soil texture such as clay, loam or sandy loam can be determined by the proportions of sand, silt and clay from the soil texture triangle show in Figure 2.5 below. If the soil is light in weight, which mean the soil has a higher sand compare to clay, whereas heavy soil contained large amounts of clay. The texture will influence the workability of soil, the water movement rate through the soil, and how much of water the soil can hold. For example, clay soils hold more water compared to sand and better in nutrients supplying. The texture of soil changes depends on depth and there are three types of soil profile which are uniform, texture-contrast and gradational. Uniform means the soil texture is the same throughout the soil profile, texture-contrast is the texture change between topsoil and subsoil and gradational is the texture increases with depth in the soil profile (Queensland Government, 2013).

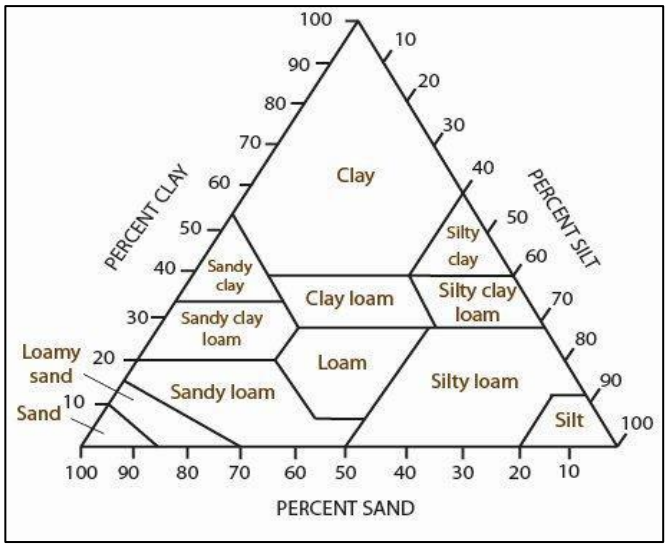

Figure 2.5: Soil texture triangle

2.7.4 Soil Structure

In general, soil structure refers to the arrangement of a group of soil particles to form peds or aggregates. The formation of aggregates from soil particles is due to the binding effect of the soil colloids. Soil structure is playing an important role in determining the rate of movement of water through the soil. There are few types of soil structure such as granular, platy, blocky, prismatic, massive and single grain. Massive and single grains do not have visible structure. Granular aggregates are in rounded shape, consist of small and porous aggregates and allow the infiltration of water into soil. They are found in the surface layers which under grassland. Platy aggregates are in relatively thin horizontal where the horizontal face is longer than vertical face and normally found in the surface layers or subsoil. Blocky aggregates are in square or angular block with sharp edge which are weak in soil drainage and root penetration. These structures are mostly found in the subsoil. For prismatic structures, the aggregates have longer vertical than the horizontal face, which giving a pillar shape. Massive structures do not have any arrangement in soil particles which stick together, whereas single grain consist of separated sand-sized particles which is known as coarse textured soils.

2.7.5 Organic Matter

Organic matter is the decomposition of dead flora and fauna by microorganisms to form humus in the soil. According to Department of Primary Industries (1993), the main sources of organic matter in agriculture field are animal manures and plant litter. The decomposition will release organic nutrients which can be absorbed by the roots of plants. The humus is a black crumbly material which binds the soil particles together. It functions well in storing plant nutrients, improves soil structure, holds the moisture in the soil, improves drainage and improves capacity on cation exchange. There are few factors control the amount of organic matter in soil such as topography, soil type, climate and vegetative growth. Hence, the soil organic matter in agriculture field must be well managed to achieve high quality of soil for crops.

2.7.6 pH Value

Soil pH is a scale to measure the acidity or alkalinity of soil. The pH scale starts from 0 to 14 while the neutral point is 7. According to Zhang et al. (2017), soil pH is a soil quality index, which controls the availability of nutrient to plant, the environment of plant roots, activities on soil microbial and chemical reaction take place in soil. Hence, the pH value of soil is very important, especially in agriculture field. When the soil is having a higher concentration of hydrogen ions, the pH value will decrease which is more toward acidity. The pH value from 7 to 0 means the soil is increasing in acidity, whereas from 7 to 14 is the increasing in alkalinity. The most suitable pH value of agriculture usage is in the range of 6.5 to 7.0 to support plant life.

2.8 LNAPL Transport Parameter

2.8.1 Density

The density of the fluid is its mass per unit volume. Density also can be expressed in specific gravity, which the ratio of mass of a unit volume of a substance to the density of reference substance. The density of water is 1000 kg/m^3 and density of LNAPL normally is range from 700 kg/m^3 to 900 kg/m^3 which is less dense than water. Hence, LNAPL will float on water. When temperature increases, the density of fluids will decrease.

2.8.2 Wettability

When the immiscible fluid has the tendency to adhere onto a solid surface whereby there is a presence of other immiscible fluid is described as wettability. The Figure 2.6 illustrates the interfaces between solid and fluids which are wetting fluid and non-wetting fluid. The first image showed the solid is in contact with the wetting fluid 1 whereas the second image is the solid in contact with the non-wetting fluid 1. The contact angle is defined as the liquid interface meets a solid surface at an angle. For wetting phase, the angle measured should be less than 90 degrees. The angle measured which is more than 90 degrees is referred as non-wetting phase. If the contact angle found that to be zero, which means the phase is perfectly wetting because the entire solid surface is coated by fluid. This concept is to described the distribution of fluid in the pore. Hence, in a multiphase system, the wetting fluid will occupy the smaller pore spaces after in contact with solid surfaces. The non-wetting fluid probably will go to largest interconnected pore spaces (De Blanc et al., 1996). In the unsaturated zone, there are four physical states presented which are air, solid, water and LNAPL shown in Figure 2.7.

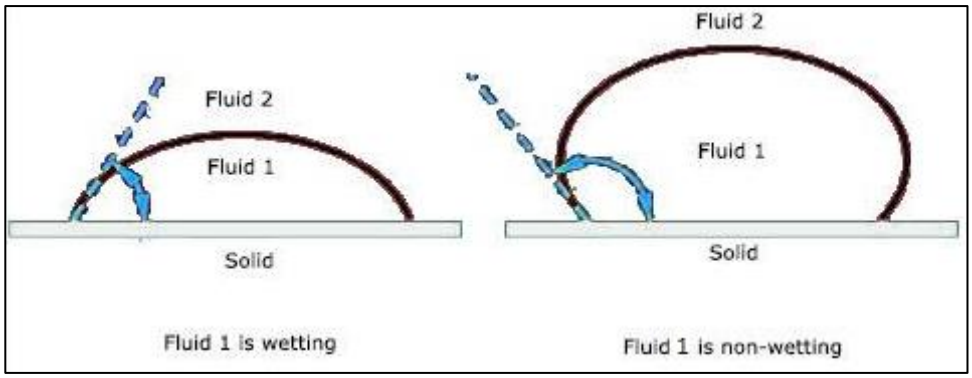

Figure 2.6: The illustration for wetting and non-wetting fluid

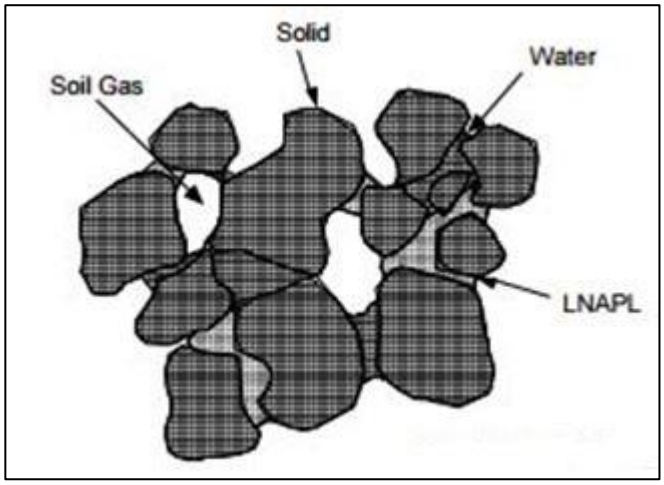

Figure 2.7: Physical states in contaminated unsaturated zone

2.8.3 Capillary Pressure

Capillary pressure plays important role in the case of multi-phase fluid flow in the layered heterogeneous system. It is the pressure difference across the interface between two immiscible fluids. This pressure exists due to the interfacial tension at the fluid interface which separate the two fluids. The capillary pressure is known as the difference of pressure between non-wetting phase (P_n) and wetting phase (P_w). The equation of capillary pressure is represented as below:

$$P_c = P_n - P_w \tag{2.1}$$

$$= \frac{2\sigma cos\theta}{r} \tag{2.2}$$

where σ is interfacial tension, Θ is the contact angle, r is the mean radius of curvature. According to Wipfler et al. (2004), fine sand has a higher entry pressure than coarse sand. Entry pressure is defined as the minimum pressure needed for the NAPL to enter the porous medium. If the capillary pressure is equal to the fine sand entry pressure, then a non-wetting fluid will infiltrate into fine sand layer saturated with wetting fluid. The largest pore spaces must have exceeded capillary pressure before NAPL can enter the porous medium.

In general, there are few factors affecting the capillary pressure. The decrease of pore size, decrease of the initial moisture content and increase of interfacial tension will increase the capillary pressure. The magnitude and configuration of trapped residual NAPL will be affected by capillary conditions. The strong capillary forces that hold residual NAPL can be overcome by viscous forces correlated with groundwater flow.

2.8.4 Relative Permeability

Relative permeability is defined as the ratio of effective permeability of fluid at specified saturation to absolute permeability of fluid at 100% saturation. The range of relative permeability is between 0 to 1. In general, finer grained materials pose lower permeability whereas the coarser grained materials have higher permeability. Darcy's Law is implemented to describe the migration of fluid in porous media. According to Niessner et al. (2011), the equation for one-dimensional migration of fluid in fluid saturated system is as below:

$$Q = (AK/\mu)(\Delta p/L) \tag{2.3}$$

where Q= flux, A= cross section, K= intrinsic permeability, μ= dynamic viscosity, Δp= pressure drop over sample length L.

2.9 Effect of Precipitation on LNAPLs Migration

Precipitation will infiltrate into the unsaturated zone once it reaches the ground, then increase the water table and the LNAPLs on the groundwater move upwards when rainfall (Wang et al., 2014). When interfacial tension between LNAPLs and groundwater reaches equilibrium, LNAPL will not continue to migrate because it reached a stable depth. Precipitation infiltrates into the contaminated sand due to gravitational force causes LNAPLs are displaced and entrapped in the saturated capillary zone.

2.9.1 Precipitation Characteristic

According to Borzenkova (2009), precipitation is liquid or solid that falling from clouds formed by the condensation process to the Earth's surface. The atmospheric vapor forms droplets through condensation of nuclei or forms ice crystal through sublimation of nuclei. Precipitation forms include drizzle, rain, glaze, sleet, snow, snow pellets, small hail and hail. Liquid precipitation has two different sizes which are diameter with 5 to 6 mm is known as rain, whereas diameter about 0.2 to 0.5 mm is known as drizzle. Their terminal velocities to the Earth's surface are between 70 to 200 cm per second. Small raindrops are normally in a spherical shape. During heavy rains, the raindrop size may increase until more than 6 mm in diameter especially starting of a rain storm. The Figure 2.8 below shows the precipitation size and speed from USDA.

	Intensity inches/hour (cm/hour)	Median diameter (millimeters)	Velocity of fall feet/second (meters/second)	Drops per second per square foot (square meter)
Fog	0.005 (0.013)	0.01	0.01 (0.003)	6,264,000 (67,425,000)
Mist	.002 (0.005)	.1	.7 (.21)	2,510 (27,000)
Drizzle	.01 (0.025)	.96	13.5 (4.1)	14 (151)
Light rain	.04 (0.10)	1.24	15.7 (4.8)	26 (280)
Moderate rain	.15 (0.38)	1.60	18.7 (5.7)	46 (495)
Heavy rain	.60 (1.52)	2.05	22.0 (6.7)	46 (495)
Excessive rain	1.60 (4.06)	2.40	24.0 (7.3)	76 (818)
Cloudburst	4.00 (10.2)	2.85	25.9 (7.9)	113 (1,220)

Source: Lull, H.W., 1959, Soil Compaction on Forest and Range Lands, U.S. Dept. of Agriculture, Forestry Service, Misc. Publication No.768

Figure 2.8: Precipitation types with different sizes and speed

2.9.2 Hydrological Cycle

The water cycle is also known as the hydrological cycle. It is a cycle due to the continuous movement of water in the system which means the water molecules move from the Earth's surface to the atmosphere and return to the Earth's surface again (USGS, 2016). The water evaporates from the Earth's surface and rise into the atmosphere, then cool down and condenses to become snow or rain in clouds, and falls onto the surface as precipitation. The water fall on the land will infiltrate into the ground and the water can be collected in rivers and lakes, porous layers of rock and flow back into oceans. The same cycle will be repeated. The water is changing between three physical states which are vapor, liquid and ice. The Figure 2.9 showed the hydrological cycle with different processes.