EFFECT OF OIL SPILL ON HYDRAULIC CONDUCTIVITY OF POORLY GRADED SAND

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by

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LIST OF ABBREVIATIONS

BS	British Standard
DNAPL	Dense Non Aqueous Phase Liquids
LNAPL	Light Non Aqueous Phase Liquids
NAPL	Non Aqueous Phase Liquids
SIAM	Simplified Image Analysis Method
USCS	Unified Soil Classification System

LIST OF SYMBOLS

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
Sw	Saturation of water
So	Saturation of diesel oil

KESAN TUMPAHAN MINYAK TERHADAP HIDRAULIK KONDUKTIVITI KE ATAS PASIR GRED TIDAK BAIK

ABSTRAK

Pencemaran tanah oleh minyak diesel kebiasaannya berlaku disebabkan tumpahan minyak daripada kenderaan, kemalangan kebocoran daripada tangki atau kebocoran paip air. Pencemaran ini menyebabkan kerosakan yang ketara terhadap alam sekitar. Hidrokarbon yang terdapat dalam minyak berterusan memberi kesan kepada kualiti dan ciri fizikal tanah. Berikutan dengan keadaan ini, tujuan penyelidikan ini ialah seharusnya untuk belajar tentang kesan dengan memperkenalkan jumlah Ringan Bukan Berair Fasa Cecair (RBRFC) ke dalam struktur pasir gred tidak baik dengan mempertimbangkan perubahan aras air. Kelakuan RBRFC bergerak diperhatikan dan diterangkan. Satu ujian lajur dimensi dan kaedah analisis gambar telah digunakan. Kes yang pertama melibatkan aras air yang mulanya turun dan kemudiannya naik. Dalam kes ini, minyak diesel terperangkap dalam kawasan tepu adalah sebanyak 9 % apabila 50 ml minyak diesel digunakan dan 4 % apabila 25 ml minyak diesel digunakan. Kes yang kedua melibatkan aras air yang mulanya naik dan kemudiannya turun. Dalam kes ini, jumlah minyak diesel terperangkap dalam kawasan tidak tepu ialah 10% apabila 50 ml minyak diesel digunakan dan 3 % apabila 25 ml minyak diesel digunakan. Di antara keadaan dan kemungkinan yang diberikan, yang paling kritikal ialah apabila aras air turun dan kemudiannya naik, dengan jumlah minyak diesel sebanyak 50 ml.

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ABSTRACT

Soil contamination by diesel oil normally occurs due to spillage from vehicles, accidental discharge from tanker, or leaks in pipes. This type of contamination causes significant destruction to the environment. The hydrocarbon of the diesel oil continuously impacts the quality and physical characteristics of soil. In regard to these concerns, the main aim of this research has been to study the effects of introducing a volume of the Light Non Aqueous Phase Liquid (LNAPL) into a body of poorly graded sand with the water table fluctuated. The behaviour of LNAPL migration was observed and described. The one dimensional column test and Simplified Image Analysis Method (SIAM) were employed. The first case involved a water table that was first lowered and then raised. In this case, the amounts of diesel oil that was entrapped in the saturated soil were 9 % when 50 ml of diesel oil was used and 4 % when 25 ml of diesel oil was used. The second case involved a water table that was first raised and then lowered. In this case, the amounts of diesel oil that was entrapped in the unsaturated soil were 10 % when 50 ml of the diesel oil was used and 3 % when 25 ml of diesel oil was used. Among the given circumstances and possibilities, the most critical was when the water table was lowered and then raised, with 50 ml of diesel oil used.

CHAPTER ONE

INTRODUCTION

1.1 Background

The discharges of hydrocarbon by oil spills in the world recently have become the focus of attention among scientists and concerned citizens. However, oil spillages due to human activity have been documented since long time ago (Ayininuola and Kwashima, 2015). Part of the major activities caused by oil spill includes exploration, production, storage, refining, and transportation (Talukdar and Saikia, 2013). Cases related with oil spill accidents were due to pipeline leakage, disposal of exile engine oil, aging oil infrastructure, and mishaps in exploration drilling process. Oil spill case was caused by the rupture of pipeline belonging to the Nigeria National Petroleum Corporation (NNPC) (Ayininuola and Kwashima, 2015). During the gulf war of 1991, accidents related to the petroleum industry have led to spillage amounting to about 240 million gallon (Singh et al., 2005).

Spilled oils have included crude oil, diesel, and kerosene. According to Anoliefo (1991), crude oil is a complex organic mixture involving hydrocarbon, sulphur, nitrogen, oxygen, and a small quantity of water. Petroleum hydrocarbon in the form of Light Non Aqueous Phase Liquid (LNAPL) in soil contaminations could adversely influence the quality of atmosphere, groundwater, and soil (Pandey and Bind, 2014). The consequences cannot be ignored or disregarded as they would alter the engineering characteristics and properties of soil. The chemical structure of the contaminant and the characteristics of soil combined towards causing the biggest problems in contamination (Fine et al., 1997).

Once a crude oil spills on a ground surface, the hydrocarbon liquid travels downward under the gravitational force into the groundwater (Elisha, 2012). The hydrocarbon liquid permeates through the unsaturated soil which a certain amount of it is preserves within the volume, while the excess travels downward to join the water below the water table, as shown in Figure 1.1. At about the groundwater table, the migration of crude oil is downward due to the gravitational force, but the crude oil also spreads horizontally through the capillary zone due to capillary forces and thus saturation of the soil can lead to serious contamination of the soil (Talukdar and Saikia, 2013).

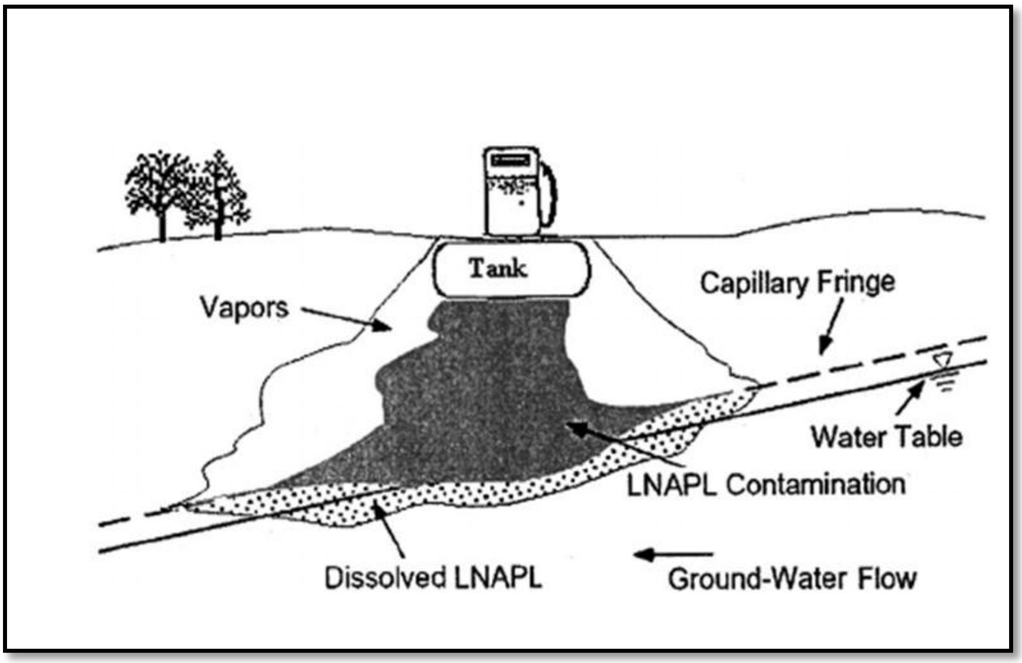

Figure 1.1: LNAPL release and subsequent migration (Hu et al., 2006).

Once the soil is in contact with the crude oil, its physical and chemical properties are changed. The degree of change relies on several aspects including soil type, the various compositions within the soil, and quantity of hydrocarbon spill. A contamination could lead to significant changes of the soil such as increased soil plasticity, loss of bearing capacity, increased ground settlement, and inhibition of drainage either for water or other liquid (Osinubi et al., 2007). These changes of soil properties could lead to a serious problem if the ground is slated for development.

An existing structure such as a building or a road can be affected by soil contamination. A proposed construction can be abandoned, or would need an extra work to deal with the contamination issue and thus increase project expenses (Ukpong and Umoh, 2015). The increasing cost due to hiring geotechnical and chemical experts required in the determination of the extent of a soil contamination can be huge, plus the overall cost would include for specific soil remediation or implementation of a costly foundation type (Akinwumi et al., 2014).

Nonetheless, the understanding about the rehabilitation of soil contamination is still lacking. Researchers also have introduced some techniques that can be practiced in order to clean up the soil due to contamination such as the bioremediation and chemical oxidation (Pandey and Bind, 2014). For the remediation method, the understanding of soil's geotechnical characteristics and properties due to contamination is necessary for the implementation of it to be successful.

1.2 Problem Statement

Oil contaminations are widely known to have given an impact on the existence of soil microbes as well as polluted the groundwater resource, which led to the adverse human health and ecological environment. In Nigeria, as reported in 2005, oil spills between 1976 and 1996 had amounted to 2,369,470 barrels (Nwilo and Badejo, 2005). In 1998, between January and June alone, three different cases have recorded an estimated oil spill of 60,800 barrels (Ja'afar et al., 2016).

An oil spillage on land has the capability of posing a long period threat to the groundwater attribute, particularly that which is associated with the LNAPL (Doick and Semple, 2003; Simantiraki et al., 2009). LNAPL normally acts in large and complex molecule once discharged into the soil and then preserve under the environment; it needs a strong reagent in order to defeat the destructive behaviour in soil. Oil and water are immiscible; oil is hydrophobic. Even for a small amount of the hydrophobic oil that is suspended in water, the water molecules would be able to attract each other strongly, while the oil molecules would behave the same in a short time (Essien and John, 2010). As a result, the oil tends to coalesce and float on top of the water. Besides, due to the density of oil that lesser than water, the oil would always float on top.

The LNAPL contamination not only brings down soil quality but also changes soil properties. With increasing of oil percentage in soil, the maximum dry density and optimum moisture content decreases (Khamechiyan et al., 2007). Oil contamination also tends to decrease permeability and strength of a soil, thus affecting any construction activity carried out on it. Permeability can be quite complex and it depends on soil's physical properties and the properties of the permeating fluid (Ayininuola and Kwashima, 2015).

Once the LNAPL is released onto the surface of a soil, it migrates downward by gravitational force. If only a small amount of LNAPL is released, it will be completely depleted within the unsaturated zone where the hydrocarbon is retained as residual globules in the soil pores, with the capillary force holding them in place. However, if there is a large quantity of the LNAPL being discharged, it will travel within the unsaturated zone, and could reach the water table and fill up the capillary fringe. In such circumstance, lateral migration would take place where the LNAPL would form a continuous and free phase layer along the upper boundary of the water saturate zone, under the effects of gravity and capillary forces (Newell et al., 1995). However, a high LNAPL accumulation would tend to result in a gravitational compression or complete subsidence of the capillary fringe even with a lowering of the water table (Muller and Sedlackova, 2003).

Meanwhile, the fluctuating of water table is able to wash off the LNAPL accumulating in the vicinity of the water table. Change in water table elevation could occur due to recharge or discharge, seasonal changes, or a tidal influence in coastal environment. Mobile LNAPL that accumulates over the water table tend to rise and fall according to the fluctuating water surface; the LNAPL in this case would endure in pores, resulting in the formation of a residual saturation (Muller and Sedlackova, 2003). With the lowering water table, LNAPL residual saturation would tend to be positioned under the water table once it comes back to the initial level. Thus the existing problems are related with estimating the amounts of contamination oil that would be entrapped within a soil and requiring removal or treatment.

1.3 Objectives

The aim of this research is to develop a better description on the consequence of oil spill especially on soil properties. Due to lack of understanding and data about the groundwater contamination due to oil spillage, it might have caused the impediment to the effective methods of treatment, bringing the long term impact to the environment, health, and economy of the affected communities. Therefore, this research attempts to provide an insight to the complexity associated with the problem of soil contamination by oil so that experts can continue seeking the necessary cures.

The objectives of this study are:

1. To evaluate the effects of oil contamination on soil’s hydraulic conductivity.
2. To evaluate the behaviour of oil contamination on soil using one dimensional column modelling and the technology of image analysis.
3. To evaluate the extent of oil migration due to fluctuating water table within the soil and the different volumes of diesel oil involved in the contamination.

1.4 Scope of research

This research involved only one type of soil which is the coarse grained type namely the Poorly Graded Sand or SP. The type of LNAPL that was chosen in this study to contaminate the test soils was diesel, which is one of the most widely used commercial fuels in the world. The geotechnical properties were determined in accordance to the British Standard (BS): 1377: 1990.

1.5 Research approach

The effect of diesel oil contamination on the soil properties was evaluated using the one dimensional column test. The water table within the soil was fluctuated first by lowering it and followed by returning it to the original level, and second by raising it and returning it to the original level. Two volumes of diesel oil were used.

The three (3) categories of experiments are given below:

1) Laboratory testing to determine the properties of uncontaminated and contaminated sand
2) One dimensional column test to study the migration of diesel oil and the evaluation is helped by capturing a lot of column images.

3) By using the Simplified Image Analysis Method (SIAM) to analyse the images, water and oil saturations were determined.

1.6 Significance of research

This research attempts to provide a better understanding on how soil characteristics change due to contamination by an oil spill. The study focuses on the changes in soil's hydraulic conductivity once the soil is polluted by the diesel oil. The results may be helpful to a remediation work. When diesel oil is completely eliminated from the soil, the quality of a groundwater can be preserved.

1.7 Thesis outline

The outline of this thesis is given in Fig. 1.2. In chapter two, the literature review about soil contamination is given. The concepts of hydraulic conductivity and hydraulic properties are explained therein. The work of other researchers are highlighted and compared. Chapter three discusses on how the laboratory tests were conducted. The tests have included the basic geotechnical evaluations and one dimensional column modelling. The soil sample that was used in the study was the poorly graded sand or SP. In Chapter four, the data obtained from tests are arranged in tables and presented in graphs, along with the discussions. In Chapter five, the conclusions are given together with some recommendations for future work.

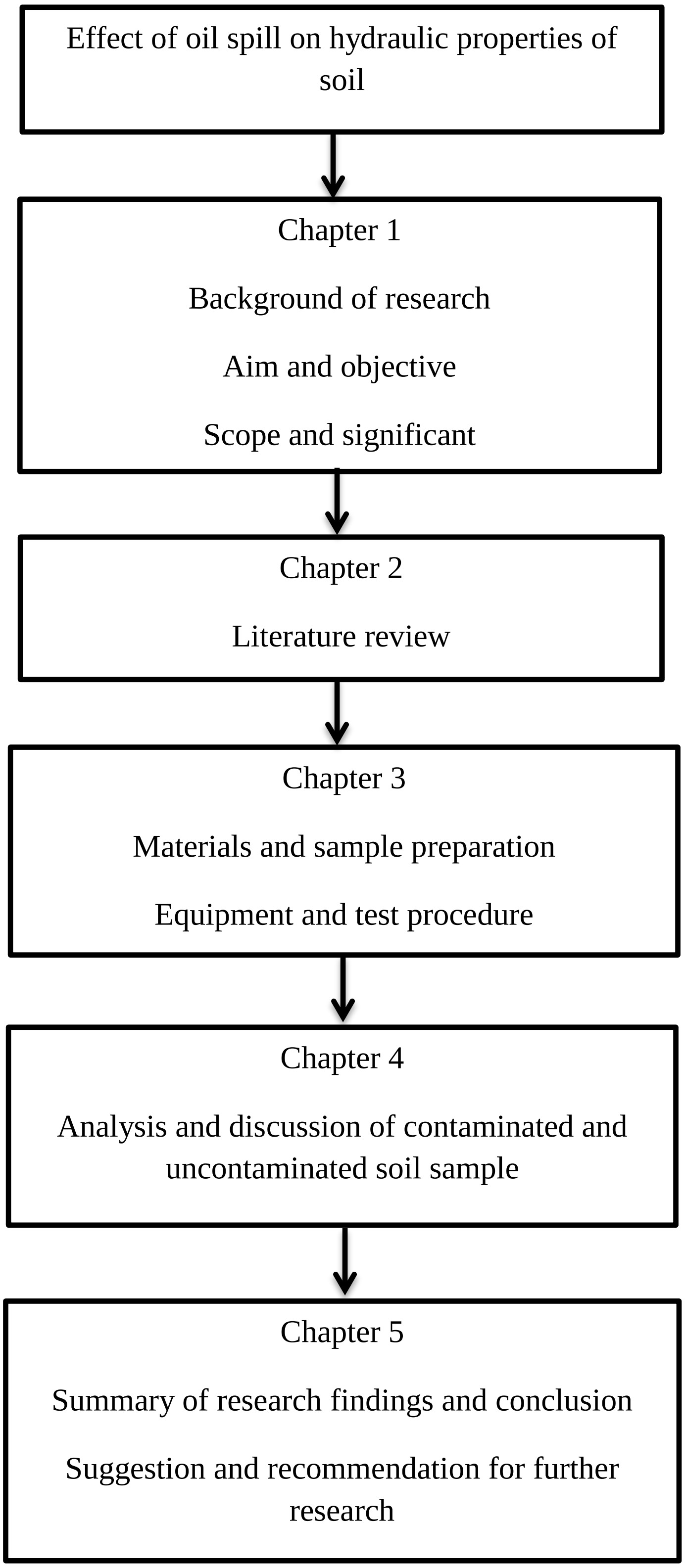

Figure1.2: Structure of thesis.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews published materials related with the Non Aqueous Phase Liquid (NAPL), the Light Non Aqueous Phase Liquid (LNAPL), and the Dense Non Aqueous Phase Liquid (DNAPL). The reviews are mainly on the characteristic of the three materials and the migration process of the LNAPL within a soil saturated with water. As the study is focussing on the soil hydraulic properties, the fundamental concept and theory of the coefficient of permeability is discussed. The coefficient of permeability is also alternatively called the hydraulic conductivity, and its understanding is important in describing the process of soil contamination by oil. Another aspect of the review is on the importance of parameters such as density, viscosity, saturation, interfacial tension, wettability, and relative permeability to an oil contamination process and how these parameters affect the geotechnical properties of the contaminated soil.

2.2 Non Aqueous Phase Liquid (NAPL)

Oil pollution probably exists in soil in discrete condition. The oil granules are disintegrated within water and get absorbed by the soil matrices. A contaminated soil consists of soil gas and the NAPL (Müller and Sedláčková, 2003). The NAPL is recognized as a single phase liquid due to its restricted solubility. NAPL is commonly formed in two different categories, which are the DNAPL and the LNAPL by referring to the specific gravity of each. The NAPL tends to perform differently in the subsurface depending on its chemical and physical characteristics. The DNAPL, which also includes the volatile chlorinated hydrocarbons (VCH) and