STABILIZATION OF CONTAMINATED SOIL IN COAL MINING AREA BY
MUNICIPAL SOLID WASTE FLY ASH (MSWFA) AND
CEMENT KILN DUST (CKD)

Ms. Thantip Punmatharith

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science in Environmental Management

(Inter-Department)

Graduate School

Chulalongkorn University

Academic Year 2004

ISBN 974-17-7167-3

การปรับเสถียรดินปนเปื้อนในเหมืองถ่านหินโดยการใช้เถ้าลอย

จากเตาเผาขยะชุมชนและฝุ่นปูนซีเมนต์

นางสาวธารทิพย์ พันธ์เมธาฤทธิ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)

บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2547

ISBN 974-17-7167-3

Thesis Title   Stabilization of Contaminated Soil in Coal Mining Area by Municipal Solid Waste Fly Ash (MSWFA) and Cement Kiln Dust (CKD)

By   Miss Thantip Punmetharith

Field of study   Environmental Management

Thesis Advisor   Manaskorn Rachakornkij, Ph.D.

Thesis Co-advisor   Associate Professor Gerald A. Miller, Ph.D., P.E.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

………………………………………….. Dean of the Graduate School

(Assistant Professor M.R. Kalaya Tingsabadh, Ph.D.)

THESIS COMMITTEE

……………………………………………… Chairman

(Chantra Tongcompou, Ph.D.)

……………………………………………… Thesis Advisor

(Manaskorn Rachakornkij, Ph.D.)

……………………………………………… Thesis Co-advisor

(Associate Professor Gerald A. Miller, Ph.D., P.E.)

……………………………………………… Member

(Khemarath Osathaphan, Ph.D.)

……………………………………………… Member

(Anong Paijitprapapon, M.Sc.)

ปัญหาสิ่งแวดล้อมที่สำคัญอย่างหนึ่งที่พบในเหมืองถ่านหินคือ การเกิด สภาวะที่น้ำในเหมืองเป็น กรดทำให้เกิดการปนเปื้อนของโลหะหนักในน้ำผิวดิน น้ำใต้ดิน และ ดิน งานวิจัยนี้เป็นการศึกษา ประสิทธิภาพของเถ้าลอยจากเตาเผาขยะชุมชนและฝุ่นปูนซีเมนต์ในการยับยั้งการปนเปื้อนของโลหะหนัก ในดินบริเวณเหมืองถ่านหิน ในเชิงการปรับปรุงคุณสมบัติทางวิศวกรรม และการทดสอบลักษณะของน้ำชะ จากดินที่ปรับเสถียร ในการปรับปรุงคุณสมบัติทางวิศวกรรมได้ทำการทดสอบการบดอัดดินเพื่อหาปริมาณ น้ำที่เหมาะสมในการบ่มตัวอย่าง จุดเปลี่ยนสภาพของมวลดิน และทำการทดสอบกำลังรับแรงอัดแบบไม่มี แรงต้านทาน ในการทดลองลักษณะของน้ำชะจากดินที่ปรับเสถียรทำการทดสอบตามข้อกำหนดใน ประกาศกระทรวงอุตสาหกรรม ฉบับที่ 6 พ.ศ. 2540 และการทดสอบการชะแบบคอลัมน์เพื่อเป็นการ จำลองสถานการณ์ในพื้นที่ เมื่อเกิดสภาวะฝนกรดขึ้น ผลการทดสอบการบดอัดดินแสดงให้เห็นว่าเมื่อเพิ่ม ปริมาณของฝุ่นปูนซีเมนต์ ในการปรับเสถียรดินแล้ว ทำให้ค่าความชื้นที่ความหนาแน่นสูงสุด และความ หนาแน่นสูงสุด เพิ่มขึ้นแต่การเพิ่มปริมาณของขี้เถ้าลอยจากเตาเผาขยะชุมชนทำให้ค่าความชื้นที่ความ หนาแน่นสูงสุดเพิ่ม แต่ค่าความหนาแน่นสูงสุดลดลง ผลการทดสอบจุดเปลี่ยนสภาพของดินพบว่าเมื่อเพิ่ม ปริมาณของเถ้าลอยจากเตาเผาขยะและฝุ่นปูนซีเมนต์ทำให้ดัชนีพลาสติกลดลงเนื่องจากการเพิ่มขึ้นของ พิกัดพลาสติก ในการทดสอบกำลังรับแรงอัดแบบไม่มีแรงต้านทานแสดงให้เห็นว่าปริมาณฝุ่นปูนซีเมนต์ที่ เพิ่มขึ้นทำให้ค่ากำลังรับแรงอัดแบบไม่มีแรงต้านทานเพิ่มขึ้น ในขณะที่การเพิ่มปริมาณของเถ้าลอยจาก เตาเผาขยะทำให้ค่าของกำลังรับแรงอัดแบบไม่มีแรงต้านทานลดลง ผลการทดสอบการชะจากดินพบว่า ความเข้มข้นของเหล็กและแมงกานีสในดินที่ปนเปื้อนมีค่าลดลงเมื่อปริมาณ ของ ฝุ่นปูนซีเมนต์และเถ้า ลอยจากเตาเผาขยะชุมชนมีปริมาณเพิ่มขึ้น รวมถึงค่าของ พีเอชเพิ่มขึ้นและเวลาในการบ่มนานทำให้ ความเข้มข้นของเหล็กและแมงกานีสลดลงในการทดสอบการชะแบบคอลัมน์สามารถช่วยยืนยันผลการ ทดสอบการชะจากดินตามข้อกำหนดในประกาศกระทรวงอุตสาหกรรม ฉบับที่ 6 พ.ศ. 2540

4689518220   : MAJOR   ENVIRONMENTAL MANAGEMENT
KEY WORD: STABILIZATION/SOLIDIFICATION (S/S) / ACID MINE DRANAGE (AMD) / MUNICIPAL SOLID WASTE FLY ASH (MSWFA) / CEMENT KILN DUST (CKD) / LEACHING TEST

THANTIP PUNMATHARITH: STABILIZATION OF CONTAMINATED SOIL IN COAL MINING AREA BY MUNICIPAL SOLID WASTE FLY ASH (MSWFA) AND CEMENT KLIN DUST (CKD).   THESIS ADVISOR: MANASKORN RACHAKORNKIJ, Ph.D., THESIS CO-ADVISOR :   ASSOC. PROF. GERALD A MILLER, Ph.D., P.E. [130] pp. ISBN 974-17-7167-3.

One of the important environmental impacts in a coal mining area is acid mine drainage (AMD). AMD causes the contamination of heavy metals in surface water, ground water, and soil. This thesis investigats the effectiveness of using municipal solid waste (MSWFA) and cement kiln dust (CKD) by to improve the engineering properties of soil and to test leaching experiment. The engineering properties consist of a compaction test for finding the appropriate amount of water for preparing the sample. The leaching tests compose of two experiments that are leaching test and column test. Leaching test based on the 6th Notification of the Ministry of Industry, B.E. 2540 (1997), and column leaching test stimulate extraction solution like acid rain scenario. The results of compaction tests revealed that increasing the CKD increased the optimum moisture content and maximum dry density but increasing the MSWFA caused the optimum moisture content to increase but reduced the maximum moisture content. From the Atterberg limits, it was found that the amount of CKD and MSWFA cause decreases in the plastic indexes due to increases in the plastic limits. Increasing the amount of CKD can increase unconfined compressive strength but increasing the amount of MSWFA caused a decline in unconfined compressive strength. According to leaching tests and column leaching tests, the concentration of Fe and Mn were reduced when increasing the amounts of CKD and MSWFA. The reducing of concentration of Fe and Mn depended on increasing of pH and curing time. The column leaching test confirms the results of leaching tests.

Field of study Environmental Management   Student's signature…………………….....

Academic year 2004   Advisor's signature...................……………..

Co-advisor's signature…………………......

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF FIGURES

Figure   Page

Figure   Page

LIST OF TABLES

Table   Page

NOMENCLATURES

APC	= air pollution control
AMD	= acid mine drainage
ASTM	= American Society for testing and Materials
BP	= Banpu
CKD	= cement kiln dust
CEC	= Cation exchange capacity
DI	= deionized
Fe	= Iron
Fly ash	= particulate matters captured from flue gas by APC system
Gs	= specific gravity
ICP	= inductively coupled plasma optical emission spectroscopy
LL	= liquid limit
LOI	= loss on ignition
OMC	= Optimum moisture content (%)
Mn	= Manganese
MSWFA	= Municipal solid waste fly ash
PL	= plastic limit
PI	= plastic index
psi	= pound per square inch
TCLP	= Toxicity Characteristic Leaching Procedure
UCS	= Unconfined compressive strength
WHO	= the World Health Organization
XRD	= X-ray diffraction spectrometer
XRF	= X-ray fluorescence spectroscope

CHAPTER I

INTRODUCTION

1.1 General

Nowadays, the environmental impacts of acid mine drainage (AMD) in coal mining areas are of great concern. The formation of AMD is mainly a function of geology, hydrology, and geochemical and microbial reactions. When water comes into contact with the coal remaining in the mine and other minerals present in the soil, several chemical reactions occur. The reactions happen when the water reacts with pyrites in the soil which causes the water to become acidic. Pyrites are any group of minerals, which principally are made up of metallic sulfides. Metallic sulfides contain sulfates, which can easily give off sulfuric acid in the presence of water.

Abandon mines containing metallic sulfides (pyrite-chalcopyrite-sphalerite) can be a major source of metal pollution in watercourses and soil. The coal mining areas in Thailand are subjected to this phenomenon. There is AMD in the coal mining area at Ban Lee, in the Northern Province of Lampoon. The concentration of manganese in the pond was found in excess of the Thai Surface Water Quality Standards. Moreover, the high concentration of iron found in the groundwater exceeded the World Health Organization (WHO) Guidelines for Drinkable Groundwater Standards. This thesis is concerned with the contaminated soil that discharges manganese and iron.

Manganese is classified as a transition metal, with the symbol Mn and atomic number of 25. Its atomic weight is 54.938. Manganese cannot accumulate over 20 mg in humans. It is a common metal that can be found in many types of rock. It can combine with carbon to produce organic manganese compounds. Furthermore, it is an essential trace element and necessary for good health. It can be found in several foods, grains and cereals such as tea.

Exposure to high levels of manganese causes mental and emotional disturbances as well as slow and clumsy body movements, called "manganism."

Manganism occurs because too much manganese injures the part of the brain that helps control body movements. It can cause damage to the brain, liver, kidneys and a developing fetus. However, the USEPA has determined that manganese is not classifiable as a human carcinogen.

Iron shows up in two forms: soluble ferrous iron and insoluble ferric particulate iron. Iron in the environment will be in the form of insoluble ferric, Fe^{3+}, which is a non-toxic chemical. However, the presence of iron at a concentration above 0.1 mg/L will damage aquatic animals and fish. Iron acts like a catalysts in water and will promote the dissociation of oxygen molecules in the water that creates a toxic effect on aquatic life.

The effects of high levels of iron in humans are governed by adsorption. Iron is adsorbed in the ferrous state by cells of the intestinal mucous. When excess dietary iron is absorbed, the body produces more ferritin. Therefore, excess iron builds up in the heart and liver, causing tissue destruction. There are many problems that may result from iron toxicity; these include anorexia, oligura, diarrhea, hypothermia, diphasic shock, metabolic acidosis, and death. Furthermore, iron is a substance that creates acid mine drainage.

Contamination by heavy metals in the soils is a major concern because of their toxicity and threat to human lives and the environment. These heavy metals may adversely affect soil ecology, agricultural production or product quality and water quality.

Stabilization and solidification (S/S) is known as one of the most effective technologies for treating and immobilizing heavy metals in contaminated soil. This treatment inhibits the mobilization of heavy metals into the surrounding area. S/S technology employs binding materials such as cement kiln dust or fly ash to transform contaminated soil containing toxic metals into less toxic forms and/or into more manageable forms by chemical and or physical immobilization. Physical stabilization refers to method of solidification that improves engineering properties, such as strength, compressibility, and permeability, of the stabilized waste. Chemical

stabilization is the modification of the contaminants' chemical forms. Thus, their leachability is eliminated or substantially reduced. Therefore, many contaminated sites achieve immobilization by a combination of stabilization and solidification.

Moreover, S/S, which is one of the remedial options for a metal contaminated site, may involve the excavation and removal of these contaminated soils. Even though this seems like a logical solution, it is not feasible in many cases due to the vast size of the contaminated area. An alternative for soil remediation is the in-situ S/S of the metals. S/S is employed to reduce the risk of the contaminants from the site entering the groundwater, surface water, and the atmosphere.

Municipal solid waste fly ash (MSWFA) refers to the fine particles that are rich in some elements and compounds such as metals and salts. There is also the potential for MSW fly ash to be used in raw materials for construction, geotechnical and agricultural applications. Therefore, the potential applications for MSWFA would provide many advantages, such as the use of a zero-cost raw material that would help to conserve natural resources and minimize waste. Moreover, MSWFA can be applied in soil stabilization as a substitute for lime or cement. MSWFA may have pozzolanic properties since MSWFA contains 24-27% lime and some silicates and aluminosilicates. Thus, MSWFA has the potential properties to improve soil properties and can be applied in soil stabilization.

Cement kiln dust (CKD) is a kind of pozzolan that exists in industrial residue produced during the manufacturing of cement clinker and during the drying process. Moreover, CKD has a strong basic character, fine particulates and uniform particle-size distribution. CKD is a waste residue composed primarily of oxidized, anhydrous, small particles generated as a byproduct in the manufacturing of Portland cement. Therefore, the recycling of CKD is an interesting alternative to landfilling. In other countries, CKD is increasingly being applied in soil stabilization such as in road pavement. This is due to the fact that CKD consists of high amounts of lime, silica, alumina, and iron. CKD has the potential to be used in soil stabilization since it will increase the unconfined compressive strength and pH and decrease the OMC in the soil. If the pH increases in the soil, the heavy metals will become immobile. Hence,

CKD can be employed in soil stabilization to improve soil properties and immobilize the heavy metals in contaminated soils

1.2 Objectives

The main objectives of the study are as follows:

1. To evaluate the efficiency and capacity of municipal solid waste fly ash (MSWFA) and cement kiln dust (CKD) as immobilizing agents for Manganese (Mn) and Iron (Fe) contained in contaminated soil at a coal mining site in Northern Thailand.
2. To evaluate effectiveness of municipal solid waste fly ash and cement kiln dust for improving engineering properties of soil; such as the unconfined compressive strength (UCS), optimum moisture content (OMC) and maximum dry density of soil.

The specific objectives are as follows:

1. To determine the mobility of the selected heavy metals present in mining soil.
2. To examine the leaching characteristics of leachate the metals in the stabilized soil.
3. To develop stabilization and solidification techniques for immobilization of heavy metals that produce acid mine drainage at their sources.
4. To estimate the total cost of stabilization and solidification at the mining site.

1.3 Scopes of the Study

Research is conducted to evaluate the efficiency and capacity of MSWFA and CKD as immobilizing agents for Mn and Fe in contaminated soil from a coal mining area in Ban Lee, Lampoon. This research focuses on the suitability of the applications, its potential environmental impacts, and economic feasibility. The following points will be studied.

1. Evaluation of the effectiveness of MSWFA and CKD for improving the engineering properties of soil, i.e., the UCS, OMC, and maximum dry density of soil.

2. Evaluation of the efficiency and capacity of MSWFA and CKD as immobilizing agents for Fe and Mn contained in the soil samples.

3. The mobility of the heavy metals present in the mining soil; multiphase waste will be analyzed by the extraction procedure described in the Notification of Ministry of Industry No.6, B.E. 2540 (1997).

4. The physical and chemical properties of MSWFA and CKD will be compared.

5. A study of leaching behaviors of the metals in the stabilized and solidified soil by using column experiments.

6. The development of stabilization and solidification techniques for the selected heavy metals at their sources of AMD.

7. Cost estimation for the total stabilization and solidification treatment of the coal mining area.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

2.1 Background

2.1.1 Mining Activities and Mine Waste

There are three main types of mining activities. Mine activities are composed of three kinds, general mining, mineral processing and metallurgical extraction. Mining is the first type of activity which is done in the mine. It can be defined as the separation of raw materials from the ground. The second process in a mine is mineral processing or beneficiation. Its goal is to distinguish and concentrate the ore minerals. Metallurgical extraction is the third process in a mine; it aspires to destruct the crystallographic bonds in the ore mineral in order to obtain an element or compound. These activities generally apply for gold, copper, nickel, uranium, or phosphate mines. Moreover, there are other minor activities in a mine as well as, crushing, grinding, gravity, magnetic or electrostatic separation; and flotation. The three principal activities of the mining industry can cause mine waste, the solid, liquid and/or gaseous by products. Mine wastes are unwanted, have no current economic value and accumulate at the mine sites.

Mine wastes can be distinguished into three groups: mine waste, processing waste, and metallurgical extraction waste. Mining waste contains overburden and waste rocks excavated and mined from surface and underground operations. Waste rock is basically wall rock materials removed from mine ore. It can be defined as the "spoils" in a coal mine. It consists of sedimentary, metamorphic or igneous rock, soils, and loose sediment.

Processing waste occurs in beneficiation or mineral processing prior to any metallurgical extraction. Mineral processing technology may contain the simple washing of ore; gravity, magnetic, electrical or optical sorting; and the addition of process chemicals to crushed and sized ore in order to aid the separation of the sought after minerals from gangue during flotation. Processing waste is described as the

division of the crushed, milled, ground, washed or treated resources estimated as too bad to be treated further. Moreover, it can refer the processing waste from a mill, washery or concentrator that has removed the economic metals, minerals mineral fuel or coal from the mined resource as tailings. These tailings can accumulate in the mine by the dumping of the waste at the surface of the mine or as sediment slurry.

Table 2.1 Steps of the operation in mining that produces mine wastes. (B.G. Lottermoser, 2003)

Activity	Mine waste
Open pit mining and underground mining	Mining waste (e.g. waste, rocks, overburden, spoils, mining water, atmospheric emissions)
Mineral processing, coal washing, and mineral fuel processing	Processing waste (e.g. tailings, sledges, mill water, atmospheric emissions)
Pyrometallurgy, hydrometallurgy, and electrometallurgy	Metallurgical waste (e.g. slag, roasted ores, flue dusts, ashes. Leached ores, process water, atmospheric emissions)
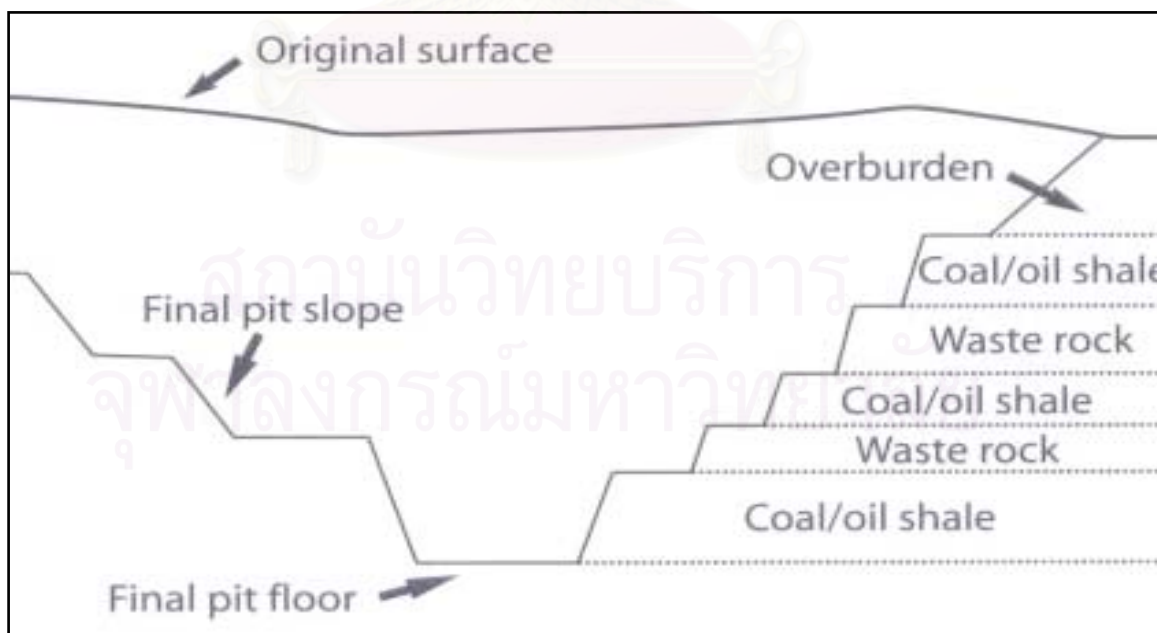
Figure 2.1 Coal and oil shale mine (B.G. Lottermoser,2003)

Metallurgical waste can be produced from hydrometallurgical and Pyrometallurgical operations. Hydrometallurgy is related to the employment of solvents to dissolve the elements of interest such as gold (Au), Uranium (U), Aluminum (Al), Cupper (Cu), Zinc (Zn), Nickel (Ni), and Phosphorus (P). On the other hand, pyrometallurgy is depended on the collapse of the crystalline structures of the ore mineral by heating or electricity. Both hydrometallurgy and pyrometallurgy release various wastes into the environment.
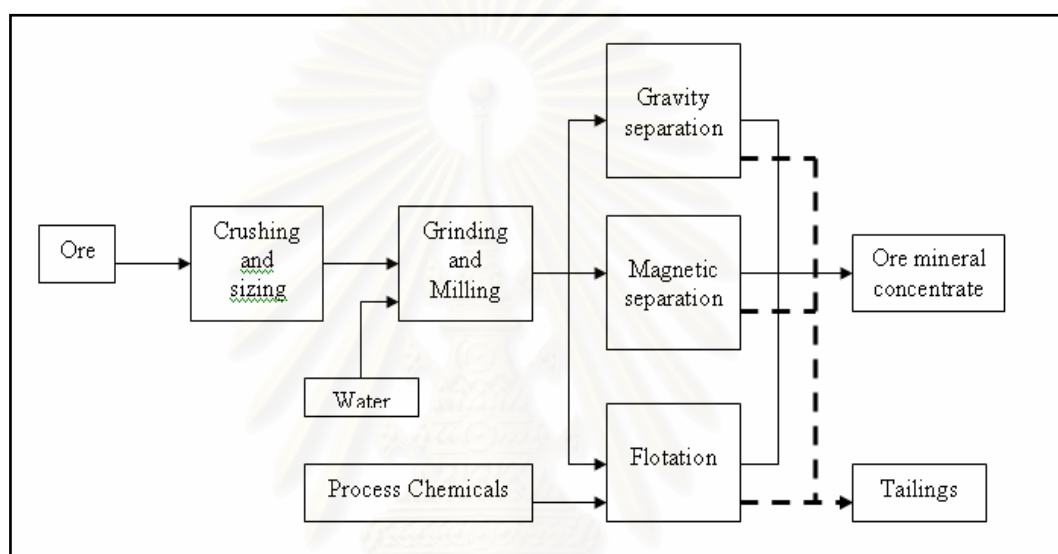
Figure 2.2 Simplified flow chart of mineral processing (B.G. Lottermoser, 2003)
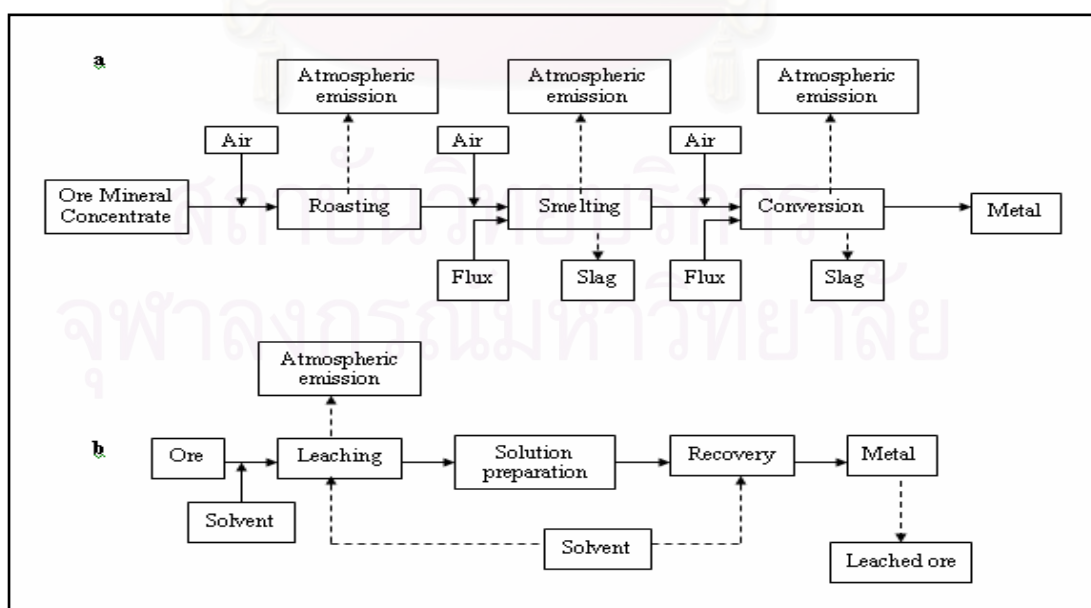
Figure 2.3 Simplified flow chart of (a) Pyrometallurgical operation and
(b) Hydrometallurgical operation (B.G. Lottermoser, 2003)

2.1.2 Acid Mine Drainage (AMD)

Acid mine drainage refers to a particular process where low pH mine water occurs from the oxidation of sulfide minerals. The environmental impacts of acid mine drainage in coal mining areas are of great concern. The formation of AMD is mainly a function of geology, hydrology, and geochemical and microbial reactions. When water comes into contact with the coal remaining in the mine and other minerals present in the soil, several chemical reactions occur. The reactions take place when the water reacts with pyrites in the soil which causes the water to become acidic. Pyrites are group of minerals, which principally are made up of metallic sulfides. Metallic sulfides contain sulfates, which can easily give sulfuric acid in the presence of water. Detailed information on pyrite oxidation can be found elsewhere (Luther1987; Evangelou 1995; Evangelou and Zhang 1995).

Pyrite oxidation transpires when the mineral becomes in contact with oxygen. The reactions can occurred in both of presence of microorganisms as biotic and without microorganisms as abiotic chemical oxidation process. These different pyrite oxidation mechanisms can be summarized as follows:

1. Oxidation by oxygen (abiotic direct oxidation)
2. Oxidation by oxygen in the presence of microorganisms (biotic direct oxidation)
3. Oxidation by oxygen and iron (abiotic indirect oxidation)
4. Oxidation by oxygen and iron in the presence of microorganism (biotic indirect oxidation)

There are four generally accepted chemical reactions that represent the formation of AMD (Figure 2.4). The first reaction in pyrite includes the oxidation of pyrite by oxygen. Sulfur is oxidized to sulfate and ferrous iron is released.

$$2\ FeS_2 + 7O_2 + 2\ H_2O \longrightarrow 2Fe^{2+} + 4SO_4^{2-} + 4\ H^+ \qquad (2.1)$$
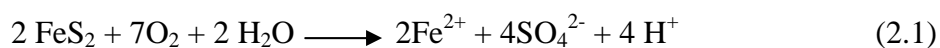
The second reaction demonstrates the conversion of ferrous iron to ferric iron. This reaction is considered the "rate deterring step" in the overall acid-generating sequence.

$$4\ Fe^{2+} + O_2 + 4H^+ \longrightarrow 4\ Fe^{3+} + 2\ H_2O \qquad (2.2)$$
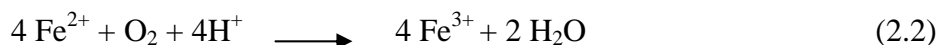
The third reaction may occur due to the hydrolysis of iron. Hydrolysis is a reaction that splits the water molecules. Many metals are capable of undergoing hydrolysis. The formation of ferric hydroxide precipitate (solid) is pH dependent. If the pH is less than pH 3.5, little or no solids will precipitate.

$$4\ Fe^{3+} + 12\ H_2O \longrightarrow 4\ Fe(OH)_3 \downarrow\ + 12\ H^+ \qquad (2.3)$$
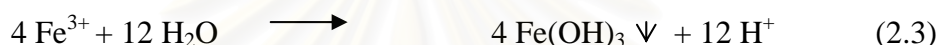
The fourth reaction is the oxidation of additional pyrite by ferric iron. Ferric iron is formed in first reaction and second reaction. This is the cyclic and self-propagating part of the overall reaction. It takes place very quickly and continues until either the ferric iron or pyrite is depleted.

$$FeS_2 + 14Fe^{3+} + 8H_2O \longrightarrow 15Fe^{2+} + 2SO_4^{\ 2-} + 16\ H^+ \qquad (2.4)$$
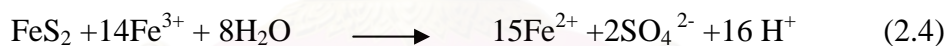
An overall summary of the reaction is as follows:

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \longrightarrow 4\ Fe\ (OH)_3 \downarrow\ + 8\ H_2SO_4 \qquad (2.5)$$

Sulfuric acid from an AMD reaction can cause water to be acidic in the stream. The acid water subsequently increases the solubility of heavy metals, such as manganese, which are toxic to plants and animals.
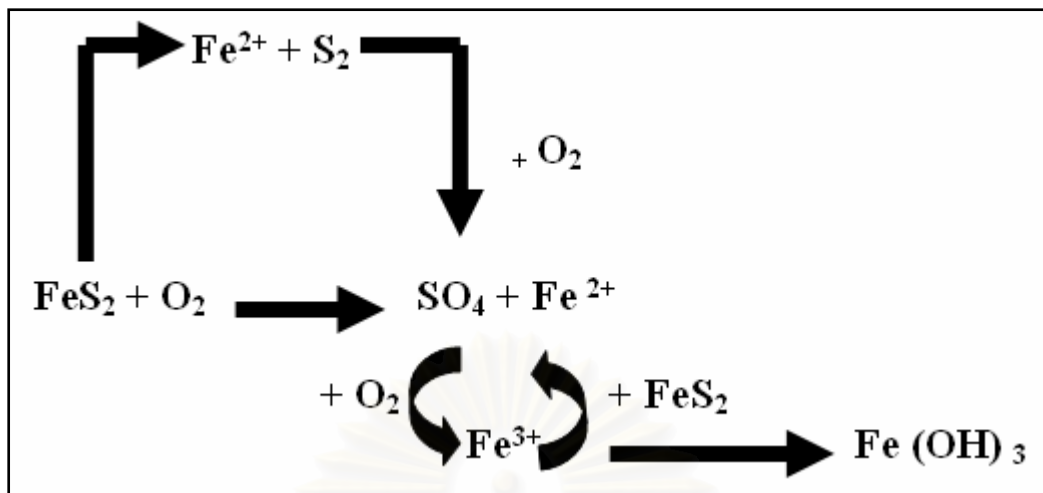
Figure2.4 Simplified diagram illustrating the reaction pathways for pyrite oxidation (B.G. Lottermoser, 2003)

At a metal mine (e.g. Cu, Pb, Zn, Au, Ni, U, and Fe), phosphate ores, coal seams, oil shale, and mineral sands have the potential to expose sulfide minerals to oxidation and generate AMD. Coal and ore stockpiles, tailings storage facilities, such as waste rock and heap leach piles are all possible sources for acid generation as are underground workings, mine adits, shafts, and pit floors (Figure 2.5).

AMD can form as the result of various processes as the following:

- Groundwater go in underground working located above the water table and egresses way surface openings or is pumped to surface (i.e. mining water);
- When groundwater penetrate pits and surface excavations;
- When meteoric precipitation comes in touch with pit faces;
- When meteoric precipitation infiltrates coal and ore stockpiles heap leach piles, coil spoil heaps, and waste rock dumps;
- When meteoric precipitation and flood inflow run through tailings disposal facilities;
- When run-off from precipitation interacts with mining, mineral processing, and metallurgical operations;

- When surface water and pore fluids of tailings, heap leach piles, ore stockpiles, coal spoil heaps, and waste rock dumps may surface as seepage water or migrate into ground water aquifers; and

- When the uncontrolled or controlled discharge of spent process waters occurs from tailings dam stacks, ponds, and heap leach piles.
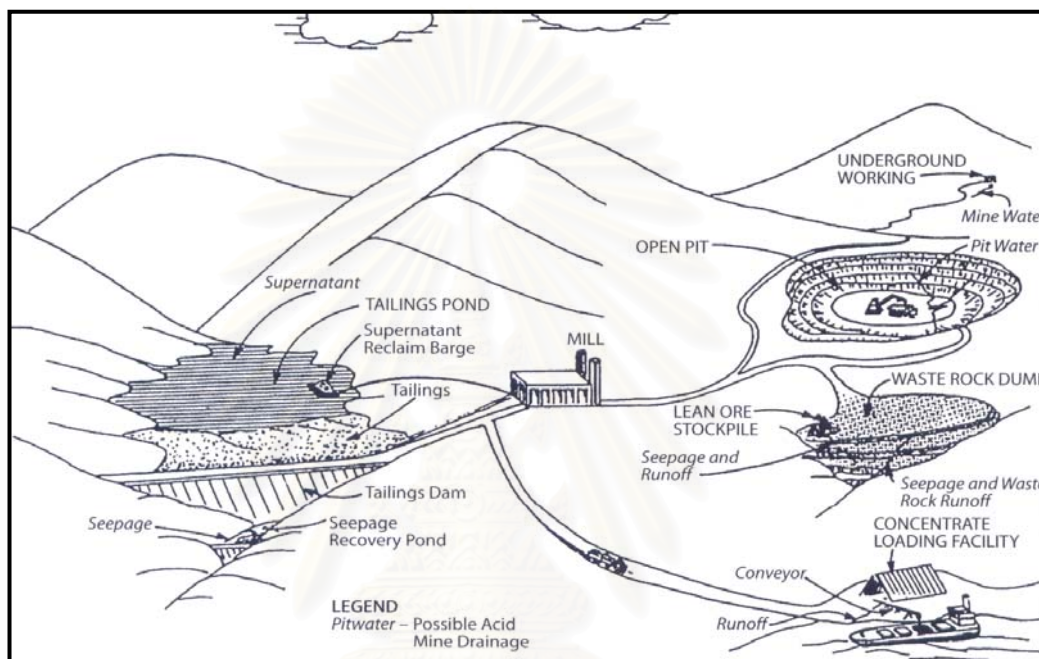
Figure 2.5 Sources of AMD at a metal mine (Ferguson and Erickson, 1988:23-24)

The most general indicators at a site for predicting the presence of AMD as follows:

- pH values less than 5.5.
- Disturbed or absent aquatic and riparian fauna and flora.
- Precipitated mineral efflorescence covering stream beds and banks.
- Discolored, turbid or exceptionally clear water.
- Abundant algae and bacterial slimes.

The environmental impacts of AMD emerge from the unmanageable discharge of AMD wastes which contain acids, salts, heavy metals, metalloids, and sulfate. It

causes the contamination in surface waters, aquatic life, soils, sediments, and groundwater.

Surface water contamination

The discharge of AMD water with their high metal and salt concentrations has an impact on the utilization of the waterways downstream for fishing, irrigation and stock watering. The high acidity of the water restricts its reuse and may cause corrosion to and incrustation of processing circuits. Moreover, AMD water has increased conductivity, total dissolved and suspended solids, and turbidity. It can be observed in the beginning of the rainy season or spring. Hence, it can cause distinct impacts on downstream ecosystems with effectively severe effected on the biota.

Impact on aquatic

The release of AMD water can devastate the natural biodiversity and cause depletion in numbers of sensitive species by destruction of the bicarbonate system. The excessive hydrogen ions, which occur in an AMD reaction, will change the bicarbonate to carbonic acid. Therefore, the loss of bicarbonate will have an adverse effect on many organisms and plants. They can't alive in acidic water. The high concentration of heavy metal in AMD water can accumulate in aquatic life and then increase bioavailability concentrations that are hazardous to organisms, plants, and human health. Moreover, the heavy metals turn into their toxic forms at low pH level.

Soil and sediment contamination

Uncontrolled wastes of AMD water from mining, mineral processing, and metallurgical operations releases contaminants into the environment. The soil and sediment contamination depends on the quality of the released effluent. The precipitation of dissolve contaminants may cause soil, stream and floodplain sediment to appear contaminated with heavy metals. The heavy metals may occur in their cation form on an exchangeable area, incorporated in carbonates and comfortable reducible iron and manganese oxides and hydroxides.

Ground water contamination

The effects of AMD on groundwater are more common than those surfaces on water. Groundwater may be initiated from tailing dams, waste rock piles, heap leach pads, ore stockpiles, coal spoil heaps, ponds, and contaminated soil. The contaminated water may penetrate into aquifers, especially if there are uncapped, unlined and permeable at their base. The migration rate of such a plume is highly variable and dependent on the physical and chemical characteristics of the aquifer or waste materials.

2.1.3 Heavy Metals

2.1.3.1 Manganese (Mn)

Manganese is classified as a transition metal with the symbol Mn and atomic number of 25. Its atomic weight is 54.938. Manganese cannot accumulate over 20 mg in human. It is a common metal that can be found in many types of rock. It can combine with carbon to produce organic manganese compounds. Furthermore, it is an essential trace element and necessary for good health. It can be found in several foods, grains and cereals such as tea.

Exposure to high levels of manganese causes mental and emotional disturbances as well as slow and clumsy body movements. It is called "manganism." Manganism occurs because too much manganese injures a part of the brain that helps control body movements. It can cause damage to the brain, liver, kidneys and a developing fetus. Manganese can classify as no carcinogenicity.

2.1.3.2 Iron (Fe)

Iron shows up in two forms, soluble ferrous iron and insoluble ferric particulate iron. The iron in the environment will be in the form of insoluble ferric, Fe^{3+}, which is a non-toxic chemical. However, the presence of iron at a concentration above 0.1 mg/L will damage aquatic animals and fish. Iron acts like a catalysts in

water and will promote the dissociation of oxygen molecules in the water to create a toxic effect of the iron on aquatic lives.

The effects of high levels of iron in humans are governed by adsorption. Iron is adsorbed in the ferrous state by cells of the intestinal mucous. When excess dietary iron is absorbed, the body produces more ferritin. Therefore, excess iron builds up in the heart and liver, causing tissue destruction. There are many problems that may result from iron toxicity; these include anorexia, oligura, diarrhea, hypothermia, diphasic shock, metabolic acidosis, and death. Furthermore, iron is a substance that creates acid mine drainage.

The contamination of heavy metals in the soils is a major concern because of their toxicity and threat to human lives and the environment. These heavy metals may adversely affect soil ecology, agricultural production or product quality, and water quality.

2.1.4 Treatment Technology for metal-contaminated soil

There are many remedial technologies for metal-contaminated soil. The significant objectives of soil remediation are to reduce the potential risk to human health or ecosystem and control a source of groundwater and surface water contamination. The favorite treatment technologies for this contamination consist of capping, vitrification, phytoremediation and stabilization/solidification.

Soil capping is utilized to cover waste or contaminated soil. The application of soil capping is used to protect direct contact with contaminated material, and/or reduce infiltration of run-off, precipitation such as snowmelt, and rain water through contaminants, and then it can pass contaminants into groundwater. Capping is generally used to enclose waste in landfills. This remedial technique is not appropriate for small volumes of hazardous waste or leachable waste, and cannot be applied as a long term treatment.

Vitrification is defined as a thermal treatment technology that melts soil or sludge into a grass phase. This technology can be applied to treat radioactive wastes, metal sludge, asbestos-containing an extraordinary amount of energy between 800 to 1000 KWh per ton of soil. So it utilized to treat relatively small quantities of wastes that are difficult to remediate by other means. The limitations of this treatment is it use of volatile organic chemicals (VOCs), loosely packed rubbish, coal or other combustible materials, increased waste, and the need for treatment after the finished treatment.

Phytoremediation refers to a technology which treats soil or sediment at a place using plants to concentrate or degrade the contaminants. Treatment happens in the soil around the contaminated site and is influenced by the roots of plants such as an herb, soy bean, and Indian mustard. This technology can treat both organic and inorganic contaminants. It involves not only organic but also inorganic mechanisms and uses the root systems of plants. This method requires the careful about selection of plants, accumulation of contaminants in plants tissues, and retardation of plants growing.

Stabilization and Solidification (S/S) is habitually applied to treat inorganic waste generally soils and sledges containing metals. It is often required prior to landfilling. The non-hazardous and/or hazardous waste may also be stabilized by mixing it with chemical additives (reagents) to reduce the solubility of the contaminants before it is solidified. This remedial technology depends on the physical and chemical characteristic of the waste. The limitations of this technique are that cannot be used with volatilization organic chemicals because energy and toxic gases occur from the mixing of the chemical reagents. Moreover, this technology increases the volume and weight of the waste, especially, in cement-based treatment and requires large volumes of chemical reagents.

2.1.5 Stabilization and Solidification (S/S) Technology

Stabilization is a process that applies an additive (reagents) to decrease the hazardous nature of the waste by changing the form of the waste to one that minimize

the rate of contaminant migration into the environment, or reduces its level of toxicity. Stabilization/solidification is known as one of the most effective technologies for treating and immobilizing heavy metals in contaminated soil. This treatment inhibits the mobilization of heavy metals into the surrounding area. S/S technology employs binding materials such as cement kiln dust or fly ash to transform contaminated soil containing toxic metals into less toxic forms and or into more manageable forms by chemical and or physical immobilization. Physical stabilization refers to the method of solidification that improves the engineering properties such as strength, compressibility, and permeability of the stabilized waste form. Chemical stabilization is the modification of the contaminants' chemical form. Thus, leachability is eliminated or substantially reduced. Many processes achieve immobilization by a combination of stabilization and solidification.

2.1.5.1 Mechanisms

There are six fundamental stabilization mechanisms in stabilization and solidification. Their fundamental stabilization mechanisms should be considered to evaluate the potential for success or failure of such developments. The knowledge of the fundamental physical and chemical mechanisms that control the effectiveness of the stabilization reagents is essential for the correct implementation of stabilization as technology. The fundamental stabilization mechanisms can employ one or more of the following mechanisms:

- Macroencapsulation
- Microencapsulation
- Absorption
- Adsorption
- Precipitation
- Detoxification

Macroencapsulation is the mechanism by which hazardous waste constituents are physically entrapped in a larger structural matrix, in which is the hazardous waste constituents are held in discontinuous pores within the stabilizing materials. However, the entrapped materials can be free to migrate; the stabilized materials can breakdown over time. Hence, the contaminants stabilized by only macroencapsulation may find their way into the environment if the integrity of the mass is not maintained.

Microencapsulation is the mechanism by which hazardous waste constituents are entrapped within the crystalline structure of the solidified matrix at a microscopic level. The contaminants however, are not chemically altered or bound and the rate of contaminant migration from the stabilizing materials may increase as the more surface area is exposed.

Absorption is the process by which contaminants are taken into the sorbent. This mechanism is similar to how a sponge takes on water. It is primarily employed to remove liquid and improve the wastes' handing characteristics. But, the stabilizing materials can release liquid by squeezing out of the materials. Hence, the application of absorption only considered a temporary measure to improve the handling characteristics. The popular common absorbents contain soil; fly ash; cement kiln dust; lime kiln dust; clay minerals including bentonite; kaolinite; and zeolites; hay and straw.

Adsorption is the phenomenon by which contaminants is electrochemically bonded to stabilizing agents within the matrix. The typical bonding occur van der Waal's or hydrogen bonding. The contaminants in wastes are fixed within the stabilized materials by chemical bonding. This process is considered more permanent than both macroencapsulation and microencapsulation.

Precipitation is the process by which the contaminants change their chemical forms into more stable forms within the waste. The chemical specimen such as hydroxides, sulfides, silicates, carbonates, and phosphates can be substituted in for the stabilizing materials as part of the materials structure. This process can be employed in the stabilization of inorganic wastes such as metals hydroxides. Precipitation

depends on pH because the metal can be stable at a high pH. Thus, the condition of the environment can effect precipitation.

Detoxification is a certain chemical reaction replacing during the stabilization process that may cause a waste with reduced toxicity. It is any mechanisms that converts a chemical constituent into another constituent that is either less toxic or nontoxic. For example, it would be the reduction of chromium in the +6 valence state to chromium in the +3 valence state using stabilization with cement-based materials. Trivalent chromium has a lower solubility and toxicity than hexavalent chromium.

2.1.5.2 Types of Additives

Stabilization and solidification technology generally can be separated in to two categories. Each of the two broad categories of technology is described below.

Cement Based

The cement-based process is principally employ cement as the main reagent. The most popular cement is Portland cement (usually type I or II). Cement is mixed with water; a hydration reaction will occur and create a product that looks like a rock, monolithic, hardened mass. Cement-base stabilization is most appropriate for inorganic waste, particularly heavy metals. Heavy metals are change in form of insolubility hydroxide or carbonate salts within the monolithic. This technology however can not be applied to organic contaminants because organic contaminants can retard and reduce the hydration reaction and strength the crystalline structure formation resulting in an amorphous product. This treatment has been employed for the immobilization of inorganic waste such as metals-contaminated soil.

There are many advantages of cement-based stabilization. It is relatively inexpensive, well known including handling, mixing, setting, and hardening. The main disadvantage is the sensitivity of the cement to the presence of certain contaminants, can mobile metals from the solid and destroy the concrete matrix after setting has occurred.

Pozzolan or Silica Based

A material that can react with lime in the presence of water to produce a cementitious material can defined as pozzolan. The reaction of pozzolanic concrete consists of the reaction between an aluminosilicious material, lime, and water. Pozzolanic materials include fly ash, ground blast furnace slag, and cement kiln dust. In pozzolan-based solidification technology, the heavy metals in waste become part of the calcium silicate and aluminate colloidal structures, or adsorb to the surface of the pozzolanic structure.

General mixes include lime/fly ash and lime/cement kiln dust. Moreover, this treatment can add other additives mixing with pozzolanic materials such as bentonite, clays and carbon or zeolites. The advantages and disadvantages are similar to that of cement-base stabilization. But pozzolan-base technology is more applicable to organic wastes than cement-based technology with the exceptions of grease and oil.

Table 2.2 Reagent applicability for waste stabilization (LaGrega, M.D., Buckingham, P.L., and Evans, J.C., 2001)

Waste Compound	Cement-based	Pozzolan- based
Nonpolar organic: grease and oil, aromatic hydrocarbons, halogenated hydrocarbon, PCBs	• May impede setting. • Decreases durability over a long time period. • Volatiles may escape on mixing. • Demonstrated effectiveness under certain conditions.	• May impede setting. • Decreases durability over a long time period. • Volatiles may escape on mixing. • Demonstrated effectiveness under certain conditions.
Polar organic : alcohols, phenols, organic acids, glycols	• Phenol will mainly retard setting and will decrease durability in the short run. • Decrease durability over a long time period.	• Phenol will mainly retard setting and will decrease durability in the short run. • Decrease durability over a long time period. • Alcohols may retard setting.

Table 2.2 Reagent applicability for waste stabilization (Cont.) (LaGrega, M.D., Buckingham, P.L., and Evans, J.C., 2001)

Waste Compound	Cement-based	Pozzolan- based
Oxidizers : sodium hypochlorate, potassium permanganate, nitric acid, potassium dichromate	• Compatible	• Compatible
Acids : hydrochloric acid, hydrofluoric acid	• No siginificant effect on setting. • Cement will neutralize acids. • Type II and IV portland cement demonstrated better durability characteristics than Type I. • Demonstrated effectiveness.	• No siginificant effect on setting. • Compatible, will neutralize acids. • Demonstrated effectiveness.
Salts : sulfates, halides, nitrates, cyanides	• Increases setting times. • Decrease durability. • Sulfates may retard setting and cause spalling unless special cement is applied. • Sulfates accelerate other reactions.	• Halides are easily leached and retard setting. • Halides may retard setting, most are easily leached. • Sulfates can retard or accelerate reactions.
Heavy metals : lead, chromium, cadmium. Arsenic, mercury	• Compatible. • Can increase set time. • Demonstrated effectiveness under certain conditions.	• Compatible • Demonstrated effectiveness on certain species.
Radioactive materials	• Compatible	• Compatible

2.2 Literature Review

Stabilization and solidification methods of contaminated wastes are employed to change the physical or the leaching characteristics of the waste or to decrease its toxicity. Stabilization transforms waste contaminants into a more immobile form, generally through chemical reactions. Solidification is a physicochemical method by which waste components are physically locked within a solidified form or a monolithic block. Stabilization and solidification refers to the treatment process that mixes or injects binding materials into the waste. The objectives of stabilization are to improve the physical characteristics of the wastes, reduce the contaminant solubility and the surface area, and limit contact of transport fluids and the contaminants.

Many works have shown that stabilization and solidification is an effective remediation technology that can reduce the potential of leachable heavy metals in contaminated areas and is one of the low cost methods. This technology uses the toxicity characteristic leaching procedure (TCLP) to measure the stabilization effectiveness of the heavy metals. In-situ stabilization and solidification involves the application of lime, cement, fly ash, and phosphates along with many other natural and synthetic additives and employs various fixation mechanisms.

Wang et al. (2001) studied the stabilization of an elevated heavy-metal-contaminated site. This research used a combination of $Ca(H_2PO_4)_2$ and $CaCO_3$ as a stabilizer and TCLP was employed to check the stabilization effectiveness of the heavy metals, especially Cd and Pb. It was found that the combination of both stabilizers decreased the extractable heavy metal concentrations of Cd, Cu, Pb, and Zn. There was a greater than 95% reduction and in particularly a 99% reduction for Pb.

Yukselen and Alpaslan (2001) studied the leaching of metals from soil contaminated by mining activities. They mixed lime and cement into the soil and evaluated the effectiveness and capacity of lime cement an immobilizing agent for heavy metals like Pb, Cu and Fe, using a leaching test. This research employed two leaching experiments: 1) TCLP to estimate the mobility of both organic and inorganic

analytes occurring in liquid, solid, and multiphase waste, and 2) Column experiment to study the leaching behavior of metals in the soil additive system. They found that the addition of lime and cement to the contaminated soil immobilized heavy metals in the soil. The column leaching experiment ensured the findings of the TCLP experiment and displayed that the degree of heavy metal leaching was highly pH dependent.

Ciccu et al. (2003) investigated the possibility of using red mud and/or coal fly ash for immobilizing heavy metals contained in contaminated soil by the column leaching experiment. The column leaching experiment demonstrated the potential of certain industrial wastes in immobilizing heavy metals in the contaminated soil. The experiment was performed in 40 cm height and 140 mm diameter plexiglass columns. Distilled water as the leaching solution was fed into the column by the pulse method in a single addition every day. The results demonstrated that relatively small additions of coal fly ash and/or red mud could significantly decrease the heavy metal content of the soil leachate.

Young et al. (2001) examined the partitioning of heavy metals on soil samples from column tests. They used the column test to determine the retention potential of the soil samples. The leaching column consisted of a plexiglass cylinder with diameter of 115 mm and height of 125 mm. The soil sample was put into the column using the compaction test at maximum dry density and optimum moisture content. Moreover, there were two steps of leaching in the columns that were saturated with distilled water, and were leached by leachate. The leaching experiments were conducted under a constant air pressure of 10 psi to reduce the time factor for leachate transport through the soil column. The concentrations of heavy metals were determined by ICP-MS. They found that the soil sample showed good buffering capability against very acidic leachate. This is a significant factor in favor of the use of such soils as clay barrier materials in a landfill. The ability of these soils to maintain their pH is important to promote the precipitation of heavy metals.

Theodoratos et al. (2000) evaluated the usage of sewage sludge for the stabilization of soil contaminated by mining activities. They applied TCLP on the

stabilized mixture and proved that the concentrations of heavy metals, Pb, Zn, and Cd, were reduced by addition of the 15% of wastewater treatment sludge.

Doye and Duchesne (2003) examined the neutralization of acid mine drainage with alkaline industrial residues using batch leaching tests. Alkaline industrial wastes, CKD and red mud bauxite (RMB) were employed to produce a neutral condition. They found that the use of 5% CKD and 10% CKD+ RMB produced neutral pH conditions and the concentrations of Al, Fe, Cu, Zn, and SO_4^{2-} in solution were significantly reduced when compared with the reactive tailing from the mine.

Dermatas and Meng (2003) investigated the use of fly ash for the S/S of heavy metal contaminated soil. They blended fly ash with quicklime to immobilize Pb, Cr (III), and Cr(VI) in artificially contaminated clayey sand soils and applied TCLP as the leaching experiment to evaluate the degree of heavy metal immobilization. Moreover, this research studied the reusability of the stabilized waste forms for their application in construction by performing unconfined compressive strength (UCS) test. The experiment results showed that the addition of fly ash increased the immobilization of all heavy metals tested, and influentially improved the strength–strain properties of the treated solid, hence permitting their reuse as rapid available construction materials.

S/S can be separated into two types; pozzolan or silica-based and cement-based, but many processes use a combination of silica and cement. Pozzolan treatment typically has an unconfined compressive strength between 30 and 200 psi or more. On the other hand, the cement-based treatments have an unconfined compressive strength between 20 and 1000 psi or more.

Nicholson and Ding (1997) were interested in improving tropical soil with an ash and lime admixture. Tropical soils have poor engineering properties including a high swelling potential, high plasticity, low strength, etc. The soil was mixed with lime and MSWFA, which has several properties similar to those of coal fly ash, and may also have similar applications. The engineering tests were used to determine or analyze moisture-density relationship via compaction tests, the Atterberg limits or

grain size distribution, particle size of soil, free swell, pH, and triaxial tests strength via. The study applied the compaction test as a part of the preparation of all soil sample specimens. The results showed that MSWFA and the combination of MSWFA and lime, when used as a soil stabilizer, were able to improve the properties of soil by reducing the moisture decreased plasticity index which increased its strength. Furthermore, the mixing of MSWFA and lime proved to be a good stabilizing agent for highly acidic soil.

Lee and Nicholson (1997) looked into an engineering test program of MSWFA mixed with quarry tailings. The quarry tailings were blended with the fly ash at different ratios and then their strength, permeability, gradation, and swell potential were measured. They used the compaction test to find the maximum dry density and optimum moisture content to provide a moisture-density relationship for sample preparation.

Raghu et al (1997) applied the standard proctor compaction experiment to determine the compaction characteristics for both natural soil and residual mixed with natural soil. They utilized unconfined compressive strength to evaluate the consistency of a cohesive soil. They showed that the samples with moisture contents close to their optimum moisture contents had greater unconfined compressive strengths than others.

Rivard et al (1997) studied incinerator bottom ash as a soil substitute in terms of its physical and chemical characteristics. The researchers applied as-received bottom ash and bottom ash amended with other fine grained natural aggregates such as clay and coal fly ash. Their research utilized TCLP, column, and batch leaching tests to analyze the chemical behaviors of the samples.

Selim, and Sparks (2001) examined arsenic mobility and speciation in contaminated soils. They used a column experiment to study the remobilization of heavy metals in leaching test. Their soil sample was packed in the column and leachates were collected by a fractional collector and analyzed by ICP-AES. The column leaching experiment used a steady feed rate at 0.2 ml min^{-1} (HPLC pump).

Kamon, Katsumi, and Sano (2000) researched s/s of municipal solid waste fly ash (MSWFA) with coal fly ash for geotechnical application. The objectives of this research were to determine the engineering properties and leaching behavior of the sample for application in embankments. The combination of MSWFA with cement and coal fly ash was tested for unconfined compressive strength, leaching and soaking. Cylindrical samples were prepared for the unconfined compressive strength test, soaking durability test, X-ray diffraction (XRD) analysis, scanning electronic microscopic (SEM) observation, and leaching test by maximum dry density and optimum moisture content, and then, sealed and cured under room temperature. The results explained that the employment of a cement and MSWFA stabilizer was able to attain strength development, high soaking durability, and the containment of heavy metals. Thus, a stabilized MSWFA mixture can be applied to road embankments and/or river dikes with cover soil in order to avoid additional leachate from MSWFA mixture.

Miller and Azad (2000) studied the potential of CKD as a soil stabilizer. This research demonstrated that increases in the unconfined compressive strength of soil occurred with the increment of CKD. While the unconfined compressive strength increased, plasticity index decreased. Moreover, they found that the addition CKD in soil changed the pH of the soil and affected the plasticity index.

The department of Transportation of the State of Indiana (2002) showed design procedures for soil modification or stabilization. The reaction of a soil-lime or a soil-cement mixture is important for stabilization and design methodology. It is based on increasing the unconfined compression strength. The ratios used for soil stabilization were lime or lime byproduct between 3% and 9%, cement between 3% and 10% and fly ash between 10% and 25%. This project uses cement at 5% for all mixture soil samples with CKD and MSWFA.

Teralta et al (1992) explained that maximum permissible concentrations in leachate from toxic waste have been set at 100 times the drinking water standards. This factor takes into account the attenuating processes such as dilution and

adsorption occurring underground that will reduce the leachate concentration from the point of leachate generation to the point of human or environmental exposure.

This thesis consider on using stabilization and solidification to immobilization of iron and manganese in contaminated soil by MSWFA and CDK. A large amount of MSWFA from Phutket incinerator is a kind of significant environmental problem such as MSWFA requires proper management. During the manufacture of Portland cement, a large amount dust is collected from kiln exhaust gases. While some of this cement kiln dust is recycled especially in Thailand, a large amount is disposed in landfills especially in USA. The CKD and MSWFA have properties that make them an effective stabilized contaminated soil.

Table 2.3 Conclusion of condition and parameter that using in this thesis

Condition or parameter	Reference
1. % 5 cement	The department of Transportation of the State of Indiana(2002)
2. % CKD vary from 5% to 15%	Miller and Azad (2000), and Doye and Duchesne (2003).
4. % MSWFA vary from 5% to 15%	Rivard et al (1997), Kamon, Katsumi, and Sano (2000)
3. Using optimum moisture content for preparing stabilized sample	Nicholson and Ding (1997), Lee and Nicholson (1997), Raghu et al (1997), and Miller and Azad (2000)
4. Improving engineering property	Nicholson and Ding (1997), Lee and Nicholson (1997) Miller and Azad (2000),and Dermatas and Meng (2003)
5. Leaching test and column test	Wang et al. (2001), Young et al. (2001), Yukselen and Alpaslan (2001), Ciccu et al. (2003)

CHAPTER III

METHODOLOGY

3.1 Materials

3.1.1 Soil

In the experiment, approximately 1000 kg of soil was sampled in a coal mining area at Ban Lee district, in Northern Province of Lampoon. There were two kinds of soil. The first was contaminated soil from the Banpu 2 well (BP2). The second soil sample was the background soil of the Banpu 2-extension. The BP2-extension has just closed and it wasn't affected by acid mine drainage. The random method used to collect these soil samples. The soil samples were collected in double plastic bags to prevent moisture in the air. Before any tests were carried out, the soil samples were passed through a standard sieve 10-mm opening to remove rocks and large materials.

3.1.1.1 Coal mining area

Banpu mining area consists of three coal mining wells which is Banpu1 (BP1), Banpu2 (BP2), and Banpu 2-extension (BP2-extention). Environmental Quality Assessment of BP1 and BP2 measured the water quality of the in mining well water, surface water, shallow well water, and groundwater. It found that the concentration of manganese in the mining well was found in excess of the Thai Surface Water Quality Standards. Moreover, the high concentration of manganese and iron found in the groundwater and shallow well water exceeded the World Health Organization (WHO) Guidelines for Drinkable Groundwater Standards. This thesis is concerned with the contaminated soil that discharges manganese and iron.

Figure 3.1 Mining well BP-1

Figure 3.2 Mining well BP-2

Figure 3.3 Mining well BP-2 extension

3.1.1.2 Random Method

The objectives of soil sampling are to determine the amount of heavy metals such as manganese and iron in a mining site and to determine physical properties such as pH, water content, and organic matter content. The apparatus for collecting sample at the site are spades, plastic barrels, 10-mm sieves, and plastic containers. The method that was used for collecting soil was random method as descried below:

1. Soil samples were collected in 20 different locations 0-15 centimeters depth at the mining site by the random method and using a spade. The spade can also be used to dig a V-shaped hold, remove a half-inch slice from the side of the hold, and shave away most of the sample on the blade.

2. Each of the collected samples was passed through a 10-mm sieve to remove the rock and other large materials.

3. Then, an amount of 1 kg of each sample was transferred and mixed in a container to make a blend of 20 samples

4. Finally, the blended soil sample (20 kg) was mixed thoroughly to ensure uniformity and stored in a plastic barrel at room temperature for use in the experiments.
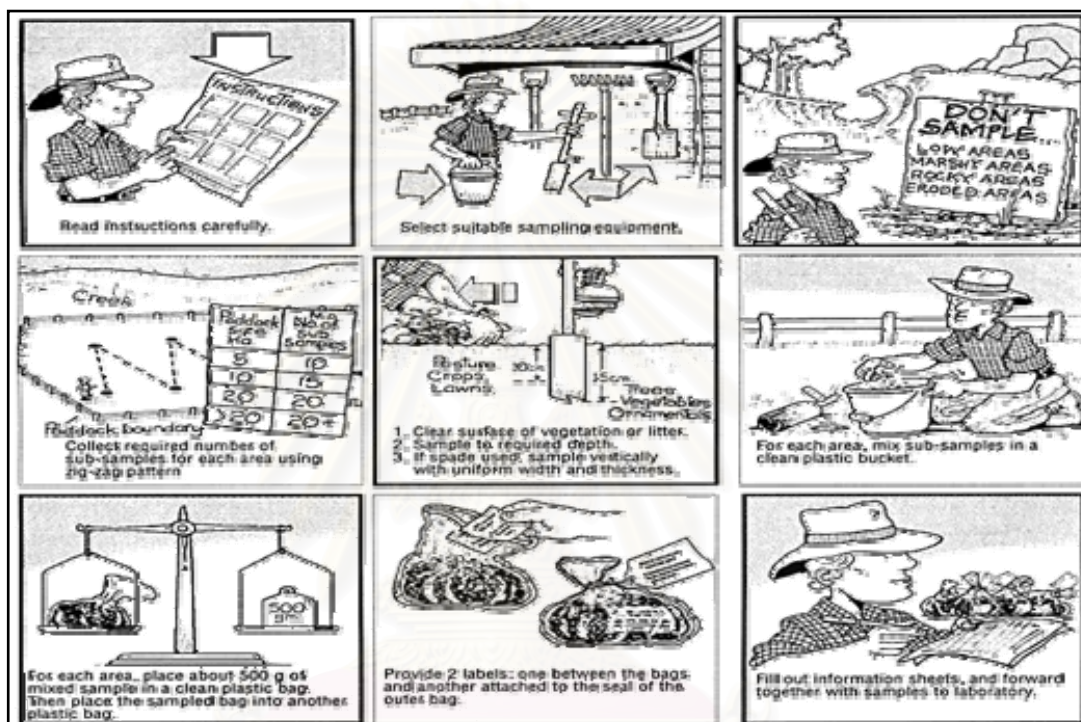
Figure 3.4 Steps of collecting the soil sample used random method.

Figure 3.5 Contaminated soil sample

Figure 3.6 Background soil sample

3.1.2 Cement

The Eagle brand ASTM Type-I Portland cement according to ASTM C150-96 manufactured by the Siam City Cement Public Company Ltd., Bangkok, Thailand was used throughout the experiments.

3.1.3 Municipal Solid Waste Fly Ash (MSWFA)

In the experiment, approximately 100 kg of MSWFA was sampled during normal plant operations in March 2001. The sample was collected in double plastic bags and kept in closed drums to prevent moisture in the air. Before any of the tests were carried out, the fly ash sample was again taken from each drum and sifted through standard sieve No.200 (75-micron openings).

3.1.4 Cement Kiln Dust (CKD)

In the experiment, approximately 100 kg of CKD was sampled during plant operations in July 2003. The sample was collected in double plastic bags and kept in closed drums to prevent moisture in the air. The CKD was contributed by the Siam City Cement Public Company Ltd., Bangkok, Thailand and was used throughout the experiments and sifted through standard sieve No.200 (75-micron openings).

3.1.5 Water

Ordinary tap water was used for all mixtures.

3.1.6 Reagents and Glassware

All chemicals were reagent grade and used without further purification. All solution were prepared with water purified by reverse osmosis and deionized using the ELGA Purelab system. All glasswares were cleaned by soaking them in 10% HNO_3 and rinsing them four times with deionized (DI) water.

Figure 3.7 Cement, cement kiln dust (CKD), and municipal solid waste fly ash (MSWFA).

3.2 Experimental Programs

3.2.1 Characterization of Soil Sample

3.2.1.1 pH

The method to determine the pH of soil has been described by Eades and Grim (1969). 20 g of the soil sample is put in a 150 milliliters flask and 100 milliliters of distilled water is added to the flask. Then, the soil sample is shaken until there is no evidence of dry materials on the bottom. After 1 hour, part of the mixture is transferred to a beaker and measured by a pH meter that must be standardized with buffer solutions.

3.2.1.2 Moisture Content or Natural Water Content

Moisture content or water content is defined as the ratio of the mass of water contained in the pore spaces of soil or rock materials. This factor is applied to determine the soil behavior and its properties. Thus, it can be employed in expressing the phase relationships of air, water, and the solid in a given volume of material.

The method for measuring water content is described in ASTM D 2216-92. The soil sample should be preserved in non-corrodible airtight containers at a temperature between approximately 3 and 30 C° and out of direct contact with sunlight. This experiment keeps soil samples in plastic bags. The soil sample was first dried to a constant mass at 105-110 C°, 12-16 hours in an oven. Then the soil sample and container were allowed to cool at room temperature for comfortable handling with hands and put in the desiccators to prevent moisture adsorption. The mass loss is assumed to be absorbed water. These laboratory tests were done in triplicate.

3.2.1.3 Heavy Metals

The method to determine heavy metals in soil is described in SW-846 method 3051. This method utilizes microwave to promote acid digestion of soil for heavy metals such as Manganese (Mn), iron (Fe), Lead (Pb), etc. It is designed to supply an accelerated multi-element acid leach digestion prior to analysis so that decisions can be made about site cleanup levels, ie. the need for leaching testing of a waste. Digests produced by the method are appropriate for analysis by inductively coupled plasma optical emission spectroscopy (ICP-OES).

A representative soil sample of up to 0.5 g is digested in 10 milliliters of concentrated nitric acid for 10 min employing microwave heating with a proper laboratory microwave unit. The soil sample is put in a fluorocarbon microwave vessel. The vessel is closed and heated in the microwave unit. After cooling, the vessel contents are filtered or allowed to precipitate and then diluted to 100 milliliters in a volumetric flask and then test will be conducted using ICP-OES to determine the amount of heavy metals.

Figure 3.8 Inductively coupled plasma optical emission spectroscopy (ICP-OES).

3.2.1.4 Leaching Test

The toxic characteristic leaching procedure is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid and multiphase wastes. The method that will be used in this project is described in the Notification of Ministry of Industry No. 6, B.E. 2540 (1997). It is similar to the TCLP test method, but the extraction fluid is different: it is made with 80% sulfuric acid and 20% nitric acid in deionized (DI) water with a pH of 5.0. The pH was chosen to mimic the condition of acid rain in Thailand. First, the materials are broken into a particle sizes less than 9.5 mm. Then, it is mixed with the extraction fluid, at a liquid-to-solid weight ratio of 20:1, and shaken in a rotary extraction for 18 hours at 30 rpm and 22 ^{o}C. After 18 hours of shaking, the sample is filtered through a 0.6 to 0.8 µm glass fiber filter, and the filtrate is defined as the TCLP extract. These extracts are measured heavy metals by ICP-ES.

3.2.1.5 Cation Exchange Capacity (CEC)

The cation exchange capacity (CEC) of soil refers to the amount of positively charged ions the soil can hold. It is the value that indicates a condition or possibly a restriction that must be considered when working with a particular soil. The CEC of soil is measured by the amount of clay and/or humus that is present. These two

colloidal substances are necessarily the cation house or reservoir of the soil and are very important because they improve the nutrient and water holding capacity of the soil. Soil pH is important for CEC because as pH increases (becomes less acidic), the number of negative charges on the colloids increase, thereby increasing its CEC. Soils with a high CEC have a much lower percentage of cations in its soil water, and are far less susceptible to nutrient loss by leaching. Concentrations of cations are expressed in centimoles of positive charge per kilogram of soil (cmol (+)/kg). The method to measure CEC involve replacing exchangeable cations by saturating the soil with a selected cation that may be generated using one of three reagents: 1N ammonium acetate (pH 7.0), 1N sodium acetate(pH8), or 0.5N barium chloride plus 0.2N triethanolamine solution (pH8.2). The detailed procedures can be found in publications such as these of Black (1965) and USEPA (1986).

3.2.1.6 Organic Matter (OM)

The method to measure organic matter has two procedures: wet digestion and loss on ignition (LOI). This project uses wet digestion. The method uses potassium dichromate ($K_2Cr_2O_7$) with external heat and back titration to measure the amount of unreacted dichromate. This method is rapid and adapted for routine analysis in a soil testing laboratory. It is primarily used to measure the organic matter of mineral soils. The method is useful for soils containing very low organic C to as high as 12% organic C with a sensitivity of about 0.2 to 0.5% organic C.

3.2.1.7 Mineralogical Composition

An X-ray diffraction spectrometer is an analytical instrument for the analysis of crystalline phases that generates x-ray diffraction peaks. The peak positions are reported by the crystal unit cell parameters, and the peak intensities are given by the placement of the atoms in the unit cell. The peak widths are a result of two parameters, finite crystallite sizes and micro-stress within the crystallites. As such, the parameters that define crystal structure can be simply accessed from an x-ray diffraction pattern. Each mineral type is defined by the characteristic crystal of each structure, with a unique x-ray diffraction pattern, allowing for the rapid identification of minerals present within the material.

3.2.1.8 Bulk Chemical Composition

Bulk chemical compositions analysis is a test that determines the qualitative and quantitative compositions of a material. It uses X-ray fluorescence (XRF) to measure the elemental compositions of the material. It is a non-destructive and reliable method, which requires no or very little, sample preparation and is suitable for solid, liquid and powdered samples. It can be used for the determination of elements across the periodic table.

3.2.1.9 Atterberg Limits and Indices

The engineering properties of fine–grained soils depend on factors other than particle size distribution and density. It is controlled mostly by their mineral and structural compositions and the amount of water. The effects of water content in the disturbed condition of soil include the liquid and plastic limits that are used to classify fine-grained soils and to evaluate their mineral compositions and engineering properties. The liquid limit, referring to the boundary between the liquid and plastic states, is the minimum water content at which the disturbed fine-grained soil will behave like viscous liquid. The plastic limit is the minimum water content at which the saturated soil can remain in the plastic state.

The method to determine Atterburg limits and indices follows ASTM D 427-93. The soil sample of the Atterburg test must pass through a No.40 sieve and a specimen of 150 to 200 g can be mixed thoroughly with distilled water on an evaporating dish using a spatula. Then, about 100 g of prepared soil is mixed with distilled water to form a uniform paste. A portion of paste take place in the cup of limit device and smooth the surface off to about 1.0 cm. in thickness, tapering to form an approximately horizontal surface. The air bubbles should be eliminated form the soil pat. Then, the crank turn on a ratio of about 2 revolutions per second, and count the blows necessary to close the groove in the soil for a length of 13 mm along the bottom of the groove. The sample mix in the cup and repeat steps 3 and 4 until the number of blows required closing the gap is substantially the same. After a consistent value in the range of 10 to 50 blows has been obtained, approximately 10 g of soil is taken near the closed groove for a water content determination. By altering the water content of soil and repeating steps obtain water content, the results are determined in

the range of 10 to 50 blows. The plots of water content are make against log of flows. The relationship between the water content and draw a straight line through the three or more plotted points are plotted. On the other hand, the preparation of soil sample for plastic limit test similar to liquid limit test. Use a 20 g portion of soil the materials prepared for the liquid limit test and reduce the water content of the soil by spreading and mixing continuously on the glass plate or in the storage dish. Then, roll the soil on the glass plate with the hand until it is 3.2 mm in diameter. Squeeze the piece together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass and reroll. Repeat steps until a 3.2 mm diameter thread shows signs of crumbling. Take some of the crumbling material obtained in this step for a water content determination. Repeat steps 2-4 to obtain the other 2 determinations.
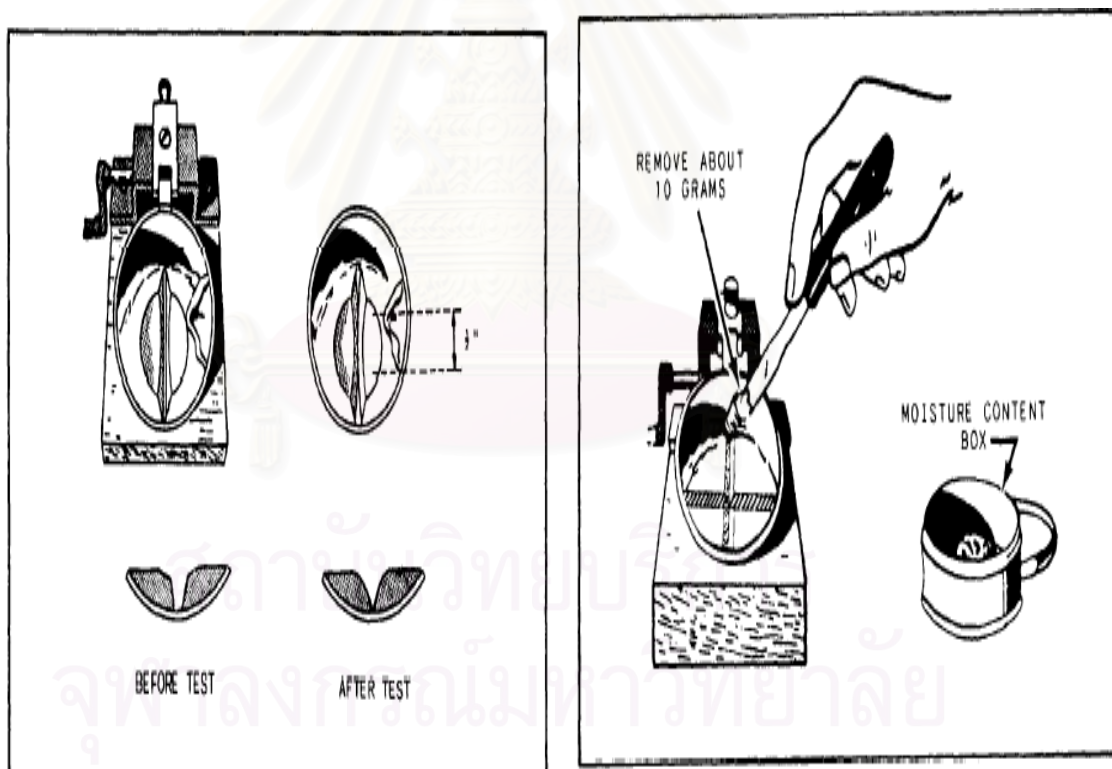
Figure 3.9 Steps of liquid limit

Figure 3.10 Instruments of plastic limit

3.2.1.10 Specific Gravity

Specific gravity is defined as the ratio of weight of a unit volume of a material at a stated temperature to the weight of the same volume of gas-free distilled water at the same temperature. While the specific gravity of soil is described as the ratio of the weight in air of a given volume of soil particle to the weight in air of an equal volume of distilled water at temperature of a 4°C. The specific gravity of soil is utilized in calculating the phase relationship of soil and employed in the identification because the specific gravities of most soils drop in narrow range. It is so the narrow, generally between 2.65 – 2.78, that the test should be carried out with precaution. The specific gravity (Gs) can also be used for computing void ratio, total density, and dry density.

The method to evaluate specific gravity is described in ASTM D 854-92. This test method includes the measurement of the specific gravity of soil that can pass through a 4.75 mm (No. 4) sieve and this test shall be applied for the materials that pass through a 4.75-mm sieve. Therefore, this method can be used to determine the specific gravity of cement kiln dust (CKD) and municipal solid waste fly ash (MSWFA).

The method can be separated into two parts: namely, the calibration of pycnometer and determination of specific gravity of the soil. The calibration of pycnometer consists of attaining at least three sets of concurrent temperature and weight measurements about 4°C apart and within the temperature range of 20°C to 30°C. Points for the calibration curve can be received by substituting different temperatures. Then, the next step is to determine the specific gravity of soil. The significant steps for obtaining an accurate outcome of specific gravity measurements are to ensure that the temperature within the pycnometer is uniform, the cleaning or the soil above and below the mask is made into the soil paste and is not any air bubbles during the test, and no loss in soil particles is necessary.

1. Put the 50g of soil in to the 500 mL volumetric flask that	2. Heat to get rid of bubbles in the flask for 10 min	3. Control the temperature to room temperature and
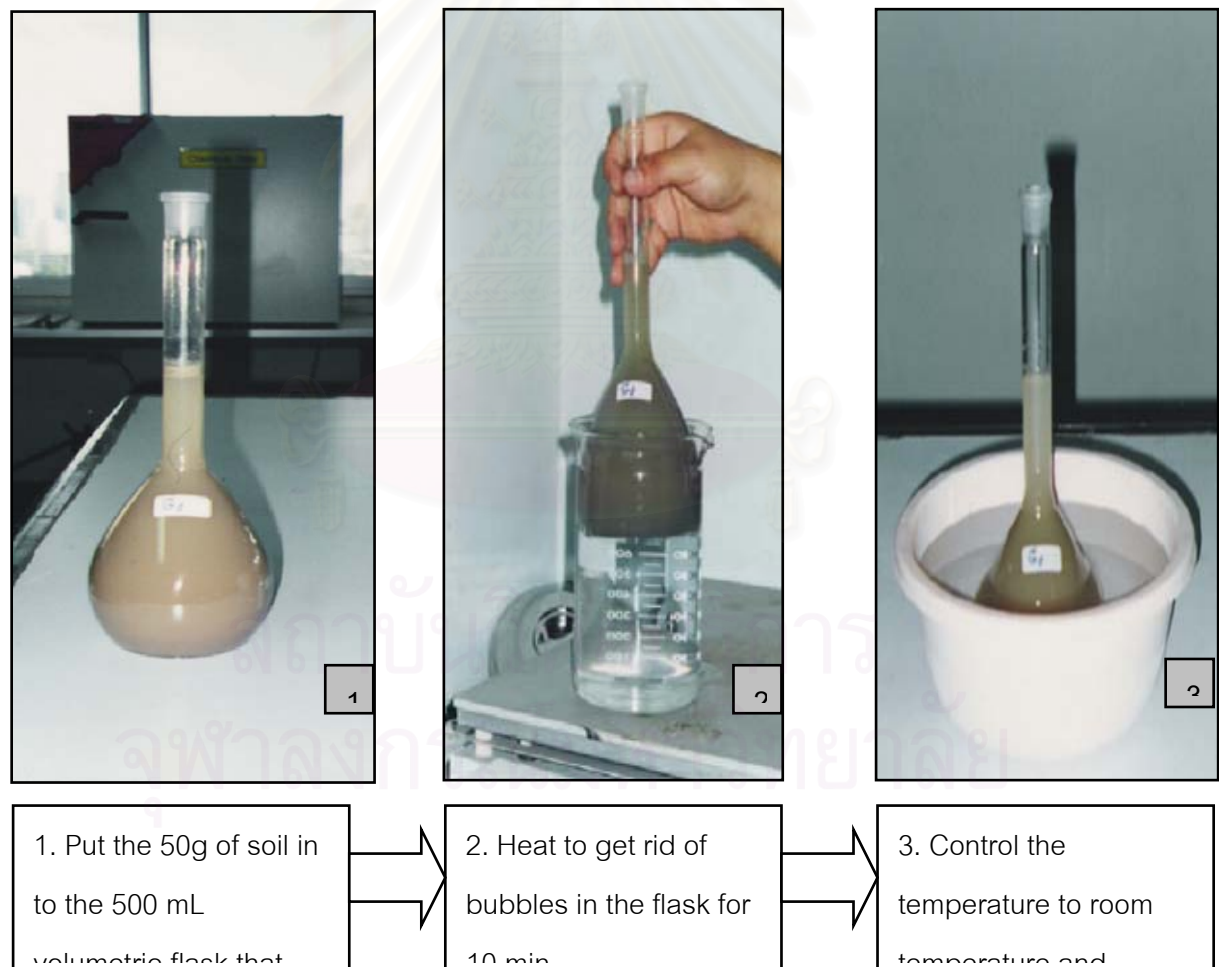
Figure 3.11 Steps of determining specific gravity

3.2.1.11 Grain-Size Analysis

Grain-size analysis is used for the engineering classification of the soil. Grain-size analysis is also utilized in part of the specification of soil for airfield, roads, earth-dams and other soil embankment construction. The standard grained-size analysis test determines the relative proportion of different grain sizes as they are distributed among a certain size range.

Grain-size analysis helps to classify soil, especially coarse soil. It is possible to tell from grain size distribution analysis whether the soil consist of predominantly gravel, sand, silt, or clay, and to a limited extent, which of these size ranges is likely to control the soil's engineering properties.

Sieve analysis determines the grain size distribution curve of the soil sample by passing it through a stack of sieves of decreasing mesh-opening sizes and by measuring the weight retained on each sieve. Sieve analysis is generally applied to the soil fraction that is larger than 75 µm. Grains smaller than 75 µm are sorted by using sedimentation such as hydrometer analysis. The grain-size analysis follows the method ASTMD 422-63.

3.2.1.12 Compaction Test

The compaction method is a preferred procedure that is used for improving the soil character of a site. It is usually the least expensive and most frequently employed method for determining soil density. Compaction can be described in terms of the dry unit weight of the soil. Generally, dry soils should be able to be compacted best and thus a greater unit weight can be achieved if for the soil, a certain amount of water is added. In effect, water acts as a lubricant, allowing soil particles to be packed together better and leading to an increase in the degree of saturation and the effective stress of the compacted soil. However, if too much water is added, a lower unit weight will result, partly due to water replacing the soil particles. Therefore, in a given compactive effort, there is particular moisture content known as the optimum moisture content, and an associated dry unit weight called the maximum dry unit weight.

The method for evaluating the optimum moisture content and maximum dry unit weight is described in ASTM D 698-91. This method covers a laboratory

compaction procedure employed to evaluate the relationship between the water content and dry unit weight of the soil (compaction curve) and to find the maximum dry unit weight and optimum water content. Its practical uses are related to compacting material in the field to have the desirable density and water content. This procedure requires 16 kg of soil for a standard effort (4 inch-molds) and soil sample break and sifting the soil through a No. 4 sieve for a 4 inch-mold. The soil sample at each selected water content is placed in three layers of a mold of given dimensions with each layer compacted by 25 blows of a rammer dropped from a distance of 12-in (305- mm), subjecting the soil to a total compactive effort of about 12,400 ft-lbsf/ft^3 (600 kN-m/m^3). The resulting dry unit weight is measured. The method is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content of the soil. This data, when plotted, represents a curvilinear relationship recognized as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.
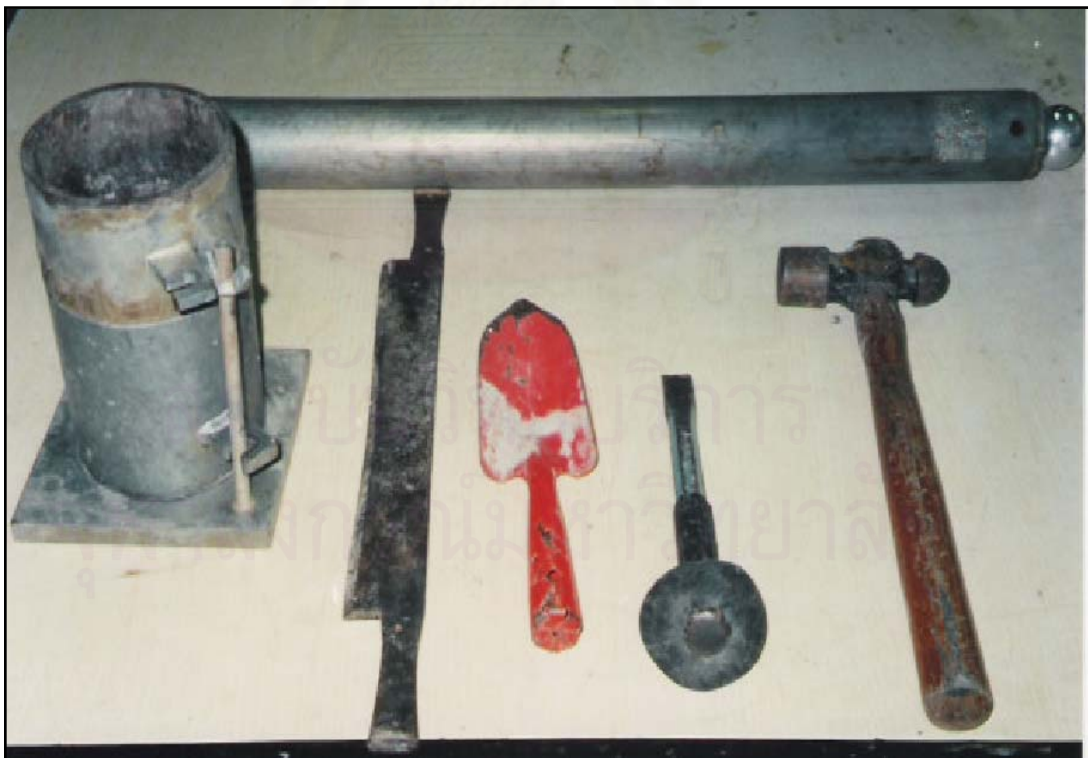
Figure 3.12 Compaction Test Instrument

3.2.1.13 Unconfined Compressive Strength (UCS)

The method for determining unconfined compressive strength is described in ASTM D 2166-91. Unconfined compressive strength (q_u) means the compressive stress at which an unconfined cylindrical soil specimen will fail in a simple compression test. The purpose of this test is to rapidly gain the approximate compressive strength of soil that possesses the sufficient cohesion to permit testing in the unconfined state.

A soil specimen should be prepared to the predetermined water content and density from the compaction test. After a sample is formed in the mold, it is removed and the mass and dimensions of the sample specimen are determined. Soil specimens should have a diameter of at least 30 mm (1.3 inches) and the biggest particle contained within the soil specimen should be slighter than one tenth of the soil sample diameter. A high diameter ratio should be between 2 and 2.5 inches. In this thesis, the soil specimens were prepared in size with a diameter of 30 mm and height 70 mm.

After preparing the soil specimens, the specimens were placed in the loading device and employ to create and axial strain at a rate of ½ of 2% per min. The unconfined compressive strength values are record.

3.2.2 Properties of Municipal Solid Waste Fly Ash (MSWFA) and Cement Kiln Dust (CKD)

3.2.2.1 Particle Size Analysis

ASTM C136-93 is designed to determine the grain size distribution of materials larger than 75 microns. As-received MFWFA and CKD was first dried to a constant mass at a temperature of $110\pm5°$ so as to avoid lumps of fine particles being classified as large particles and also to prevent the clogging of the finer sieves. With the mash sizes of 4, 8, 16, 30, 50, 100, and 200, the sieves were nested in the order of decreasing sizes of the openings from the top to the bottom. About 500 grams of dried sample was placed on the top sieve and constantly sifted for a sufficient period as described in this standard test method.

MSWFA and CKD particles that passed though standard sieve No. 200 was next studied for their size distribution of fined textures. The ash was subjected to

particle size analysis by a Malvern Particle Size Analyzer model Mastersizer S that can measure particle size ranging from 0.05 to 880 microns. In this experiment, water was used as a medium with a dispersing refractive index of 1.33. This thesis considers only particle size analysis.

3.2.2.2 Moisture Content and Loss on Ignition (LOI)

The technique used to determine moisture content is defined in ASTM C311-96. The sample was first dried to a constant weight at 105-110° C in a ceramic crucible. Then, it was further cooled to room temperature in a desiccator to prevent moisture absorption. The weight loss is assumed to be water.

Loss on ignition (LOI) is also defined in ASTM C311-96 and ASTM C114-94 as the weight fraction of materials that is lost by heating in a furnace at 750°C. The residue left from moisture content determination shall be ignited to a constant weight in an uncovered porcelain crucible at 750± 50°C. LOI is a measurement of the unburned carbon remaining in the ash. This value is perhaps the single most critical characteristic of fly ash: higher carbon contents can results in air-entrainment problems and can adversely affect the performance of fly ash concrete. LOI can also be used as an indicator of the degree of burnout in fly ash or define the combustion efficiency.

3.2.2.3 Mineralogical Composition

The mineralogical composition is determined using an instrument similar to that of soil analysis which is an x-ray diffraction spectrometer (XRD). An XRD is an analytical instrument for the analysis of crystalline phases that generates x-ray diffraction peaks. The peak positions are reported by the crystal unit cell parameters, and the peak intensities are given by the placement of the atoms in the unit cell. The peak widths are a result of two parameters, finite crystallite sizes and micro-stress within the crystallites. As such, the parameters that define crystal structure can be simply accessed from an x-ray diffraction pattern. Each mineral type is defined by the

characteristic crystals of each structure, with a unique x-ray diffraction pattern, allowing for the rapid identification of minerals present within the material.

3.2.2.4 Bulk Chemical Composition

Bulk Chemical Composition is performed using an instrument similar to that of soil analysis which is X-ray fluorescence (XRF). A bulk chemical compositions analysis is a test that determines qualitative and quantitative compositions of a material. It uses X-ray fluorescence (XRF) to measure the elemental compositions of the material. It is a non-destructive and reliable method, which requires no or very little, sample preparation and is suitable for solid, liquid and powdered samples. It can be used for determination of elements across the periodic table.

3.2.2.5 Leaching Test

Thai regulatory leaching test is used to determine whether a waste is hazardous or non-hazardous based on the 6th Notification of Ministry of Industry, B.E. 2540 (1997). The purpose of this experiment is to analyze the mobility of both organic and inorganic matter that are found in liquid, solid and multiphase wastes. The soil mixture samples are extracted with a leaching solution that is made with 80% sulfuric acid and 20% nitric acid in deionized (DI) water which has a pH similar to that of acid rain in Thailand. First, the soil mixture samples are broken into particles less than 9.5 mm in size and mixed with the extraction fluid, in a liquid-to-solid ratio of 20:1, and then shaken in a rotary agitator at 30 rpm. After 18 hours of shaking, the sample is filtered through a 0.6 to 0.8-μm glass fiber filter, and the filtrate is defined as the extract. The solution is then analyzed for heavy metal concentrations by ICP-OES.

3.2.2.6 Heavy Metals

The method for determining heavy metals in soil is described in SW-846 method 3052. This method utilizes microwaves to promote the acid digestion of fly ash for heavy metals such as manganese (Mn), iron (Fe), lead (Pb), etc. It is design to

supply an accelerated multi-element acid leach digestion prior to analysis so that decisions can be made about site cleanup levels, ie. the need for leaching tests of a waste. Digests produced by the method are appropriate for analysis by inductively coupled plasma optical emission spectroscopy (ICP-OES).

3.2.3 Soil Stabilization to Evaluate Engineering Properties

Soil stabilization experiment is defined as laboratory techniques for evaluating the effectiveness of chemicals for improving the engineering properties of fine-grained soils. Effectiveness is estimated by comparing the unconfined compressive strength, optimum moisture content and maximum dry density of soil samples, and Atterberg limits and indices with mixing cement, MSWFA, and CKD. This method follows the ASTM D 4609.

1. The ratios used for soil stabilization are 5%cement by dry weight in all of testing, and MSWFA and CKD employed at 5, 10, and 15% by dry weight and soil samples with found optimum moisture content and maximum dry density that are tested for Atterburg limits and indices.

2. The results from the compaction test are used for preparing the soil specimens for testing unconfined compressive strength. Soil sample in many ratios are mixed and soil sample are put in a spilt mold of diameter 30mm and height 70mm with collar and compacted soil specimen in three layer. Then, the soil specimens removed from the mold with the ejector, weighed, wrapped in plastic food-wrapping materials, and placed in a high-humidity chamber at room temperature for the desired curing period of 1, 7, 14, and28 days.

3. At the completion of the curing time, the wrapping materials of the six soil specimens are removed, and weighed, and three specimens are tested for unconfined compressive strength according to ASTM D2166 and the residual specimens are immersed in water for 2 days, removed from the water, surface-dried by blotting with a towel, and reweighed.

Any gain in weight due to immersion represents the moisture adsorption.

4. Each specimen are calculated and recorded for as a percentage of the dry weight of specimen. If appreciable disintegration or slaking of an immersed cylinder occurs, are accurate determinations of adsorbed moisture is not possible and the record should so indicate. Thus, after weighing as indicated above, test the three specimens for unconfined compressive strength with test method D 2166. This test is called soaked unconfined compressive strength (UCS soaked) for determination of the moisture adsorption. This method will test the samples at curing age of 14 and 28 days.

Table 3.1 Recipe of soil sample mixing with cement, MSWFA, and CKD for compaction tests for evaluating optimum moisture content and maximum dry density.

Sample No.	Recipe of Mixing Sample			
	% Soil	%Cement	%MSWFA	%CKD
Ratio 1 (Control)	100	0	0	0
Ratio 2 (5%CKD)	90	5	0	5
Ratio 3 (10%CKD)	85	5	0	10
Ratio 4 (15%CKD)	80	5	0	15
Ratio 5 (5% MSWFA)	90	5	5	0
Ratio 6 (10%MSWFA)	85	5	10	0
Ratio 7 (15%MSWFA)	90	5	15	0

Table 3.2 Recipe of soil sample mixing with cement, MSWFA, and CKD for Atterburg Limit and indices.

Sample No.	Recipe of Mixing Sample				
	% Soil	%Cement	%MSWFA	%CKD	%Water
Ratio 1 (Control)	100	0	0	0	9.5
Ratio 2 (5%CKD)	90	5	0	5	13
Ratio 3 (10%CKD)	85	5	0	10	11
Ratio 4 (15%CKD)	80	5	0	15	11
Ratio 5 (5% MSWFA)	90	5	5	0	13
Ratio 6 (10%MSWFA)	85	5	10	0	14
Ratio 7 (15%MSWFA)	90	5	15	0	13

Table 3.3 Recipe of soil sample mixing with cement, MSWFA, and CKD for unconfined compressive strength (UCS)

Ratio	OMC%	Dry Density (g/m^3)	Wet Density (g/m^3)	Volume (cm^3)	Mass dry(g)	Mass wet(g)	Water (ml)	Avg. Water
1	9.5	1.86	2.04	59.87	111.36	121.94	10.58	11
2	13	1.89	2.14	59.87	113.15	127.86	14.71	15
3	11	1.89	2.10	59.87	113.15	125.60	12.45	13
4	11	1.89	2.10	59.87	113.15	125.60	12.45	14
5	13	1.84	2.08	59.87	110.16	124.48	14.32	15
6	14	1.85	2.11	59.87	110.76	126.27	15.51	17
7	13	1.83	2.07	59.87	109.56	123.81	14.24	15
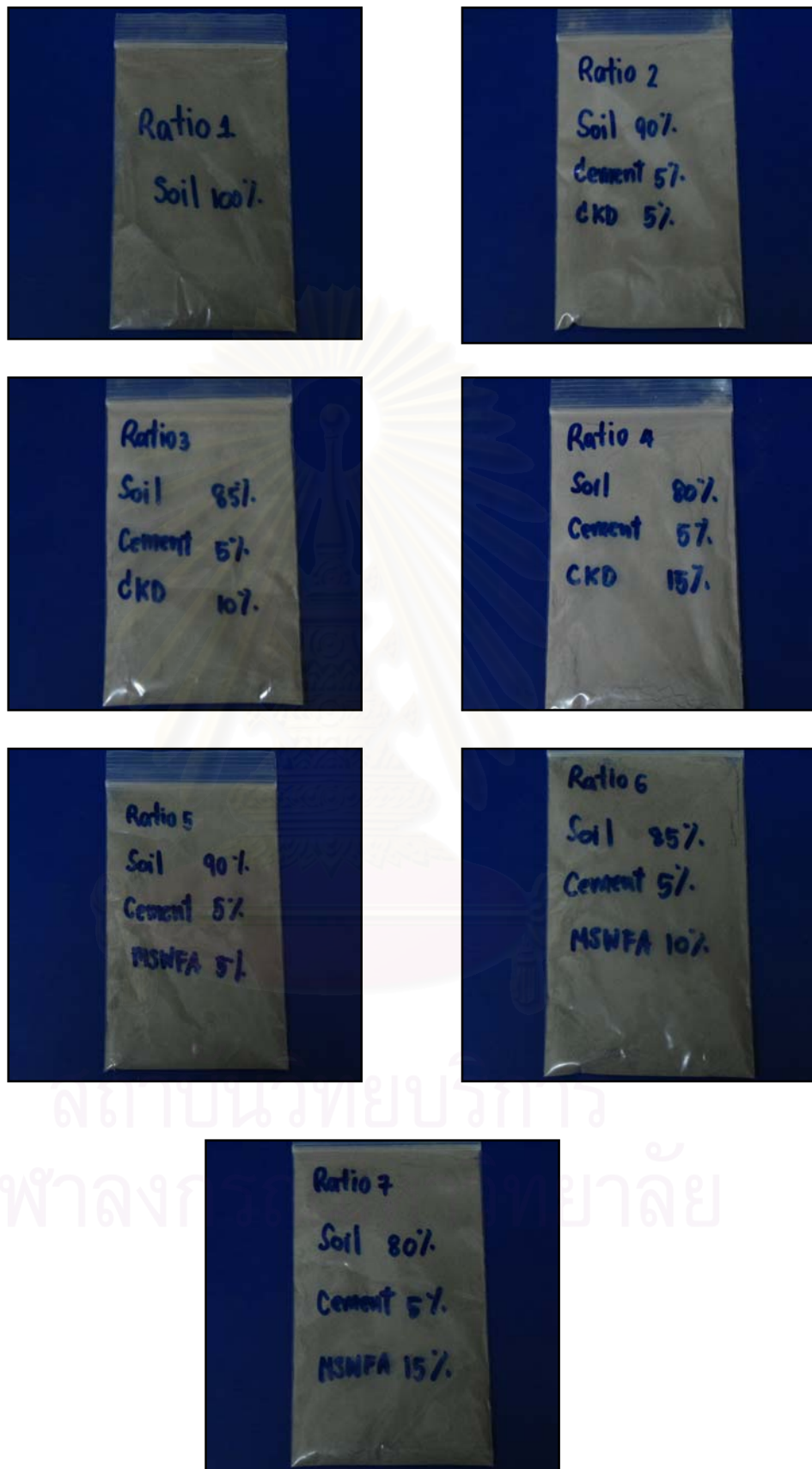
Figure 3.13 Mixture samples

3.2.4 Leaching Test

This experiment describes a laboratory method for evaluating the concentration of Manganese (Mn) and Iron (Fe). This is to determine the efficiency and the capacity of municipal solid waste fly ash (MSWFA) and cement kiln dust (CKD) as immobilizing agents in the leaching test and column experiment.

3.2.4.1 The Notification of Ministry of Industry No. 6, B.E. 2540 (1997) Test

Thai regulatory leaching test is used to determine whether a waste is hazardous or non-hazardous based on the 6th Notification of Ministry of Industry, B.E. 2540 (1997). The purpose of this experiment is to analyze the mobility of both organic and inorganic that is found in liquid, solid and multiphase wastes. The soil mixture samples are extracted with a leaching solution that is made from 80% sulfuric acid and 20% nitric acid in deionized (DI) water which has a pH similar to that of acid rain in Thailand. First, the soil mixture samples are broken into particles less than 9.5 mm in size and mixed with the extraction fluid, in a liquid-to-solid ratio of 20:1, and then shaken in a rotary agitator at 30 rpm. After 18 hours of shaking, the sample is filtered through a 0.6 to 0.8-μm glass fiber filter, and the filtrate is defined as the extract. The solution is then analyzed for heavy metal concentrations by ICP-OES. This thesis will determine the leachate from the soil mixture at the curing times of 1,7,14, and 28 days.

The mixing soil sample are put in a spilt mold of diameter 30mm and height 70mm with collar and compacted soil

The soil specimens are removed from the mold with the ejector, weighed,

Take place sample in a high-humidity chamber at room temperature for the desired curing period of 1, 7, 14, 28

Soil sample are broken into particles less than 9.5 mm in size and mixed with the extraction fluid and then shaken in a

Sample is filtered through a 0.6 to 0.8-m glass fiber filter and digested by

The solution is then analyzed for heavy

Figure 3.14 Leaching test

3.2.4.2 Column Leaching Test

The column experiment is operated to study the leaching behavior of metals in the soil additive system. This experiment more closely simulates field conditions than the leaching experiments. Furthermore, it contributes detailed information about the mobility of the contaminant with respect to time. The worst-case of acid rain is chosen to simulate leaching solution and the stabilized specimen applied with a simulated leaching solution and deionized (DI) water.

The experiments are operated in Teflon columns (3 cm internal diameter by 20 cm length) using an upflow mode. The column soil samples are compacted at their maximum dry density and optimum moisture content using the loading apparatus for compaction. A fine textured synthetic cloth acts as a 6-µm filter for the leachate. There are two steps of leaching: (a) the saturation steps using distilled water and (b) leaching steps using a test leachate. The column soil samples are saturated by leaching solution at the bottom of the column at a steady flow of 0.2 ml/min. The column soil samples are continuously washed for 48 hours with the leaching solution. The leaching solution is collected by a fractional collector and an aliquot of each sample is checked for its pH level and concentration of heavy metals by the ICP-OES. This research employs two leaching solutions: namely, distilled water and leaching solution that is made with sulfuric acid in deionized (DI) water which has a pH of 3.

Figure 3.15 Column leaching test

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Characterization of soil sample

4.1.1 pH

The pH of soil is one of the most significant parameters. It can be defined as the measure of the hydronium ion (H_3O^+, or more generally the H^+), activity and means as the negative logarithm (base 10) of the H^+ activity (mole per liter) in the soil solution (Peach, 1965; Coleman and Thomas, 1967). According to the definition, soils having a pH less than 7.0 are commonly described as "acidic", when above pH 7 as "alkaline", and at pH 7.0, "neutral". There is classification systems depend on water pH. It is shown in Table 4.1 below.

Table 4.1 Classification of soil systems based on water pH (Soil and Plant Analysis Council, 2000)

pH	Category
4.5-5.5	Very acidic
5.6-6.0	Acid
6.1-6.8	Slightly Acidic
6.9-7.6	Neutral
7.3-9.3	Alkaline

The measured soil pH is influenced by the soil-to-water ratio (or dilution), the solubility of salts, and CO_2 in the atmosphere. With regard to Eades and Grim (1966), pH of two sampled soils, background soil and contaminated soil were analyzed and reported in Table 4.2 below.

Table 4.2 pHs of background soils and contaminated soil

Sample	pH	Classification
Background 1	7.22	Neutral
Background 2	7.03	Neutral
Background 3	6.20	Slightly Acid
Background 4	8.35	Alkaline
Contaminated Soil	5.98	Acid

4.1.2 Moisture content or natural water content

By ASTM D2216-92, the moisture contents of five soil samples were determined and reported in Table 4.2 as follows. It was found that the moisture content of contaminated soil is higher than those of the background soils.

Table 4.3 Moisture contents of background soils and contaminated soil

Sample	Moisture Content (%)
Background 1	3.80
Background 2	4.75
Background 3	4.39
Background 4	4.96
Contaminated Soil	6.65

4.1.3 Cation exchange capacity (CEC)

The cation exchange capacity (CEC) is one of the most important soil parameters. Different types of soil have different CEC values. CEC is dependent on clay content, clay types, and organic matter content of the soil. High value of CEC implies that there are high organic matter and clay content. The results of CEC on the background soils and the contaminated soil are demonstrated in Table 4.4 and the CEC values for several clay minerals are given in Table 4.5 as references.

Adsorption of contaminants in soil depends on CEC values of the soil. A contaminated soil with high CEC value will have a higher degree of adsorption of cation contaminants which could result in the difficulty in removal during a remediation process implementation.

Table 4.4 Cation exchange capacities (CEC) of background and contaminated soil

Sample	Cation exchange capacity (CEC, meq/100g)
Background 1	3.80
Background 2	4.75
Background 3	4.39
Background 4	4.96
Contaminated Soil	6.65

Table 4.5 Cation exchange capacities (CEC) of different clay minerals and soil types (Sharma and Reddy, 2004)

Clay Mineral/ Soil Types	Cation exchange capacity (CEC, meq/100g)
Chlorite	10-40
Illite	10-40
Kaolinite	3-15
Montmorillonite	80-150
Oxides and oxyhydroxides	2-6
Soil organic Matter	>200
Sand	2-7
Sandy loam	2-18
Loam	8-22
Silt Loam	9-27
Clayey Loam	4-32
Clay	5-60

It was found that the CEC value of contaminated soil is greater than that of the background soils. It can be concluded that the contaminated soil adsorbed heavy metal more than the background soil.

4.1.4 Organic matter (OM)

Organic matter in soil is a parameter which depends upon soil temperature and moisture. It endlessly undergoes decomposition producing humus, which is a very stable substance and contributes to structural stability, the water-holding and cation exchange capacities of the soil. The organic matter of contaminated soil is 4.6% .

4.1.5 Heavy metals in soil and water

By EPA method 3051 together with analysis using ICP-OES, the concentrations of iron and manganese, of the background soils and the contaminated soil were determined and described in Table 4.6 below. The results showed that the concentrations of iron and manganese in the contaminated soil are higher than those of the background soils and Thailand soil standard. Hence, both iron and manganese are of significant concern. From the concentration of Fe and Mn in water shown in Table 4.7, the concentration of Mn was higher than Thai surface water quality standard and the concentration of Fe was higher than WHO guideline for drinkable standard.

Table 4.6 Concentrations of iron and manganese in background soils and contaminated soil

Sample	Concentration of heavy metal (mg/kg of soil)	
	Fe	Mn
Background 1	13307	391
Background 2	14139	180
Background 3	100883	187
Background 4	22212	1686
Contaminated Soil	79537	5019
Thai Soil Quality Standards [a]	-	1800

(a) Residential direct contact soil cleanup standards

Table 4.7 Concentrations of iron and manganese in the water at BP2

Heavy metals	Concentration of heavy metal contaminated water in BP 2 (mg/L)	Thai Surface Water Quality Standards[a] (2-5)	Guideline Value[b]
Fe	13.41	-	0.3
Mn	17.94	1.0	0.5[c] /0.1[d]

4.1.6 Leaching test

According to the 6th Notification of Ministry of Industry, B.E. 2540 (1997), the result of leaching of the contaminated soil are evaluated and shown in Table 4.7 below.

Table 4.8 Leaching test results of the contaminated soil

Heavy metals	Concentration of heavy metal contaminated soil in leachant (mg/L)	Guideline Value[a] (mg/L)	100 times of Guideline Value (mg/L)
Fe	16.80	0.3	30
Mn	20.10	0.5[b] /0.1[c]	50[b] /10[c]

Note: [a] Guidelines for Drinking-water Quality of WHO [b] Health Significant [c] Objectionable to consume

The analytical results of leaching test following the procedure described in the 6th Notification of Ministry of Industry was compared with 100 times of Guidelines for Drinking Water Quality of the WHO (Teralta et al, 1992). Because of the 6th Notification of Ministry of Industry has not standard for Mn and Fe. It can be concluded that the concentrations of iron from contaminated soil was less than the 100 times of the Guidelines for Drinking Water Quality of the WHO. But the

concentration of Mn from the contaminated soil was higher than the 100 times of objectionable to consume in Guidelines for Drinking Water Quality of the WHO. Hence, manganese was of significant concern.

4.1.7 Bulk chemical compositions

Table 4.8 shows the chemical composition of the contaminated soil determined by X-ray fluorescence (XRF) spectroscopy. All of elemental compositions of contaminated soil are reported in oxide forms. It was found that the major chemical compositions of soil are SiO_2, Al_2O_3 and Fe_2O_3, respectively.

Table 4.9 Bulk chemical composition of the contaminated soil

Concentration of sample,%	Contaminated Soil
Na_2O	0.16
MgO	1.88
Al_2O_3	16.57
SiO_2	69.15
P_2O_5	0.13
SO_3	0.54
K_2O	3.58
CaO	2.11
TiO_2	0.76
Cr_2O_3	ND
MnO	0.31
Fe_2O_3	4.60
NiO	0.01
CuO	ND
ZnO	0.02
Rb_2O	0.01
Y_2O_3	0.01
ZrO_2	0.03
BaO	0.07
WO_3	0.04
SrO	ND
Cl	ND
Br	ND
SnO_2	ND

NA = Not Detected

4.1.8 Mineralogical composition

The crystalline phases of contaminated soil observed by X-ray powder diffraction (XRD) spectrometer are shown in Figure 4.1. The most abundant composition in the crystalline phase of the soil is SiO_2 (quartz). The results verified that these major minerals consist of Al, Si, K, Ca, Fe and Mg that were determined by XRF.
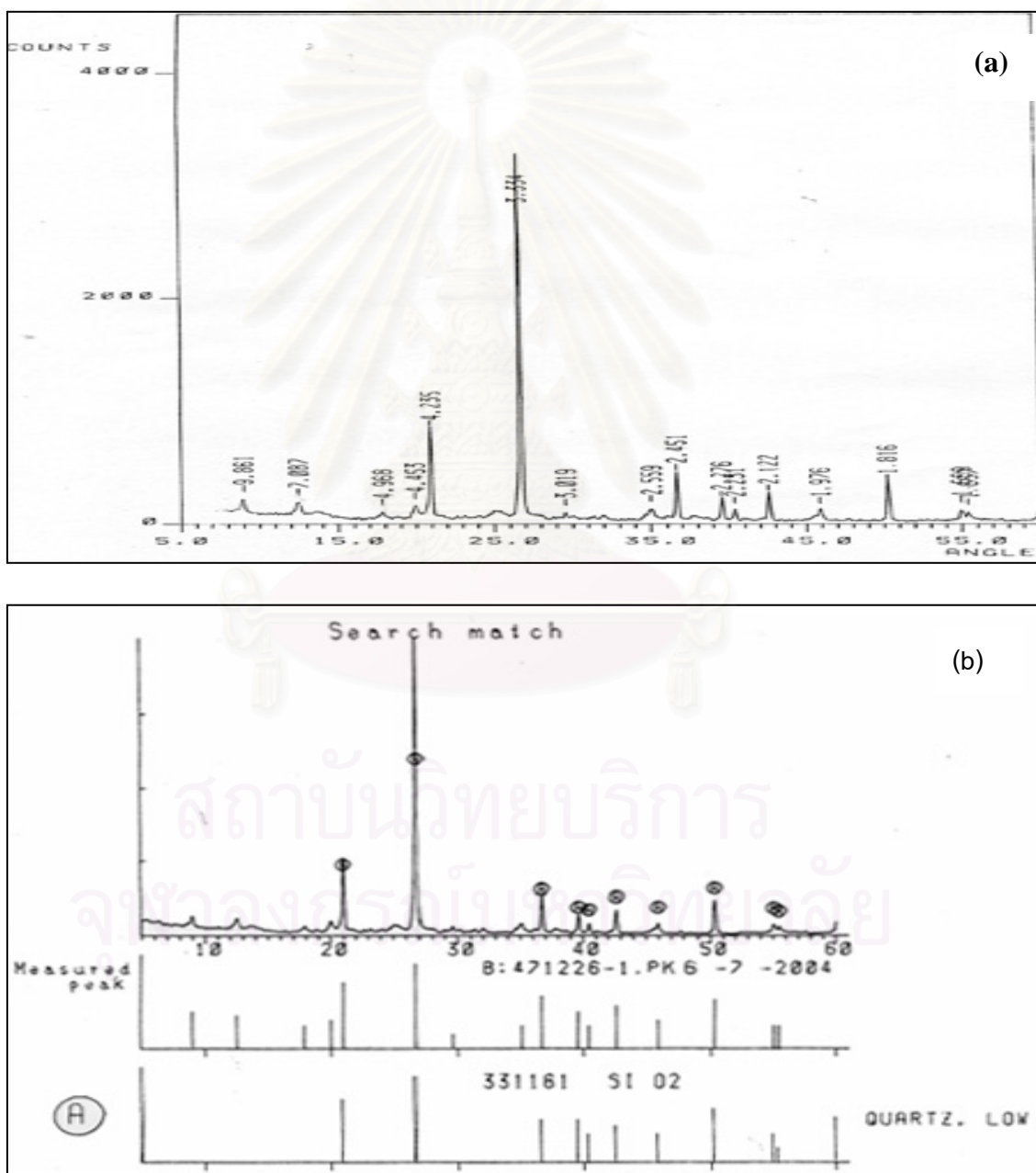
Figure 4.1 (a) XRD spectrum of the contaminated soil (b) Search and match results of the contaminated soil

4.1.9 Atterberg limits and indices

The Atterberg limit of soil describes a change from its solid state to fluid state or to its semi-solid state with a change in water content. Figure 4.2 shows a soil changing its state from solid state to fluid state with increasing water content. The shrinkage limit (SL) is defined as the water content at which a soil changes from a solid to a semi-solid. The plastic limit (PL) refers to the water content at which a soil changes from a semi-solid state to a plastic state to a fluid state. The plastic limit and liquid limit were mostly applied to classification of soil with regard to engineering properties.
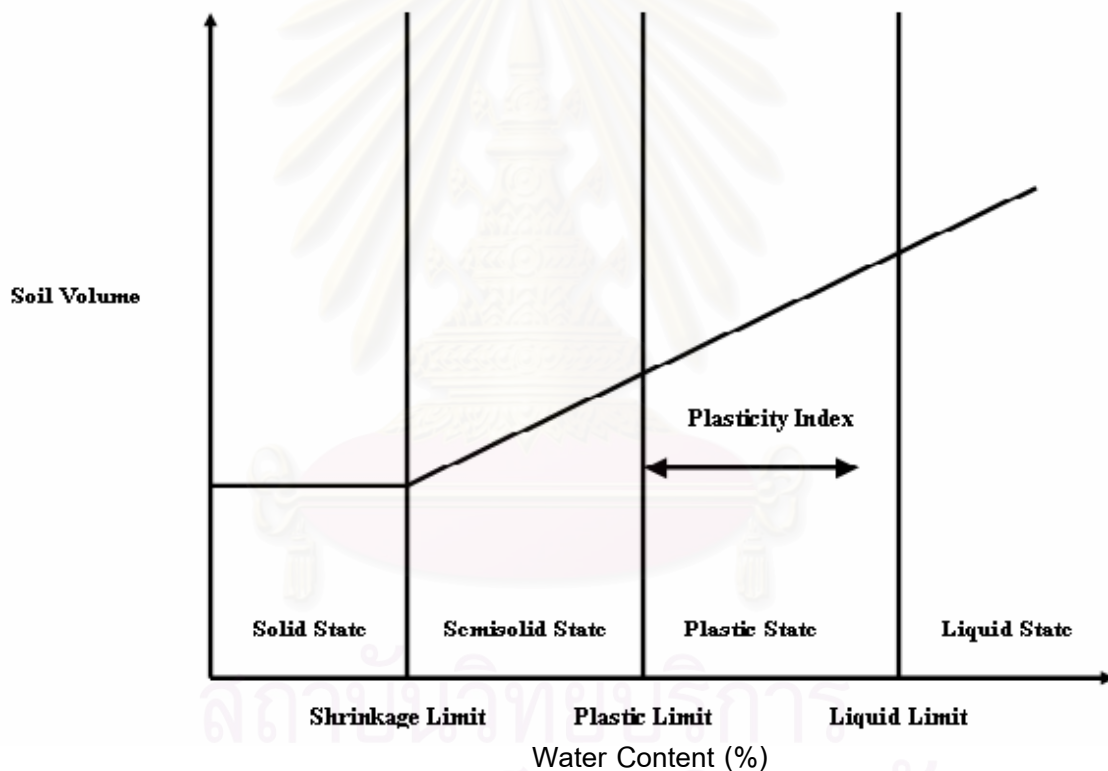
Figure 4.2 State of soil with increasing water content and Atterberg limits

Following the ASTM D 427-93 procedures, the plastic limit, liquid limit, and plastic index were analyzed and shown in Table 4.9. The results were then used to determine soil type of the contaminated soil according to ASTM D 2487.

Table 4.10 Atterberg limits and index of the contaminated soil

Atterberg limit and index	Contaminated soil (% water content)
Liquid Limit	28.91
Plastic Limit	14.21
Plastic Index	14.69

Figure 4.3 illustrates the classification of fine – grained soil using plasticity chart (ASTM D 2487). The result from Table 4.9 can be plotted in the CL area. It means that this soil may be categorized as low plastic inorganic clay such as sandy and silt clay.
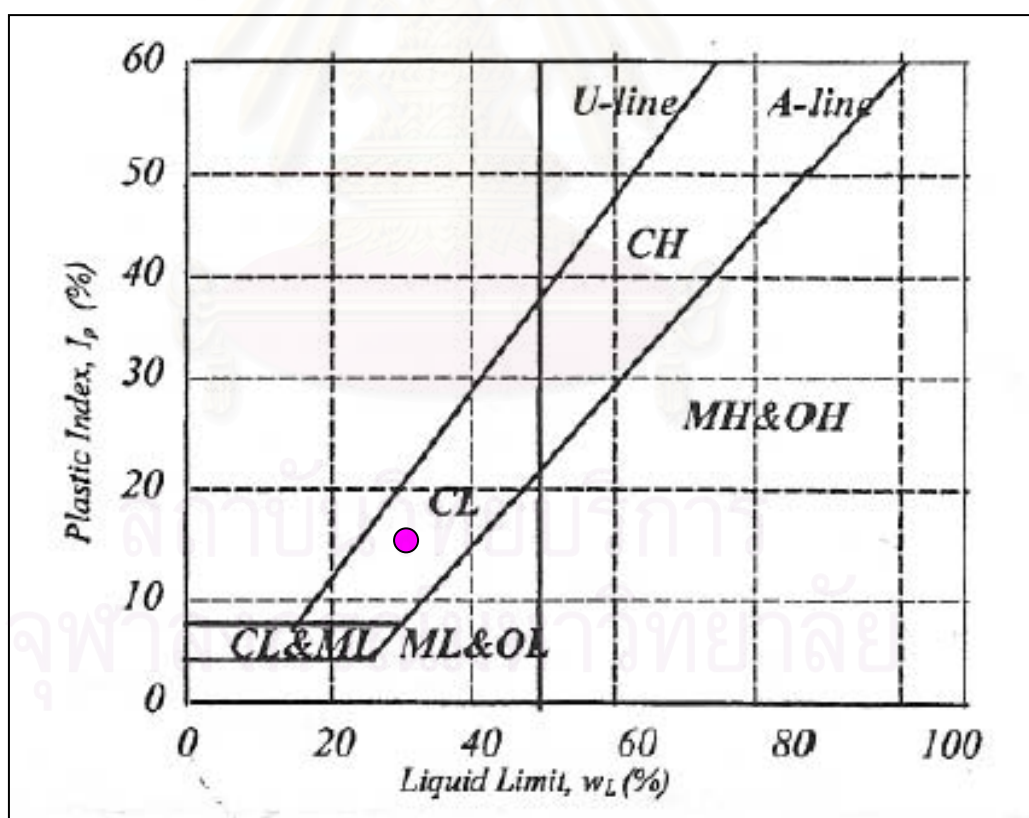
Figure 4.3 Classification the contaminated soil using plasticity chart (⬤) according to ASTM D 2487

4.1.10 Specific gravity

The specific gravity of the soil can be determined accurately in the laboratory. Most minerals have specific gravity values that fall within a general range of 2.6 to 2.9. According to ASTM D 854-92, it was found that the specific gravity of the contaminated soil is 2.68.

Table 4.11 Specific gravity of important minerals (Das, 2000)

Mineral	Specific Gravity, Gs
Quartz	2.65
Kaolinite	2.60
Illite	2.80
Montmorillonite	2.65-2.80
Halloysite	2.00-2.55
Potassium feldspar	2.57
Sodium and calcium feldspar	2.62-2.76
Chlorite	2.60-2.90
Biotite	2.80-3.20
Muscovite	2.76-3.10
Hornblende	3.00-3.47
Limonite	3.60-4.00
Olivine	3.27-3.37

4.1.11 Grain-size analysis

According to ASTM D 422-63, the soil sample can be described as follows:

- Gravel fraction (retained on No.4 Sieve) = 0%
- Sand Fraction (passing No.4 sieve but retained on No.200 sieve) = 31.24%
- Silt and clay (passing No.200 sieve) = 68.76%
- Liquid limit = 28.91
- Plasticity index = 14.69

From the above information, the soil sampled from the mine site can be classified by the Unified Classification System as a fine- grained soil. The group symbol is CL and the group name is sandy lean clayl.
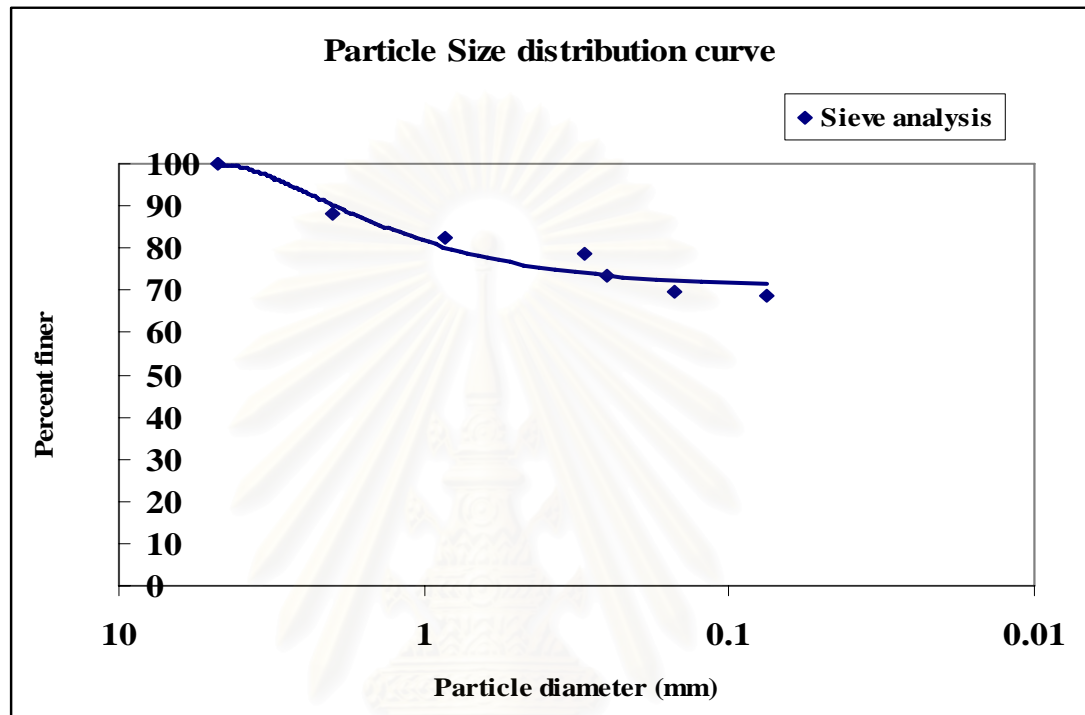
Figure 4.4 Particle size distribution of the soil

4.1.12 Compaction test

Compaction can be defined as the densification of an unsaturated soil by decreasing volume of voids filled with air. The advantages of compaction are that it generally improves soil properties by increasing shear strength and reducing compressibility. The compaction tests can be accomplished on both coarse- and fine-grained soils. The standard proctor test (ASTM D 698) provides a result in Figure 4.5 which depicts the relationship between the moisture content and the dry density of the contaminated soil. It can be determined from the graph that the optimum moisture content of contaminated soil is 9.5 % and maximum dry density of contaminated soil is 18.25 KN/m^3.
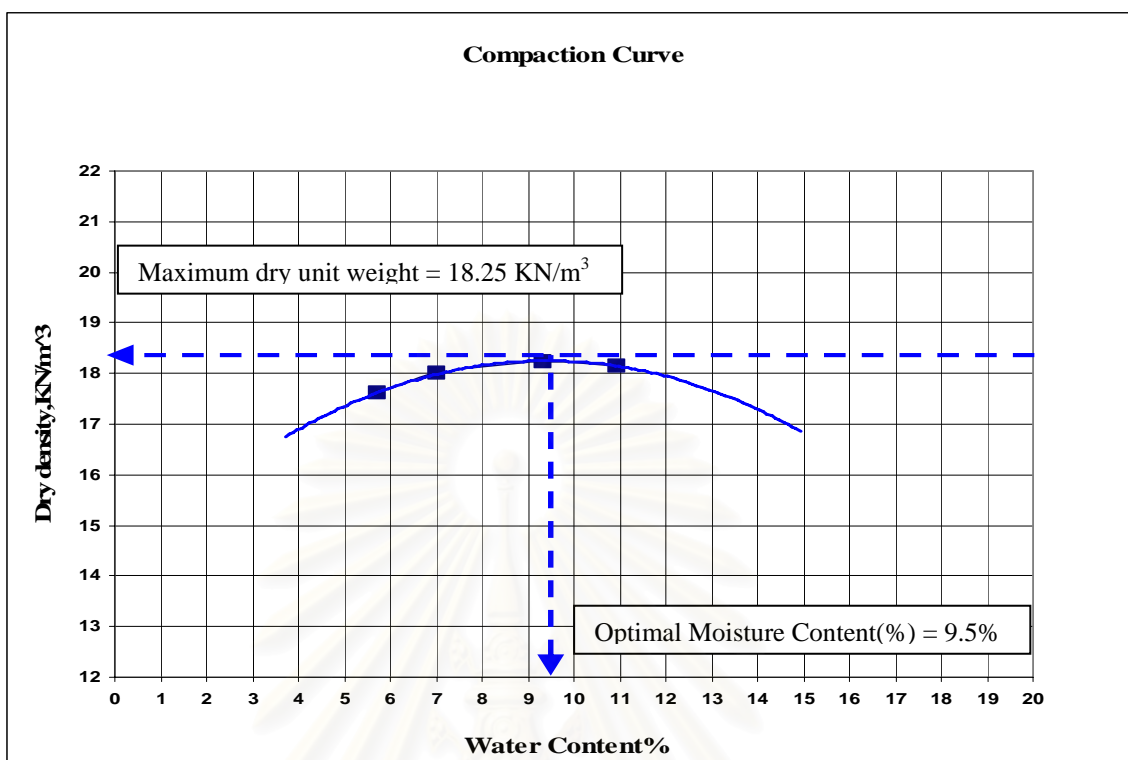
Figure 4.5 Compaction curve of soil

4.1.13 Unconfined compressive strength (UCS)

According to ASTM D 2166-91, the unconfined compressive strength of the contaminated soil is measured and the value is13.63 psi.

4.2 Properties of Municipal Solid Waste Fly Ash (MSWFA) and Cement Kiln Dust (CKD)

4.2.1 Particle Size Analysis

MSWFA and CKD which passed through a standard sieve No.200 (75-micron openings), was measured for particle size distribution using a laser diffraction particle size analyzer. Figure 4.6 shows the particle size distribution curves of municipal solid waste fly ash is similar to cement kiln dust and Portland cement.
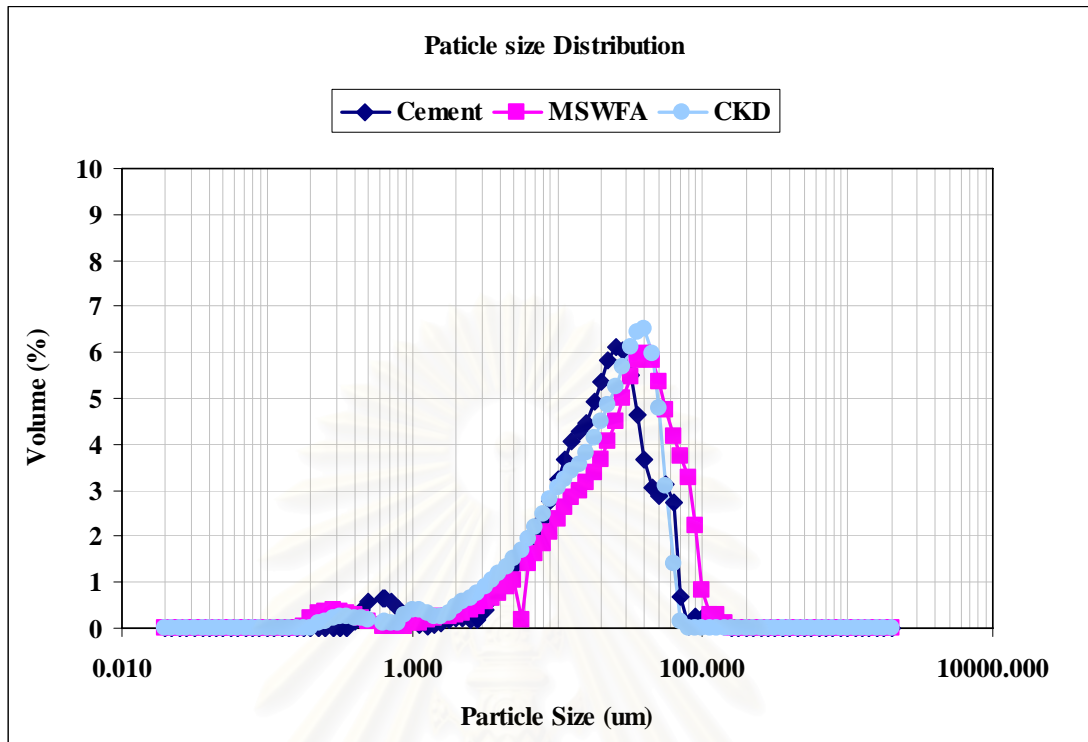
Figure 4.6 Particle size distribution curve of the cement, municipal solid waste fly ash and cement kiln dust.

4.2.2 Moisture Content and Loss on Ignition (LOI)

Moisture content of MSWFA and CKD generally depends on the way in which these raw materials are stored after leaving the plants. The moisture content of MSWFA collected directly from the ash pits is commonly low. On the other hand, fly ash taken from the landfill commonly has high moisture content. Phutket MSWFA is usually stored in fly ash pits and then dumped into an ash monofill near the incineration plant. CKD occurs during production of cement, where a small percentage of the materials in the form of dust are collected. The moisture content of MSWFA and CKD are shown in Table 4.11. It depicts that the moisture of MSWFA is similar to CKD and both have higher moisture content than that of Portland cement. However, it is still with in the limit of 3% required by ASTM C 618-95.

Loss on ignition is a determination of amount of organic matter, carbonates, and chlorides via ignition loss. This carbon is obligatory in evaluating the water

requirement for concrete. The amount of water needed to acquire a paste at normal consistency is higher when carbon in the ash increases. Deviation in carbon content in MSWFA and CKD may also lead to uncertain behavior with respect to air entrainment since some air entraining agents and other additives can be adsorbed by the porous carbon particles. Table 4.11 also reveals high LOI values of Phuket MSWFA and CKD. The massive amounts of lime and chloride from the flue gas treatment system for MSWFA increases the LOI of MSWFA. According to ASTM C 618 specification for fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete, the LOI of Phuket MSWFA exceeds the 6% limit for both Class-C and Class-F pozzolans.

Table 4.12 Properties of MSWFA and CKD

Sample	Moisture Content (%)	LOI	pH	Specific Gravity, Gs
MSWFA	1.29	9.70	12.8	2.57
CKD	1.27	1.71	12.0	3.76
Cement	0.67	1.12	11.7	3.14

4.2.3 Bulk chemical compositions

The chemical composition of soil, MSWFA, and CKD were determined by X-ray fluorescence (XRF) spectroscopy. All elemental compositions of these materials were reported in oxide forms. It was found that the chemical composition of CKD contains mainly CaO, SiO_2, Al_2O_3, Fe_2O_3 and MgO, respectively. The chemical composition of MSWFA contains mostly CaO, Cl, K_2O, SO_3, Na_2O and SiO_2 Moreover, the hydration moduli are given to indicate intrinsic cementitious properties of the products.

Table 4.13 Bulk chemical composition results

Concentrations,%	Cement	MSWFA	CKD
Na_2O	0.15	5.67	0.12
MgO	1.63	1.69	1.60
Al_2O_3	3.44	2.10	4.96
SiO_2	17.76	4.01	13.09
P_2O_5	0.08	1.75	0.09
SO_3	5.37	5.70	0.21
K_2O	0.81	8.00	0.90
CaO	65.87	35.01	72.35
TiO_2	0.25	0.68	0.32
Cr_2O_3	ND	0.02	ND
MnO	0.04	0.05	0.07
Fe_2O_3	3.44	1.04	4.35
SrO	0.04	0.05	0.04
Cl	ND	24.41	0.30
Br	ND	0.05	ND
SnO_2	ND	0.09	ND
Hydration modulus	2.72	5.17	3.23
LOI	1.12	9.70	1.71

Note: Hydration modulus   = CaO / $(Al_2O_3+SiO_2+Fe_2O_3)$ and ND = Not Detected

4.2.4 Mineralogical composition

The major crystalline phases of cement kiln dust (CKD) are Calcite ($CaCO_3$), and quartz (SiO_2). Several components in the crystalline phase of municipal solid waste fly ash (MSWFA) consist of KNa_8Cl_2, Na_2O, Tilleyite ($Ca_5Si_2O_7(CO_3)_2$), Chlorapatite ($Ca_5(PO_4)_3Cl$), and Aragonite ($CaCO_3$). The physical and chemical properties of MSW and CKD can vary from plant to plant, depending on the composition of raw materials employed, burning conditions, and type of dust collection process in the plant.
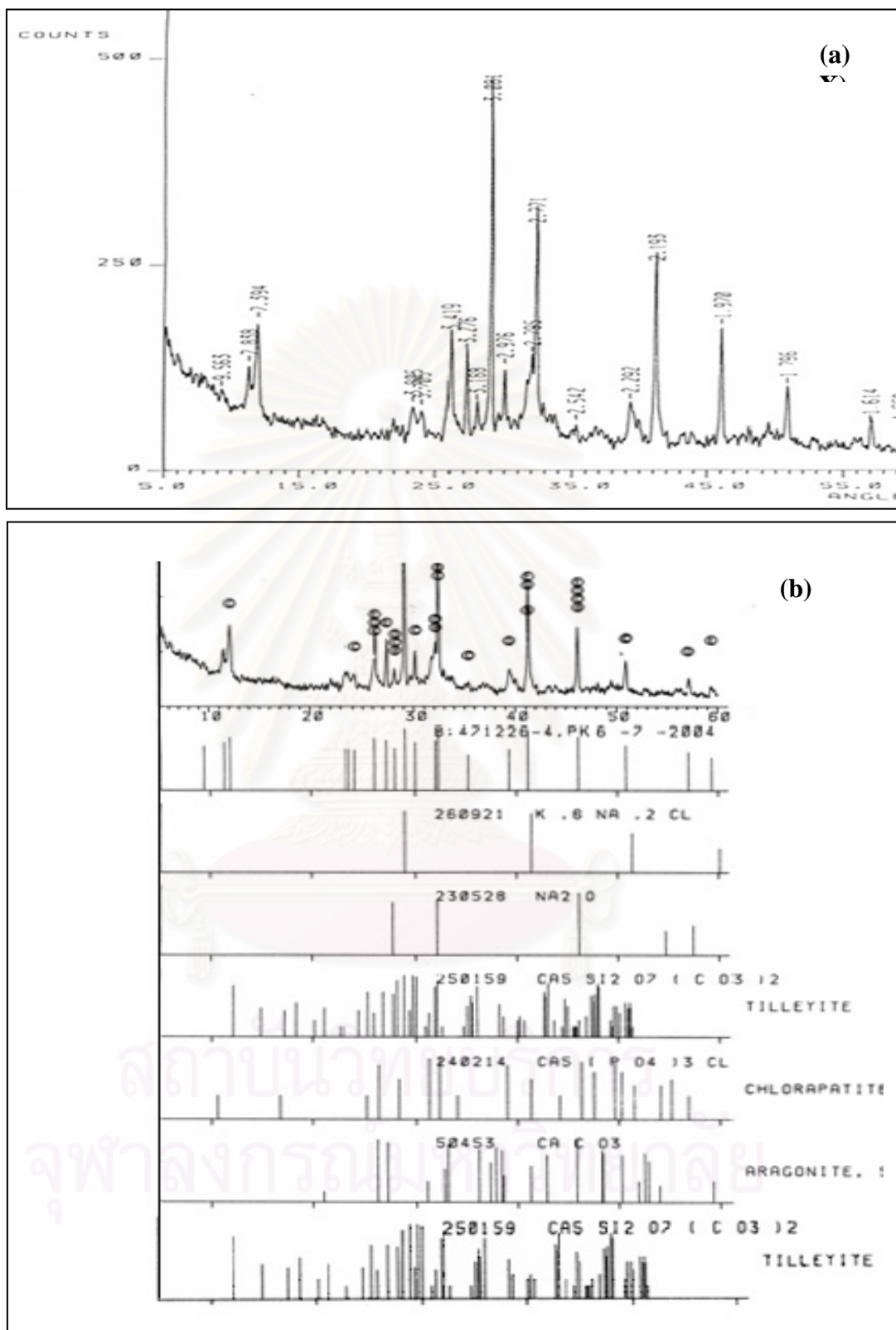
Figure 4.7 (a) XRD spectrum of MSWFA (b) Search and match of MSWFA
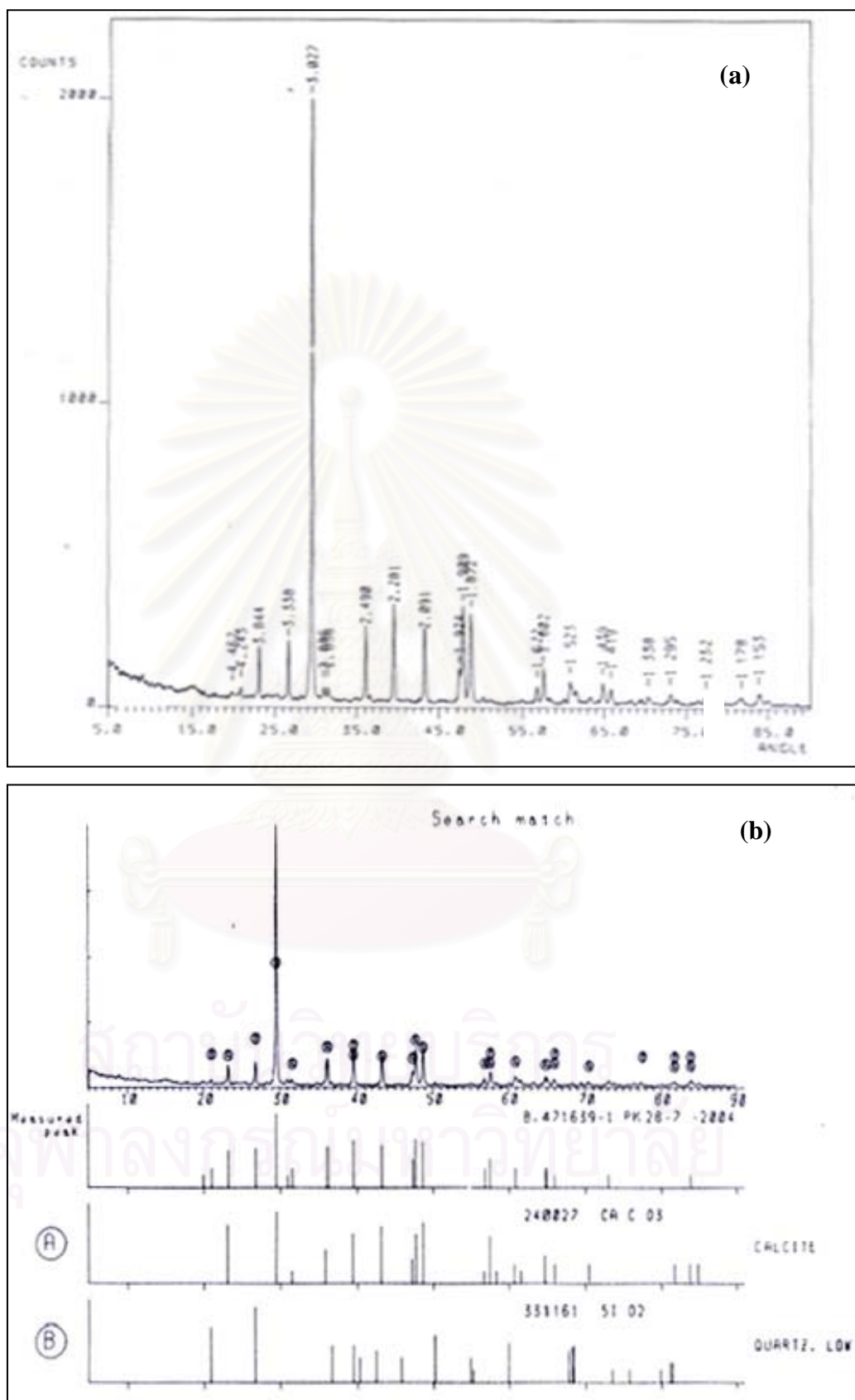
Figure 4.8 (a) XRD spectrum of CKD (b) Search and match result of CKD

4.2.5 Heavy metals

By EPA method 3052 together with ICP-OES analysis, the concentrations of heavy metals of MSWFA and CKD were determined and shown in Table 4.13 below. The results also show the total concentrations of heavy metals in MSWFA and CKD for comparison. The results show that the major heavy metals of MSWFA are Al, Fe, Mn, and Zn, while the concentrations of heavy metals in CKD are Al, Cu, Fe, Mn, and Pb.

Table 4.14 Concentrations of iron and manganese in the background and the contaminated soil

Concentration of heavy metals (mg/kg)	Raw Materials	
	Municipal solid waste fly ash (MSWFA)	Cement kiln dust (CKD)
Ag	5.43	18.26
Al	32669.00	24347.00
Cu	30.14	644.20
Fe	41041.00	18198.00
Mn	715.86	1284.40
Ni	56.51	73.12
Pb	22.56	3956.90
Zn	232.39	11351.00

4.2.6 Leaching Test

According to the leaching procedure described in the 6th Notification of Ministry of Industry, B.E. 2540 (1997), the results of leaching of MSWFA and CKD are evaluated and shown in Table 4.14 below. The analytical results of leaching test following the 6th Notification of Ministry of Industry was compared Guidelines for Drinking-water Quality of the WHO.

Table 4.15 Leaching test results of MSWFA and CKD

Heavy metals	Concentration of heavy metal in MSWFA (mg/kg Soil)	Concentration of heavy metal in CKD (mg/kg Soil)	Guideline Value(a)	100 times of Guideline Value
Cu	4.50	2.88	2	200
Fe	4.11	29.01	0.3	30
Mn	0.28	0.256	0.5[b] /0.1[c]	50[b] /10[c]
Pb	2.67	2.98	0.01	1

Note: [a] Guidelines for Drinking-water Quality of WHO [b] Health Significant [c] Objectionable to consume

4.2.7 Specific gravity

The specific gravity of the soil can be determined accurately in the laboratory. Most of the minerals have specific gravities that fall within a general range of 2.6 to 2.9. According to ASTM D 854-92, the results of are shown in Table 4.11.

4.3 Improvement of Engineering Properties

ASTM D 4609 Standard guide for evaluating effectiveness of chemicals for soil stabilization is intended to assist users and producers of chemicals, soil modifiers, and stabilizers in the evaluation of a product's potential for improving a soil's engineering properties. Chemical soil stabilizers are screened by comparing the results of suite of engineering soil tests conducted on untreated soil and the same soil treated at appropriate amounts of the material being evaluated. Effectiveness is assessed by comparing the Atterberg limits, optimum moisture content, maximum dry density, and unconfined compressive strength. The results of these tests can be used to

make a decision to continue experimentation to assess longevity, durability, and practical value and, establish appropriate rates of application for field trials.

4.3.1 Optimum moisture Content and Maximum dry density

In ASTM D 4609, optimum moisture content (OMC) and maximum dry density (γ_{dry}) were evaluated and employed to find the amount of water and volume of soil. It used ASTM D 698 Test methods for moisture-density relationship of soils and soil-aggregate mixture using 5.5-lb (2.49kg) rammer and 12-in. (305-mm) drop to find optimum moisture content and maximum dry density. Then, the results from the compaction test are used for preparing the soil specimens for testing unconfined compressive strength, the Atterberg limits and indices.

According to ASTM D 4609, improving soil compactability, that is, reducing the optimum moisture content or increasing the maximum dry density, is often of engineering significance. Lowering the optimum moisture content would be considered beneficial because frequently water must be purchased, or in any event transported, and distributed on the soil, requiring the use of motor fuel and time. An increasing in maximum dry density would indicate that an increase in strength was afforded by chemical treatment or that a target density could be achieved with less compactive effort. The change in optimum moisture content of grater than about 15 % from the optimum for the untreated soil must be interpreted as a result of chemical treatment.

Table 4.16 OMC and maximum dry density results

Sample Ratio	Required OMC (%) (ASTM D 4609)	OMC (%)	Dry Density (KN/m^3)
Ratio 1 (Control)	< 15	9.50	18.25
Ratio 2 (5%CKD)	< 15	13.00	18.50
Ratio 3 (10%CKD)	< 15	11.00	18.64
Ratio 4 (15%CKD)	< 15	11.00	18.50
Ratio 5 (5% MSWFA)	< 15	13.00	18.03
Ratio 6 (10%MSWFA)	< 15	14.00	18.11
Ratio 7 (15%MSWFA)	< 15	13.00	17.98
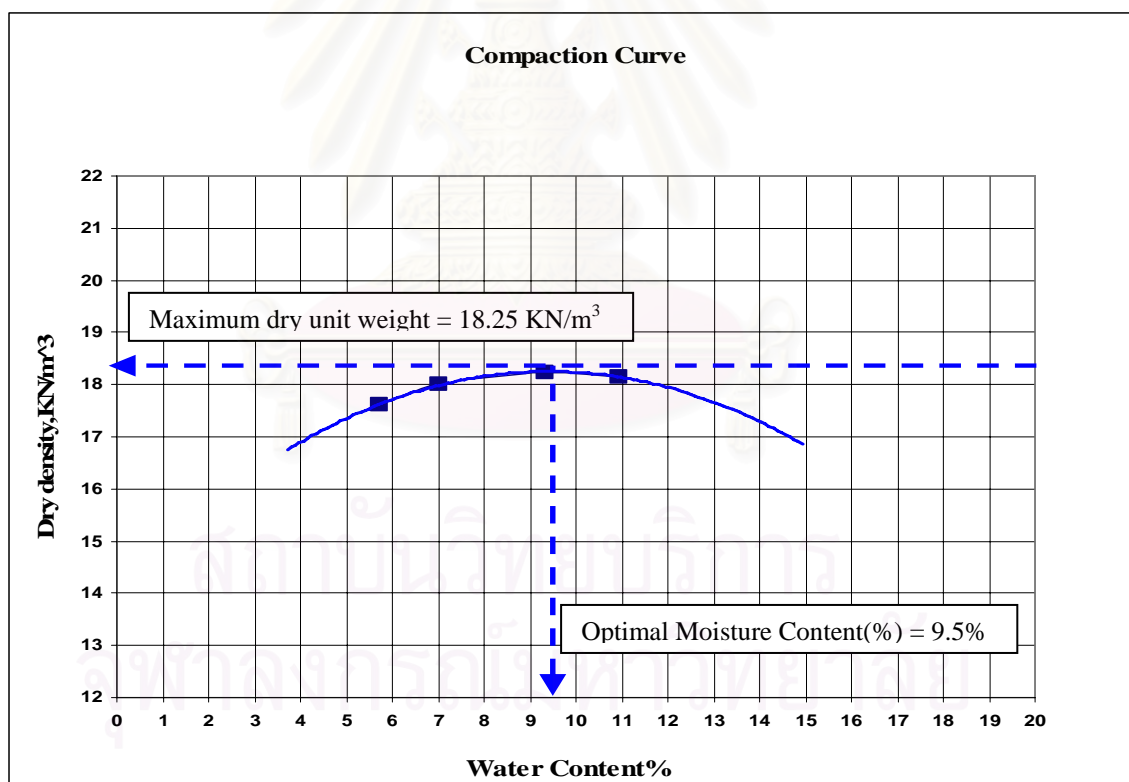
Figure 4.9 Compaction curve of soil
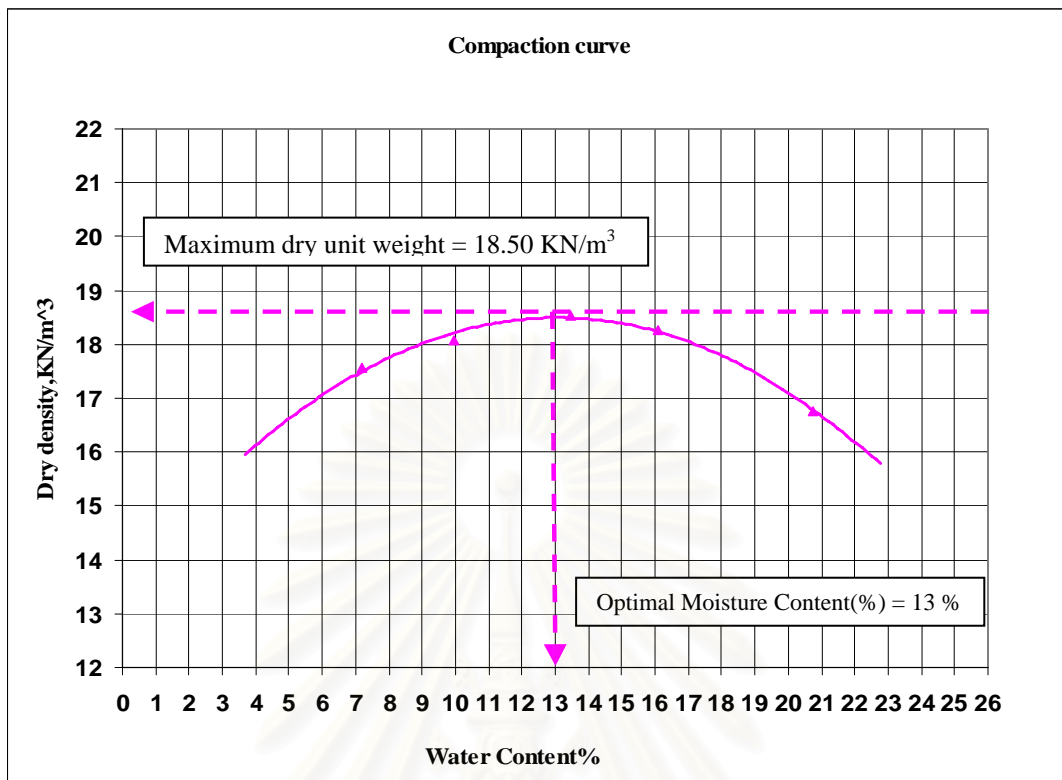
Figure 4.10 Compaction curve of 5%CKD
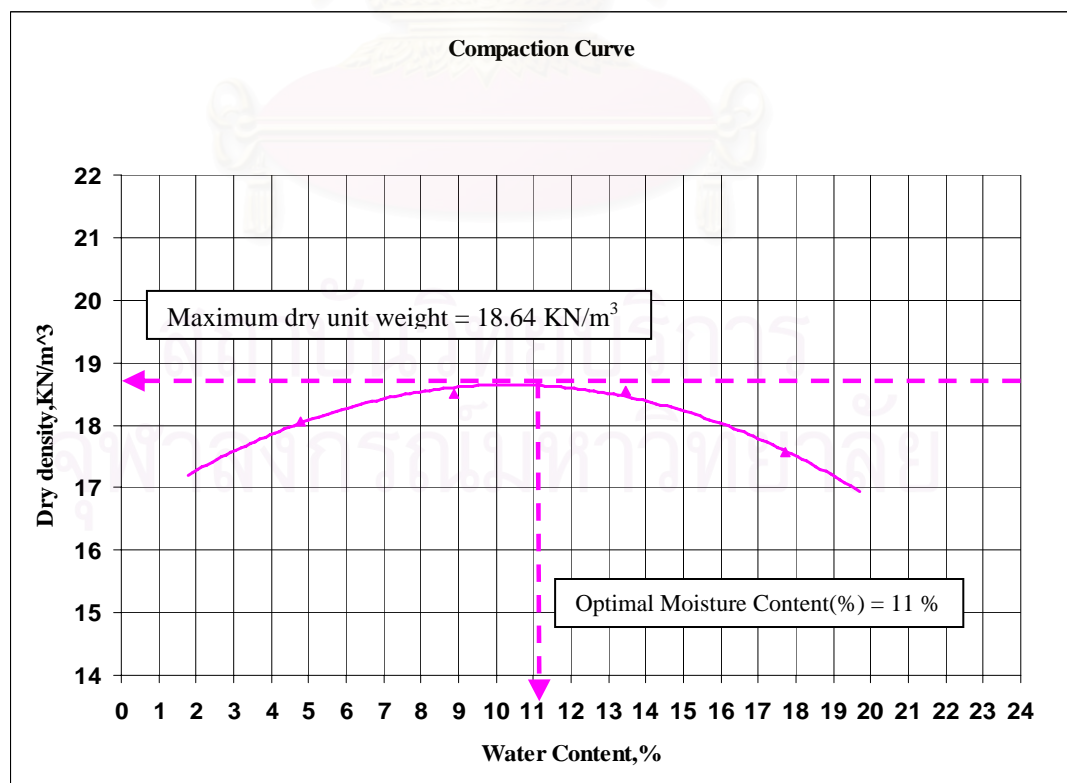
Figure 4.11 Compaction curve of 10%CKD
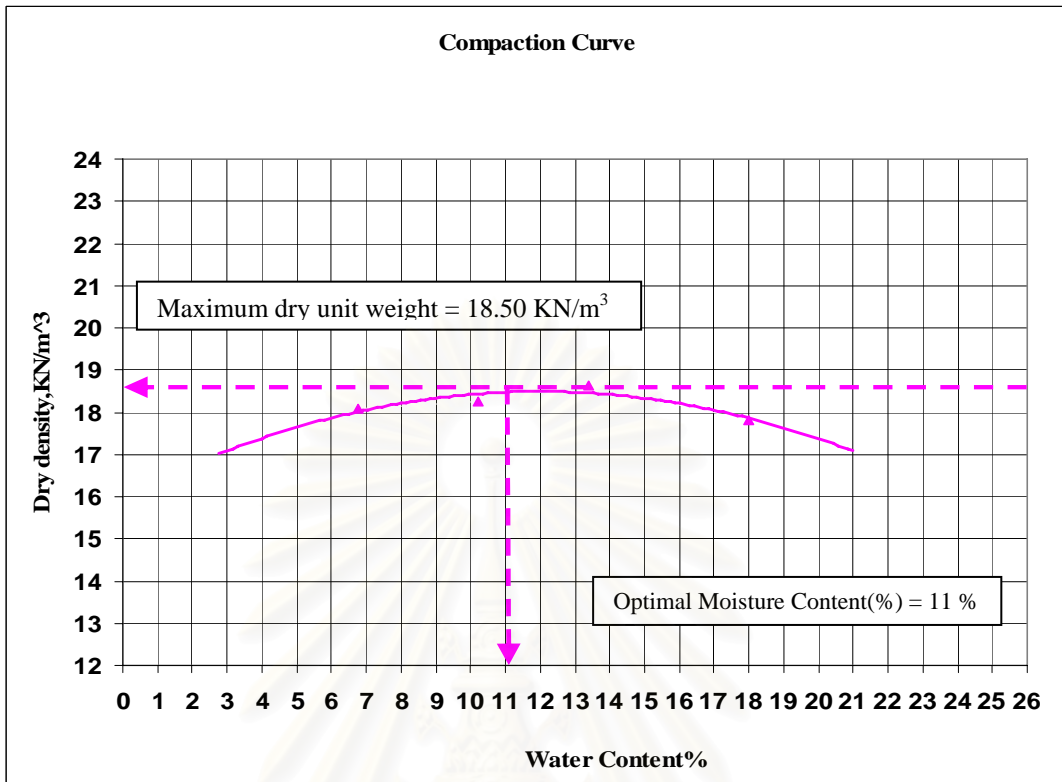
Figure 4.12 Compaction curve of 15%CKD
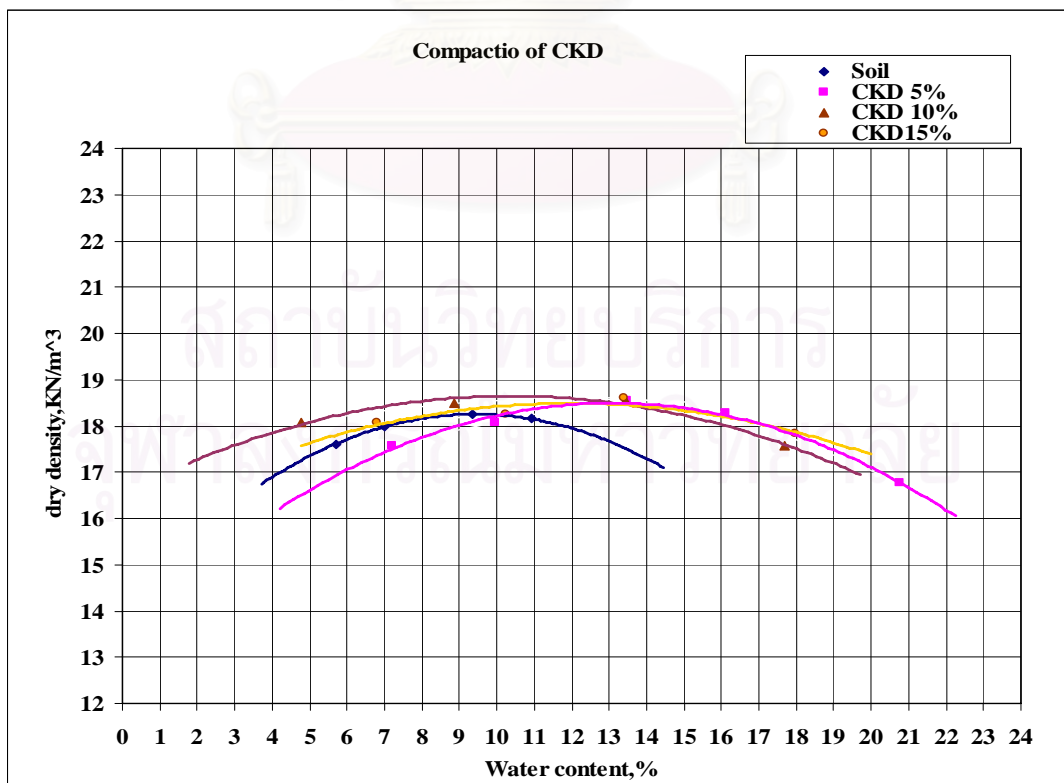
Figure 4.13 Comparison of compaction curve between soil and all of CKD
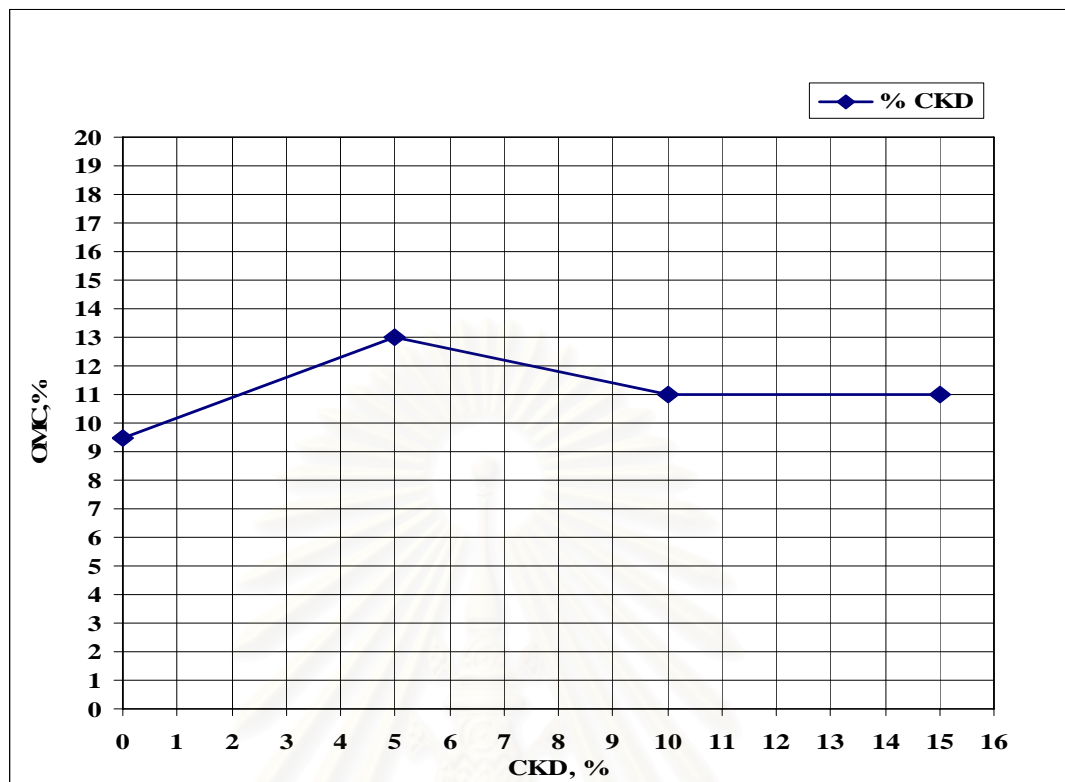
Figure 4.14 Optimum moisture content vs. CKD content for contaminated soil
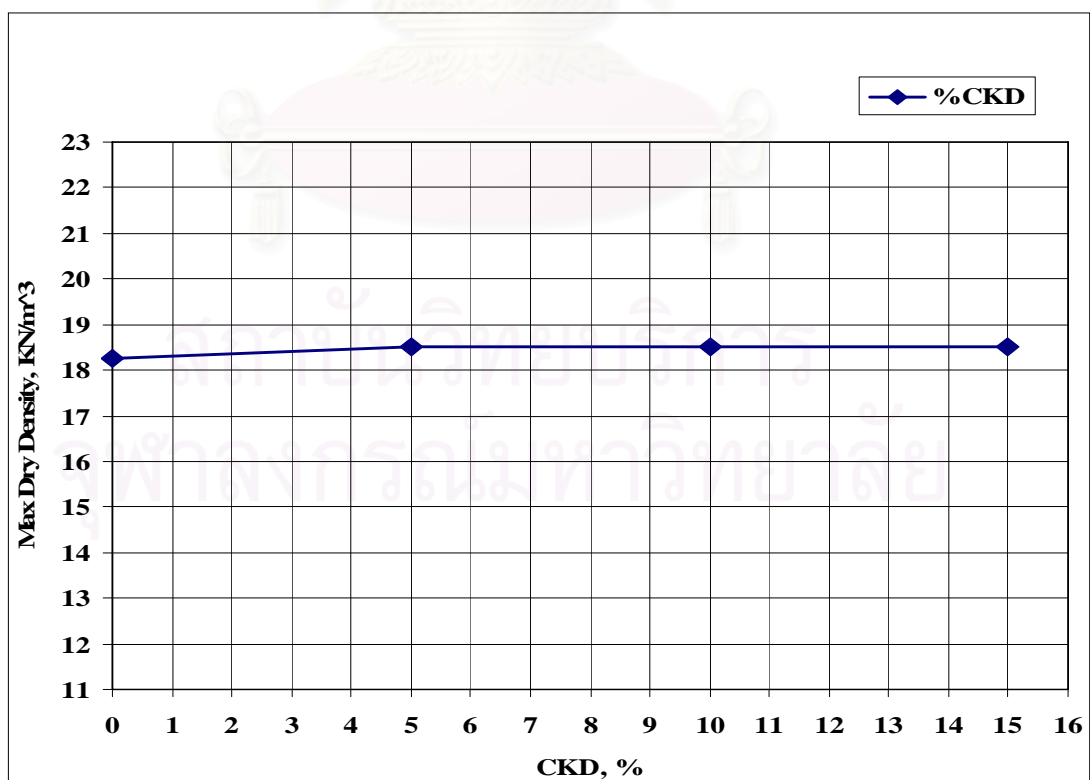
Figure 4.15 Maximum dry density vs. CKD content for contaminated soil
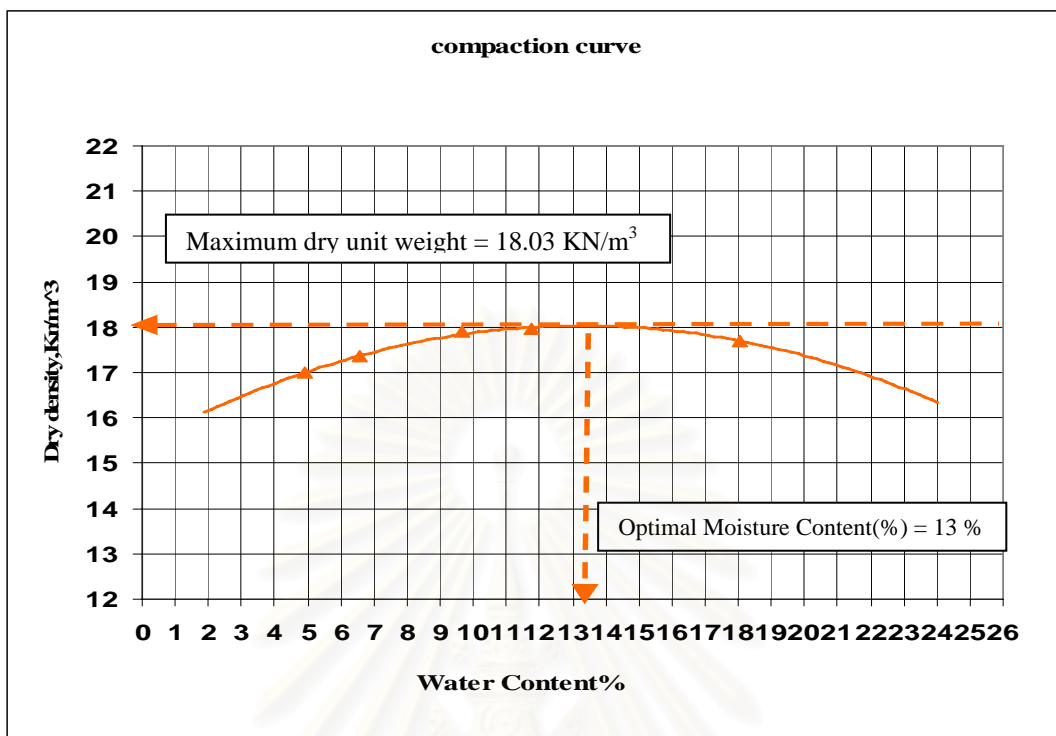
Figure 4.16 Compaction curve of 5%MSWFA
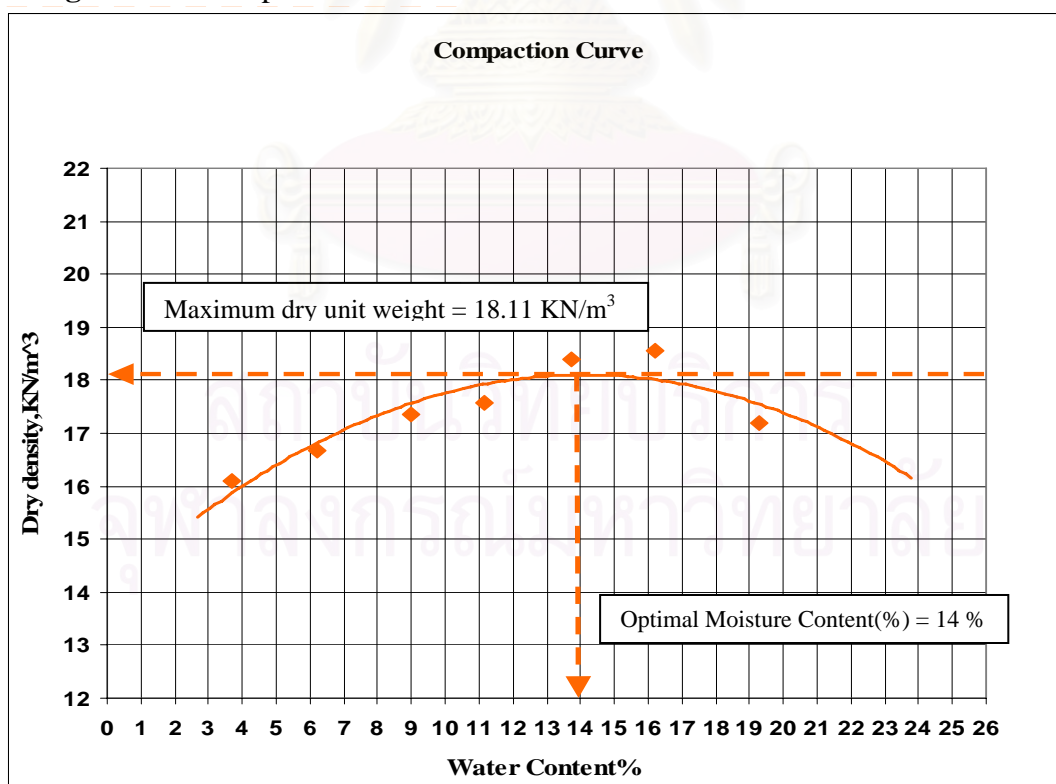
Figure 4.17 Compaction curve of 10%MSWFA
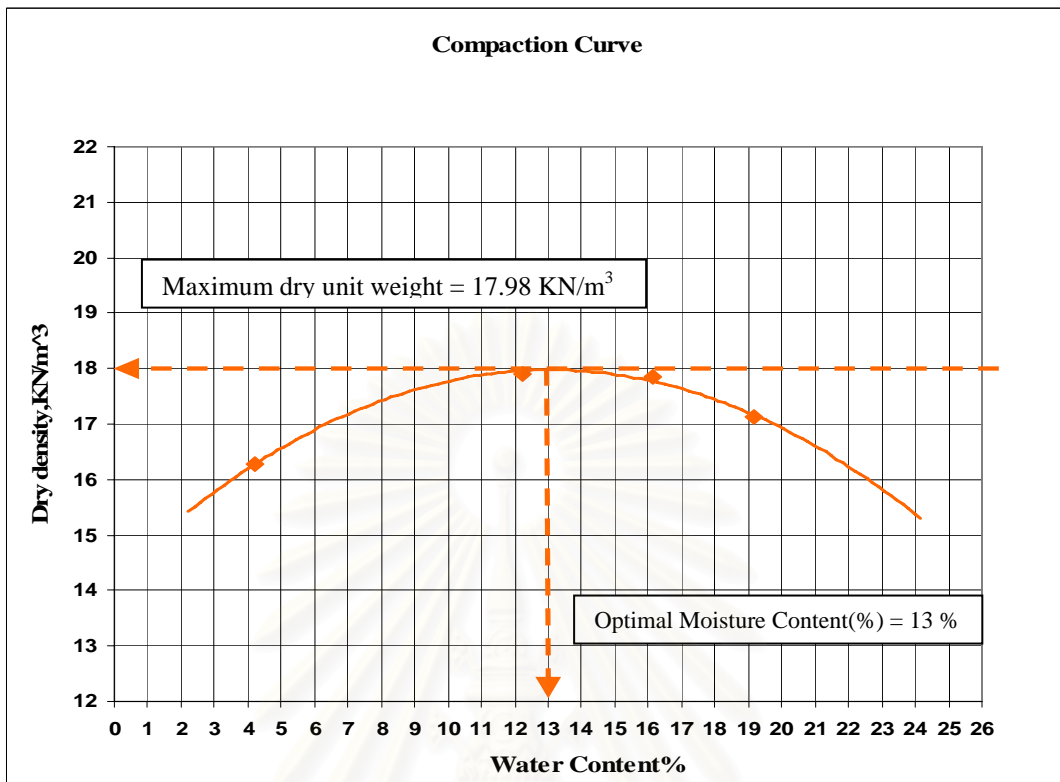
Figure 4.18 Compaction curve of 15%MSWFA
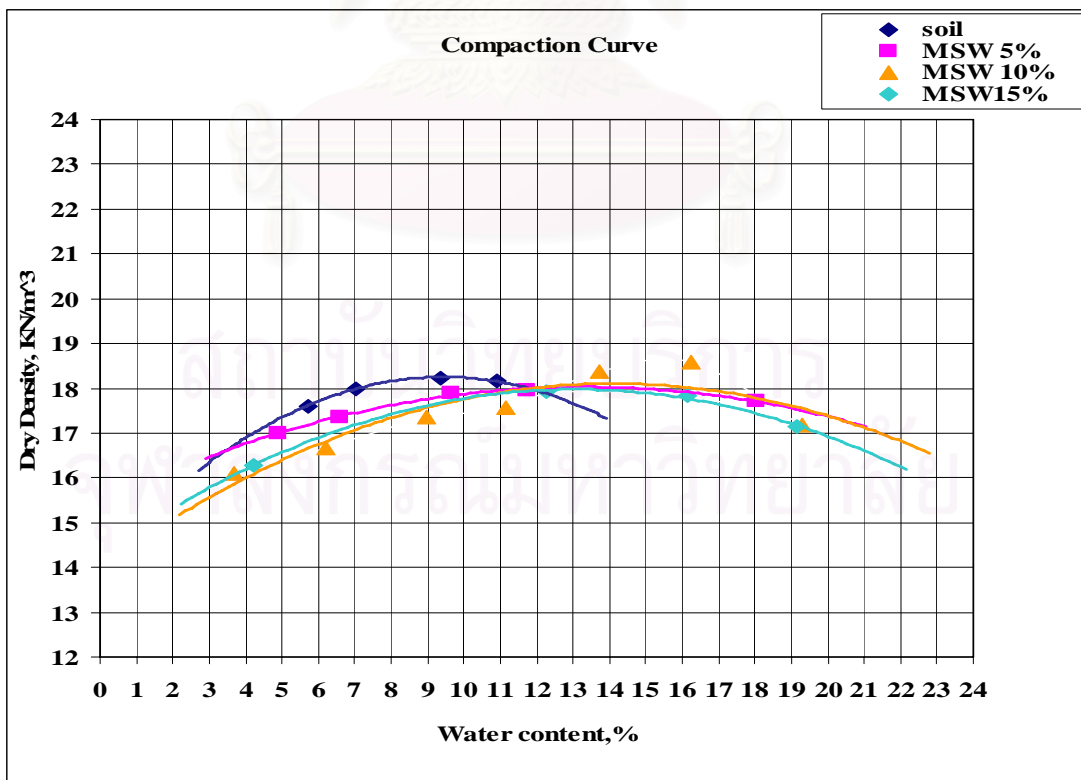
Figure 4.19 Comparison of compaction curves between soil and all of MSWFA
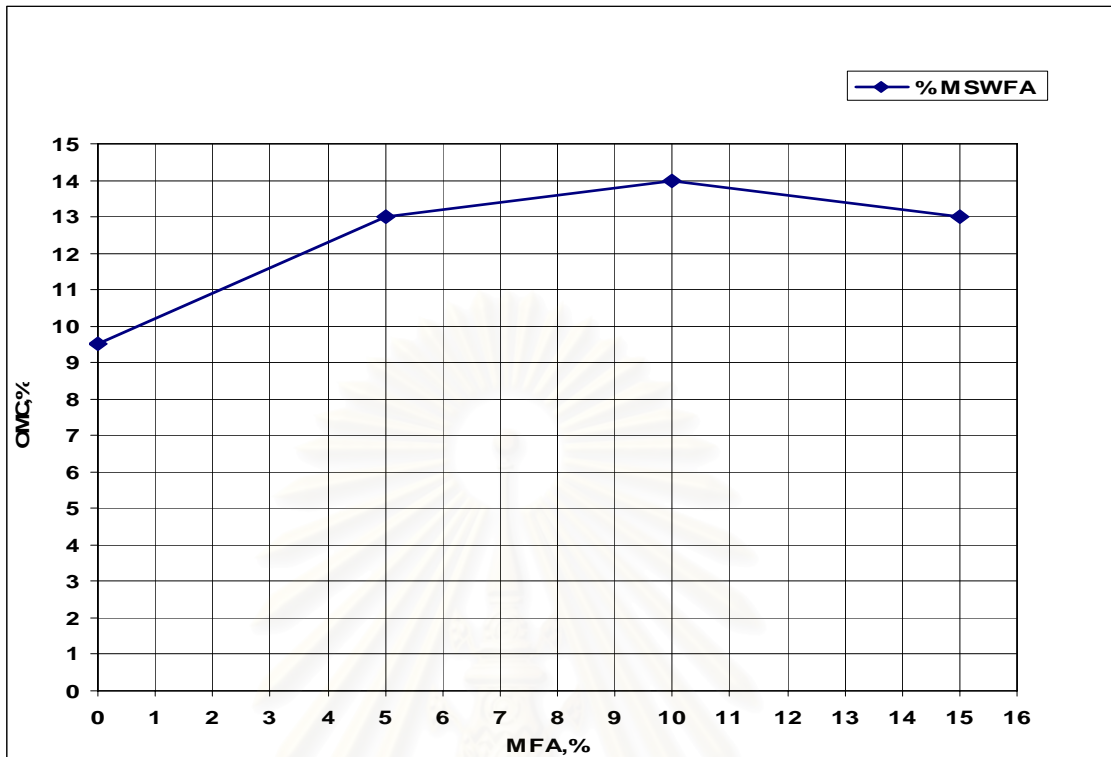
Figure 4.20 Optimum moisture content vs. MSWFA content for contaminated soil
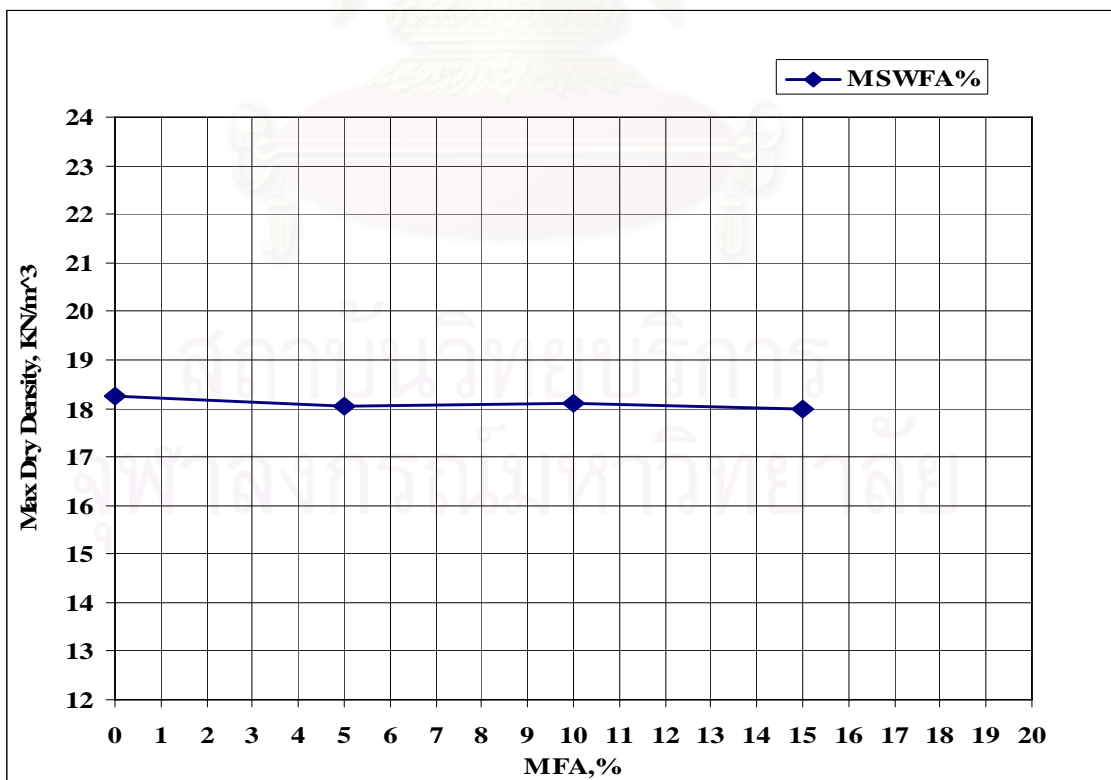
Figure 4.21 Maximum dry densities vs. MSWFA content for contaminated soil

In Figures 4.14 and 4.15, the optimum moisture content and maximum dry density were compared with the amount of CKD. In addition, the bell-shape compaction curve is common in most clayey soils. It was found that an increase in OMC and an increase in the dry unit weight occurred as the CKD content increased. On the other hand, Baghdahi (1995) evaluated that CKD added to pure kaolinite increased maximum dry density and reduced the OMC slightly. Others have indicated effects similar to the current study (Fatani and Khan, 1990:39-37). The effects of CKD on dry density and OMC are a function of the soil and CKD type as well as the process of compaction. According to this study, the increase in OMC apparently resulted from the affinity of CKD for water, and maximum dry density increased because of the aggregation of particles due to CKD results in small macropores within the soil.

As a result, Figures 4.20 and 4.21, optimum moisture content and maximum dry density are compared with the amount of MSWFA content. It was found that an increase in OMC and a decrease in maximum dry density occurred as the MSWFA content increased The shape of the compaction curve is similar to that of pure soil. The decreased maximum moisture content and increased optimum moisture content occurred as the fly ash content increased. Moreover, the maximum dry density decreased when water content went up to the point of optimum moisture content beyond which the increase in water content reduced further maximum dry density (Bahar, Benazzoug and Kenai, 2004).

Furthermore, the decrease of the maximum dry density with an increase of the moisture content can be ascribed to the capillary tension effect. At lower moisture content, the capillary tension in the pore water restrains the tendency of the soil particles to move around and be densely compacted (Das, 1999: 56-57).

According to ASTM D 4609, if soil compactability is to be improved the recipe that has lowest OMC or highest maximum dry density is should consider. An increase in maximum dry density should increase unconfined compressive strength. Moreover, it was ascertained that the samples with moisture content close to their optimum moisture content had higher unconfined compressive strengths than the others. Thus, in order to get higher strength, the contaminated soil sample should be

taken when the water content is close to the optimum moisture content and maximum dry density.

4.3.2 Atterberg Limits and Indices

According to ASTM D 4609, significant reduction of liquid limit and plasticity index is indicative of improvement. Liquid and plastic limit tests were conducted in accordance with ASTM D 4318. The results of the Atterberg limit test are shown in Table 4.16 and Figure 4.22 -4.27.

Table 4.17 Atterberg limit and indices results.

Sample Ratio	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)
Ratio 1 (Control)	26.23	14.97	11.26
Ratio 2 (5%CKD)	30.18	16.54	12.65
Ratio 3 (10%CKD)	28.81	19.78	10.25
Ratio 4 (15%CKD)	29.19	19.93	9.03
Ratio 5 (5%MSWFA)	26.49	16.54	10.70
Ratio 6 (10%MSWFA)	26.09	18.01	9.96
Ratio 7 (15%MSWFA)	29.73	19.03	8.08
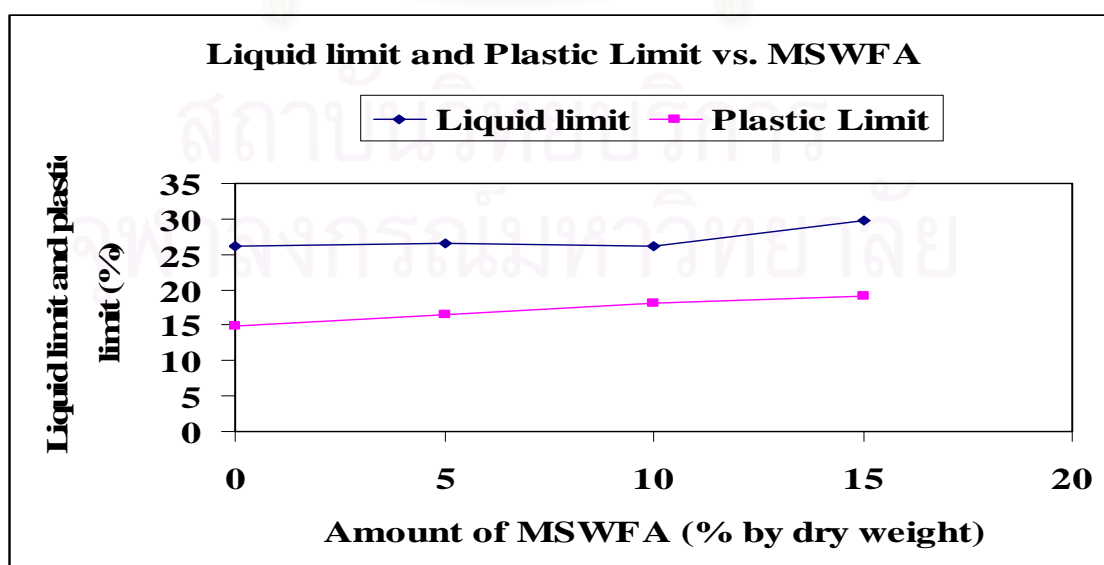
Figure 4.22 Liquid limit and plastic limit vs. the MSWFA content
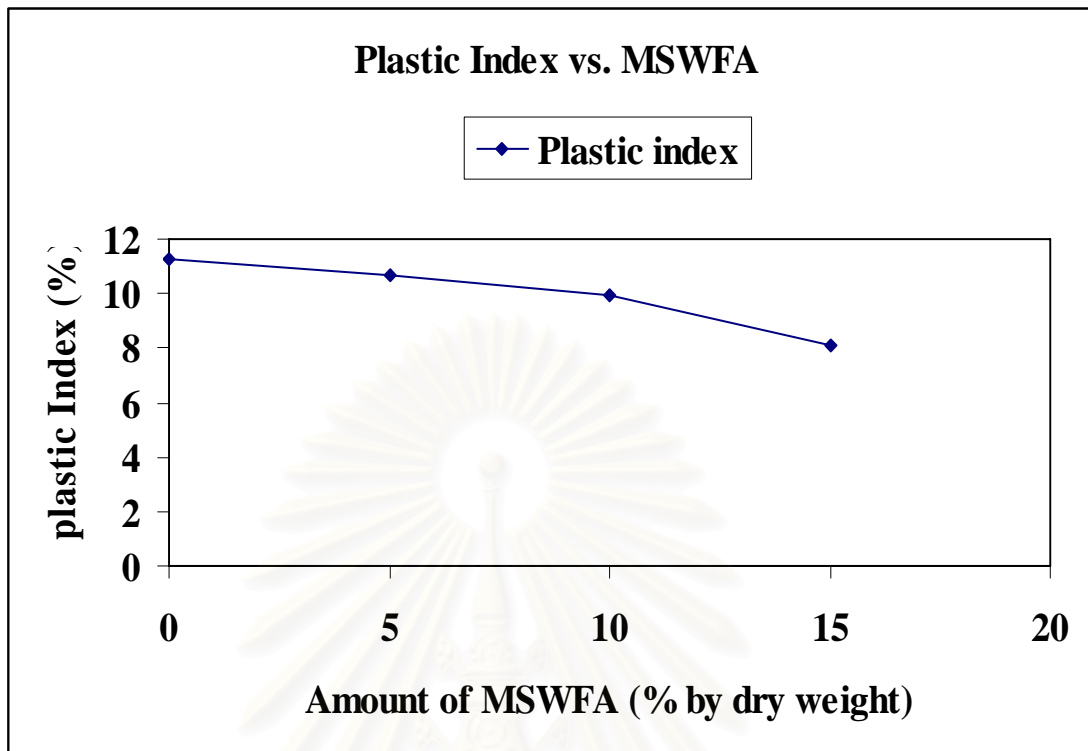
Figure 4.23 plastic indexes vs. the MSWFA content
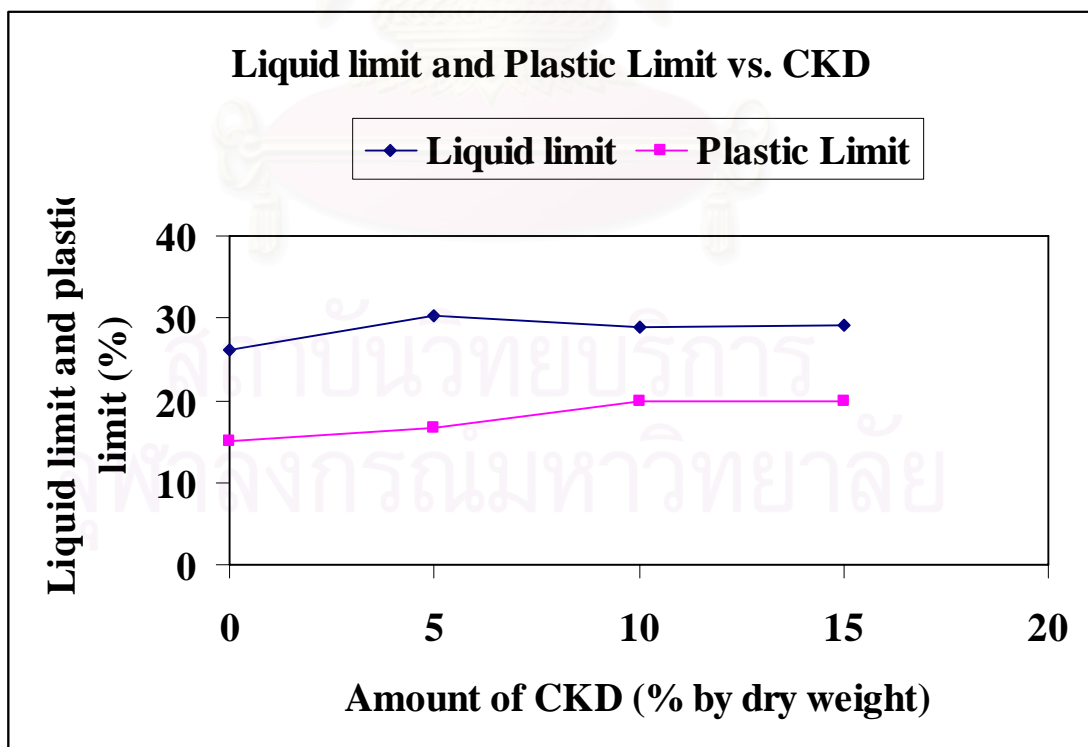
Figure 4.24 Liquid limit and plastic limit vs. the CKD content
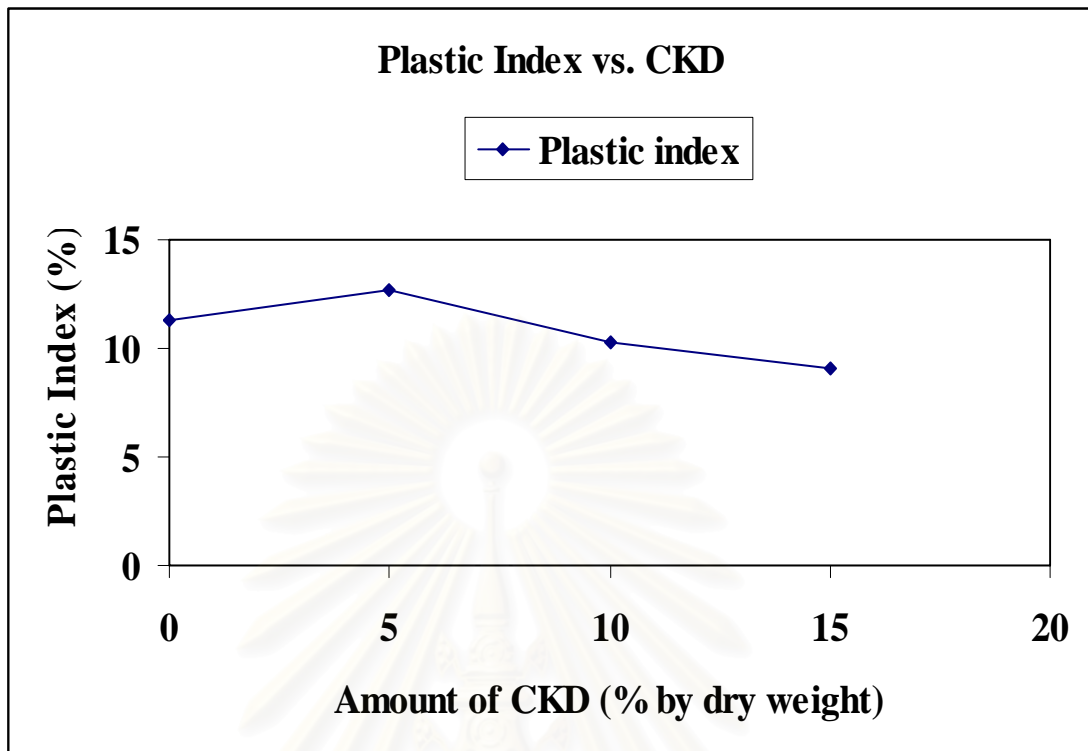
Figure 4.25 Plastic indexes vs. the CKD content
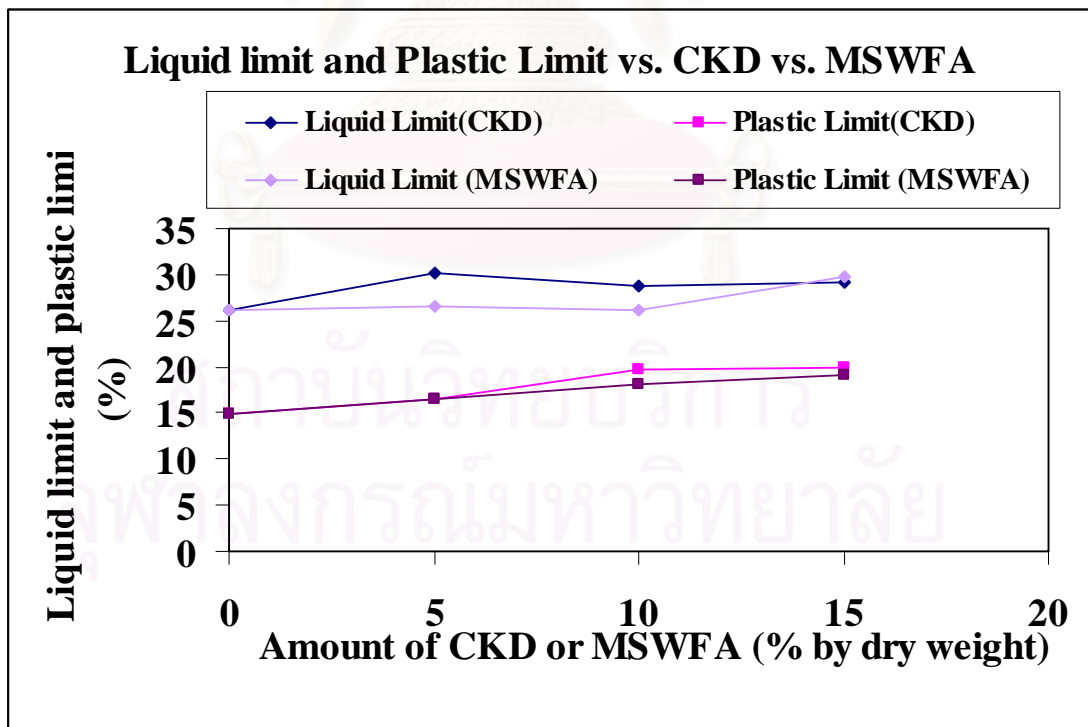
Figure 4.26 Liquid limit and plastic limit vs. the CKD and MSWFA content**s**

Plastic Index vs. CKD vs. MSWFA

◆ **Plastic index (CKD)**   ■ **Plastic index (MSWFA)**
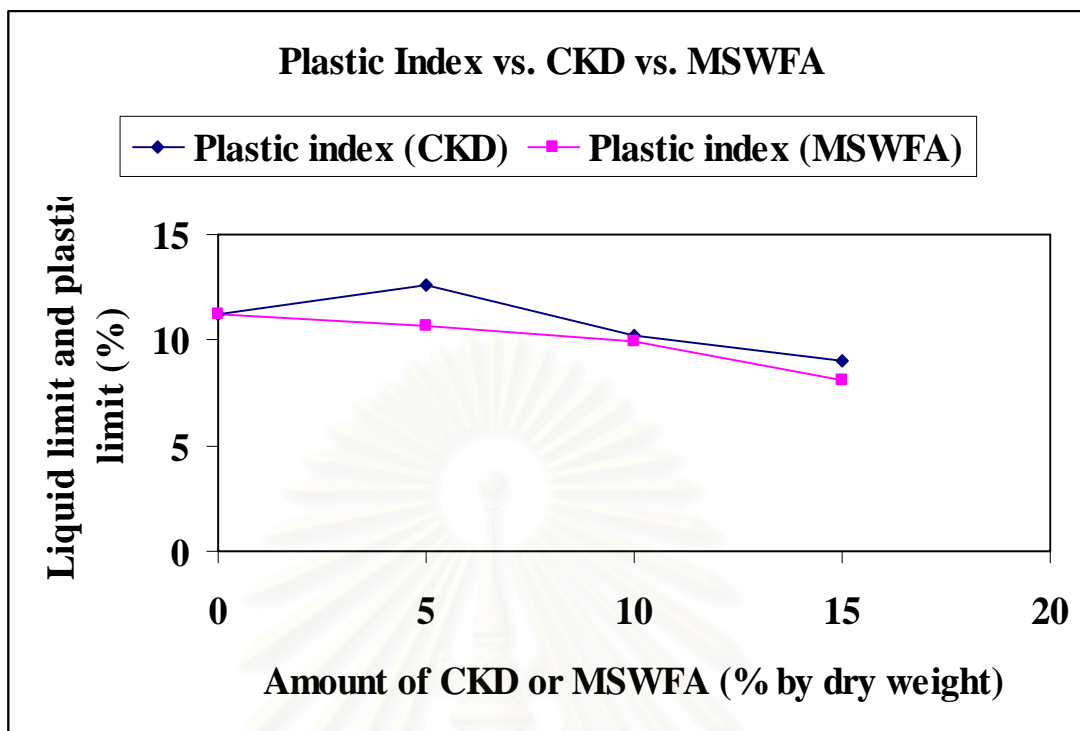
Figure 4.27 Plastic indexes vs. the CKD and MSWFA content

The results revealed that the PI reductions eventuated with modest amounts of both of CKD and MSWFA for contaminated soil. It caused an increase in PL and decrease in LL when CKD and MSWFA content were increased. The tendencies of the decreasing liquid limit were evaluated in both CKD and MSWFA when increasing the amount of CKD and MSWFA content. On the contrary, the tendencies of increasing PL of both CKD and MSWFA ascertain that the plasticity index of CKD and MSWFA stabilized soils decrease mostly due to an increase in the plastic limit. The liquid limit may increase or decrease depending on the type of soil as well.

Fly ash chiefly reduces the plastic index of high plasticity soil but has little effect on the plasticity index of low plasticity fine soils. The fly ash refers to smaller particle size, higher specific surface area and less crystalline those make the clay minerals more susceptible to lime attack (Thompson, 1966; Diamond and Kinter, 1965; Bell, 1996; Rodriguez, Castillo and Sowers, 1998). Lime attack refer to the effect of cation exchange begins to take place between the metallic ions associated with the surface of the soil particle and the calcium ions of the lime. The LL is much more sensitive than the plastic limit to the cation exchange complex of the soil. The

LL has been scrutinized to increase or decrease due to lime treatment depending on the nature of the cation exchange complex whereas the PL nearly always increases significantly (Diamond and Kinter, 1965; Bell, 1996). The reduction of plastic index caused increasing shear strength and decreasing settlement.

4.3.3 Unconfined Compressive Strength (UCS)

All unconfined compressive strength samples were prepared at the optimum moisture content and maximum dry density of the soil. The samples were allowed to cure for 1, 7, 14, and 28 days prior to unconfined compressive strength testing. For each curing time, six samples were provided, wrapped in plastic food-wrapping sheet and kept in a high-humidity tank at room temperature for the desired curing time period. Three samples were measured after the prescribed curing time, and the remaining three samples were submerged in water for 48 hours prior to testing. Immersed sample were used to determine the resistance of the stabilized soil to being soaked in water.
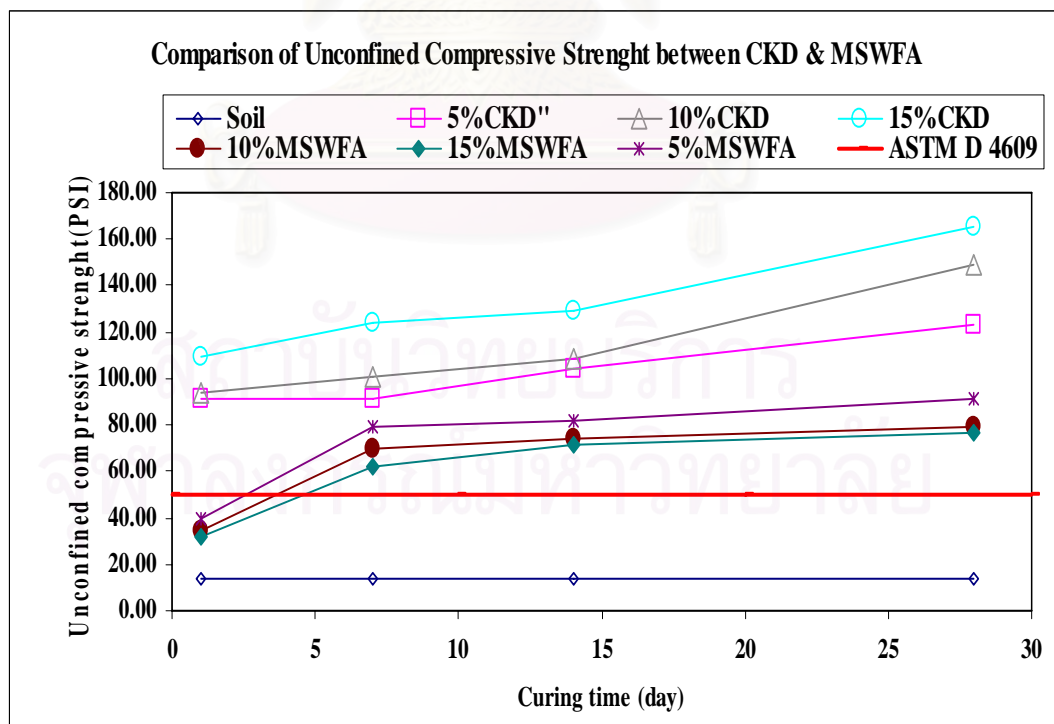
Figure 4.28 Unconfined compressive strength vs. curing times for CKD and MSWFA
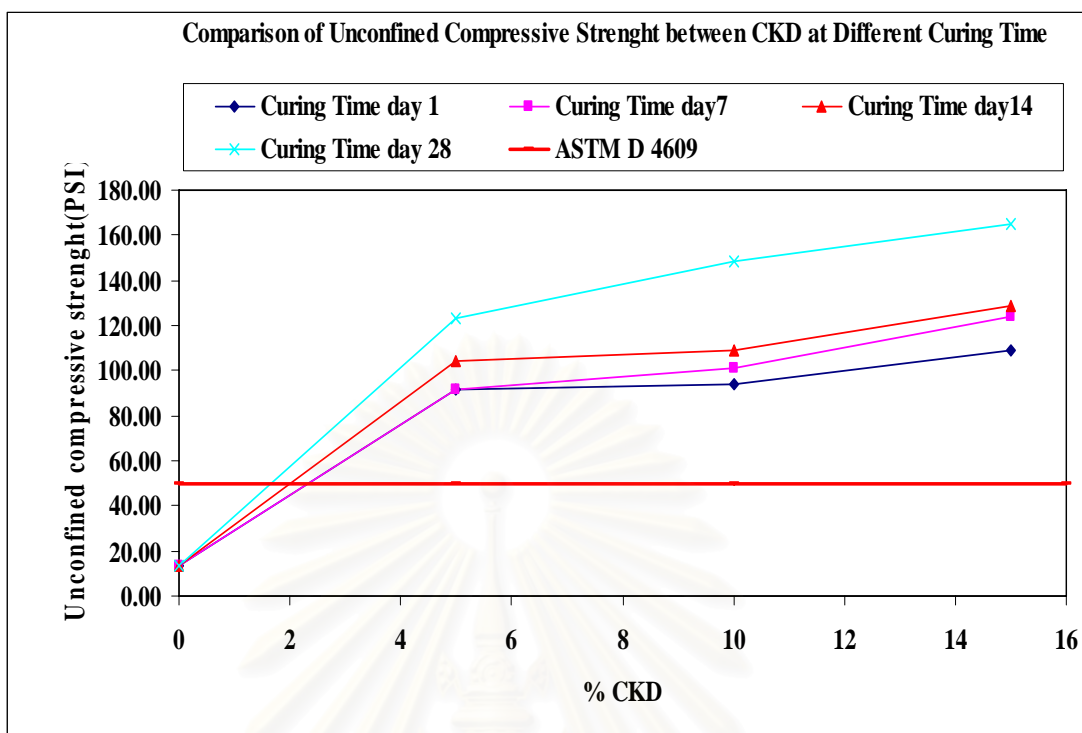
Figure 4.29 Unconfined compressive strength vs. the amount of CKD at different curing times
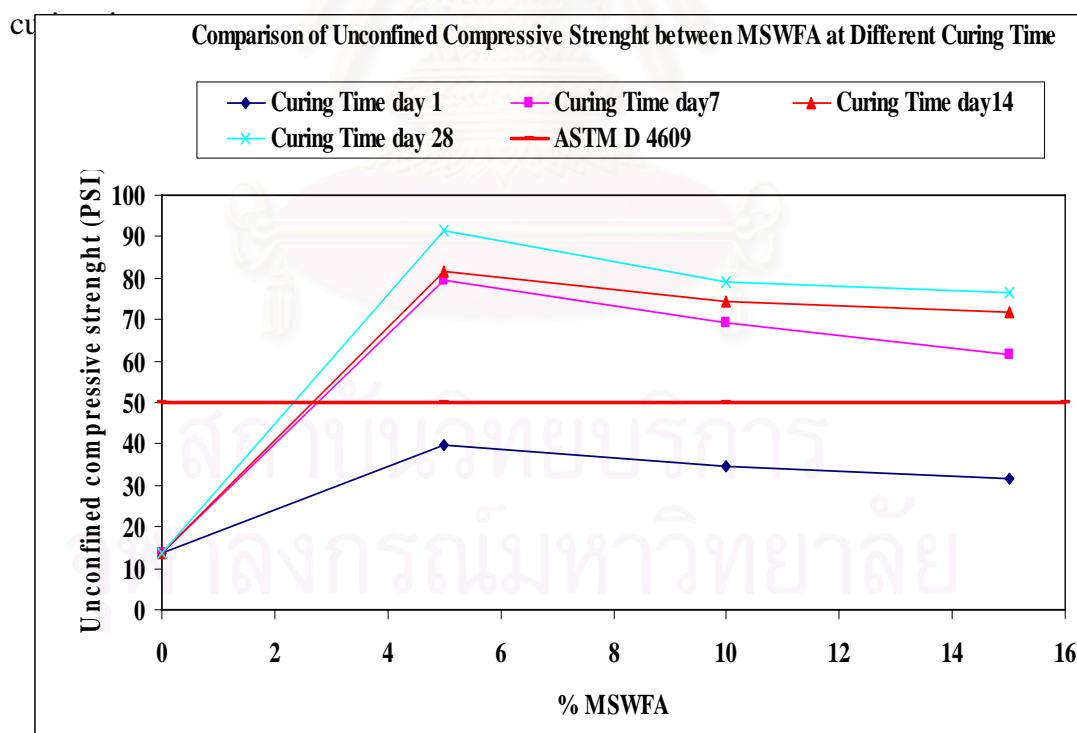
Figure 4.30 Unconfined compressive strength vs. the amount of MSWFA at different curing times
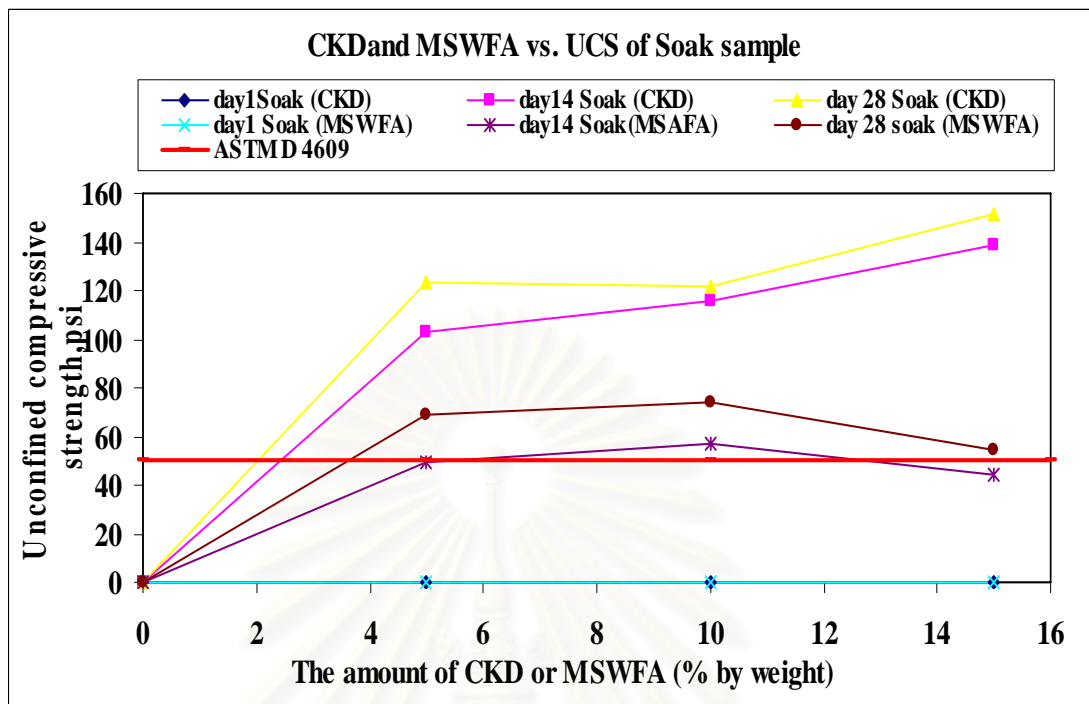
Figure 4.31 Unconfined compressive strength of soaked sample vs. the amount of CKD and MSWFA at different curing times

According to ASTM D 4609, it is suggested that an increase in unconfined compressive strength of 50 psi or more due to chemical treatment be consider effective. Also, if stabilized soil sample do not slake during immersion, the treatment may be effective; and if no significant strength is lost due to immersion, the treatment may be effective for waterproofing soils.

Figures 4.28 to 4.31 show comparisons of the strength response of soil samples to CKD or MSWFA stabilization. Some important observations are as follows:

1. Unconfined compressive strengths of the contaminated soils were in all cases lower than those of the stabilized soils. For the contaminated soil, the UCS did not increase with increasing curing time. The contaminated soil disintegrated when immersed in water (as indicated by UCS values of zero in Figure 4.31)

2. For CKD-stabilized soil, the most significant strength received occurred after the first 1 days. While MSWFA-stabilized soil, the most important strength received occurred after the first 7 days

3. Significant increases in UCS occurred with increases in the CKD content in the stabilized soil and curing time. On the other hand, the increasing UCS in MSWFA-stabilized soil occurred after long curing time and decreasing MSWFA content in the stabilized soil.

4. The immersed samples of all recipes at 1 day curing time disintegrated when soaked in water.

5. The UCS values of the immersed CKD-stabilized soil samples are higher than those of the immersed MSWFA-stabilized soil samples.

6. Increase in the UCS of soaked stabilized soil sample occurred at when curing time increased, CKD content increased, or when MSWFA content was reduced.

7. It was found that all of CKD stabilized soil samples had UCS values greater than the value of 50 psi given by ASTM D4609; however, 1-day MSWFA-stabilized soil samples and 14-day soaked MSWFA-stabilized soil samples had UCS values higher than value given by the ASTM standard.

4.4 Leaching test

4.4.1 The Notification of Ministry of Industry No. 6, B.E. 2540 (1997) leaching procedure

According to the Notification of Ministry of Industry No.6 B.E. 2540 (1997), stabilized and solidified materials must be evaluated for the presence of heavy metals in their leachate by leaching extraction procedure. The objective of this part is to evaluate the efficiency and capacity of municipal solid waste fly ash (MSWFA) and

cement kiln dust (CKD) as immobilizing agents for manganese (Mn) and iron (Fe) contained in the contaminated soil at a coal mining site in the northern Thailand. The leaching procedure described in the Notification of Ministry of Industry No.6 B.E. 2540 (1997) was employed for measuring the leaching of Fe and Mn in the contaminated soil from the mining area. There are not the standard of concentration of Fe and Mn in the Notification of Ministry of Industry No.6 B.E. 2540 (1997). The results of leaching test following the procedure described in the 6th Notification of Ministry of Industry was compared with 100 times of Guidelines for Drinking Water Quality of the WHO for Fe and 100 times of objectionable to consume of Guidelines for Drinking Water Quality of the WHO for Mn (Teralta et al, 1992). All of the results are shown in Figure 4.32 to Figure 4.37.
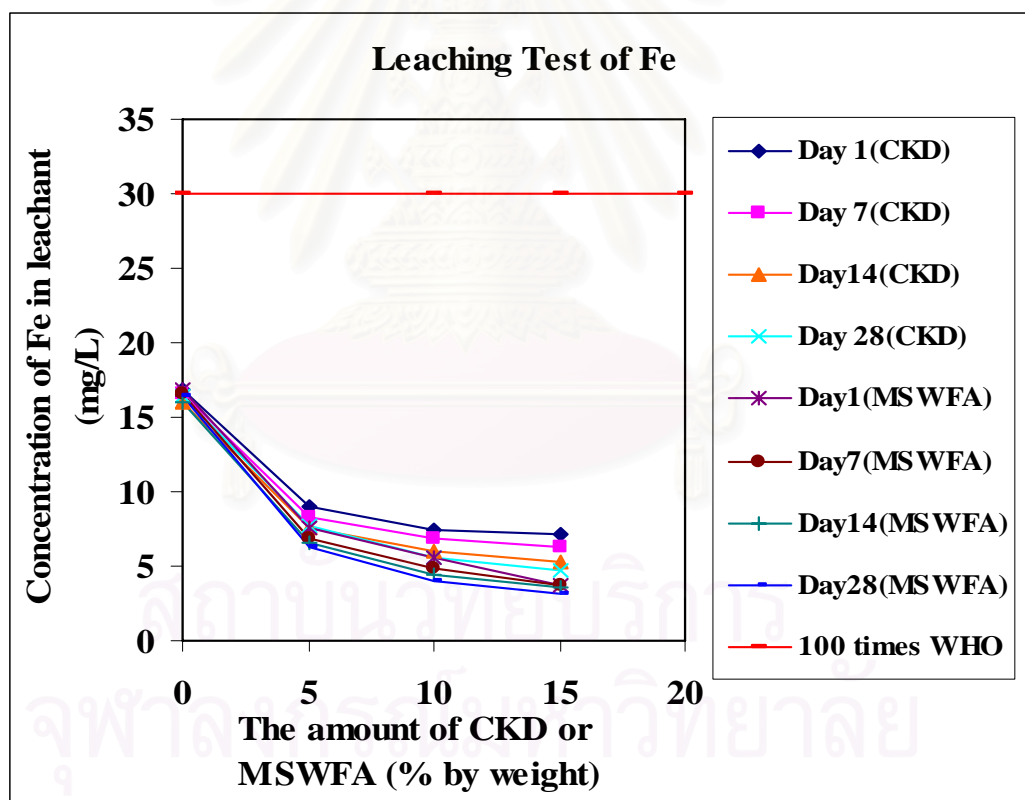
Figure 4.32 Leaching test plots between the concentration of Fe and the amount of CKD or MSWFA content
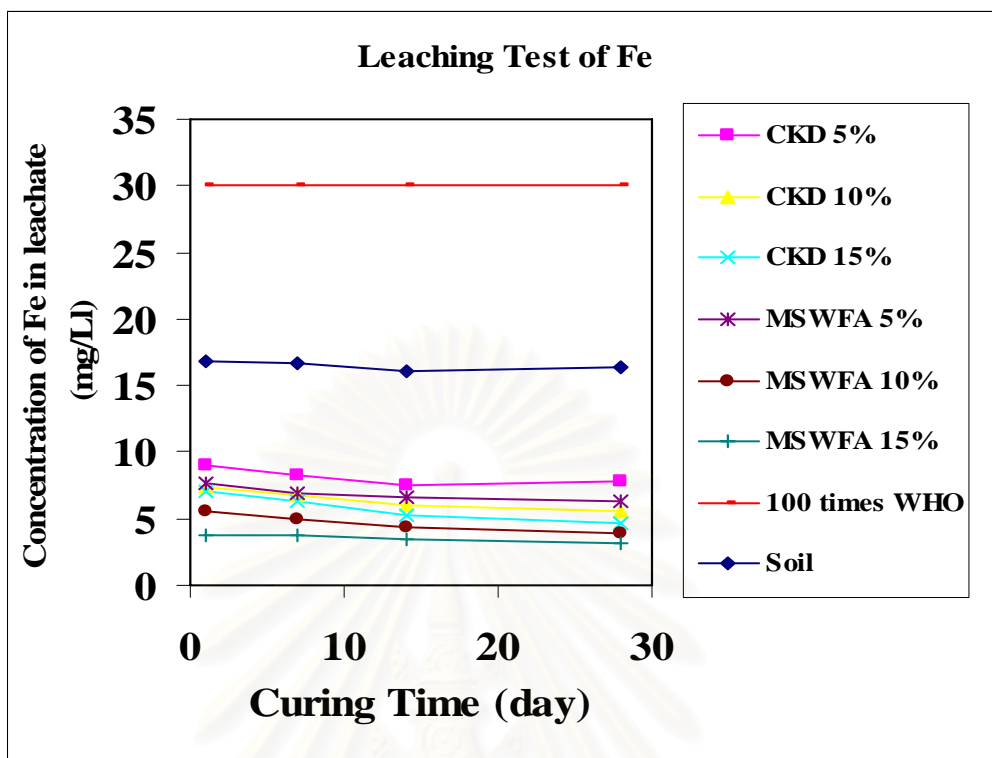
Figure 4.33 Leaching test plots between the concentration of Fe and curing time
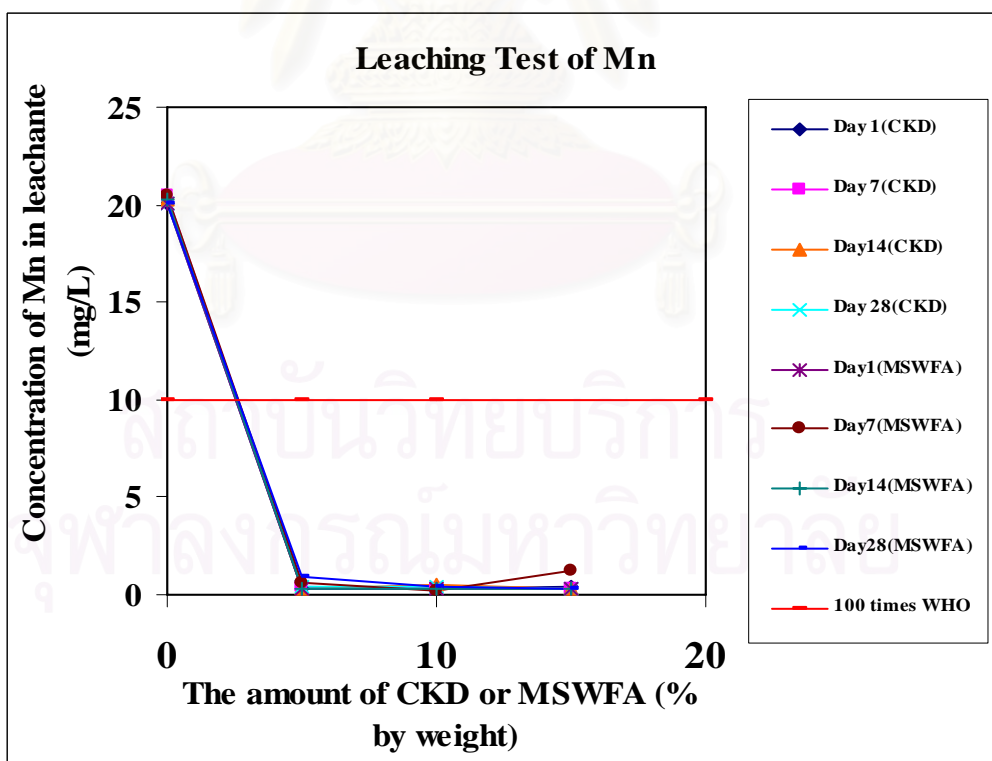
Figure 4.34 Leaching test plots between the concentration of Mn and the amount of CKD or MSWFA content
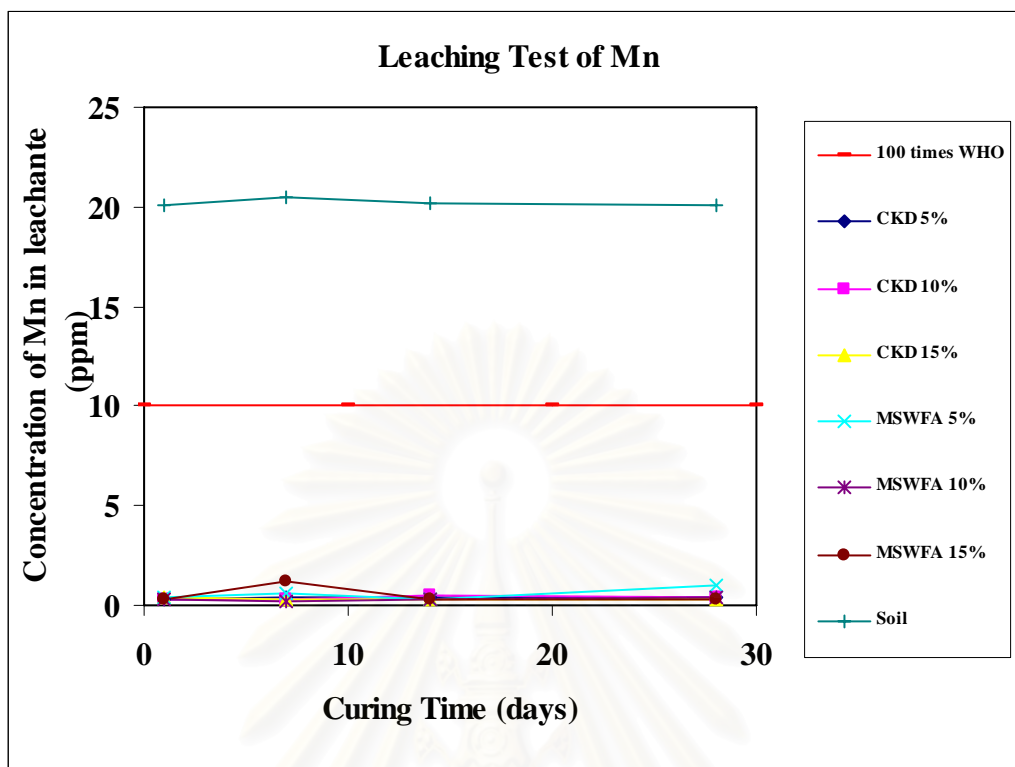
Figure 4.35 Leaching test plots between the concentration of Mn and curing time
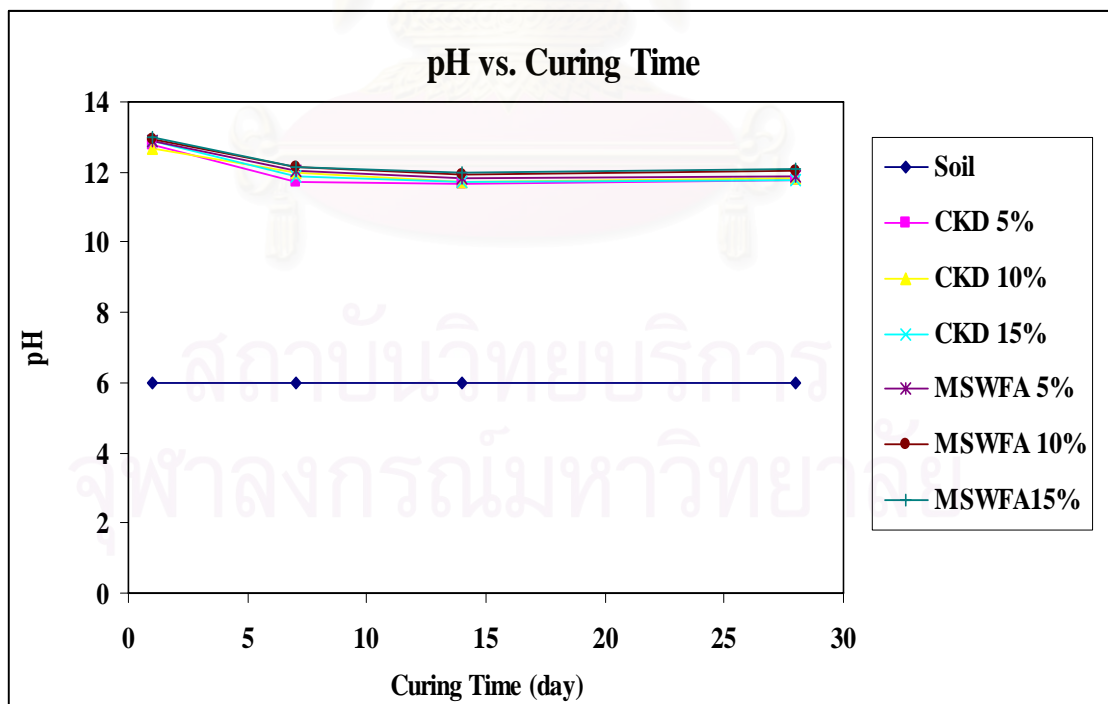
Figure 4.36 Leaching test plots between pH and curing time
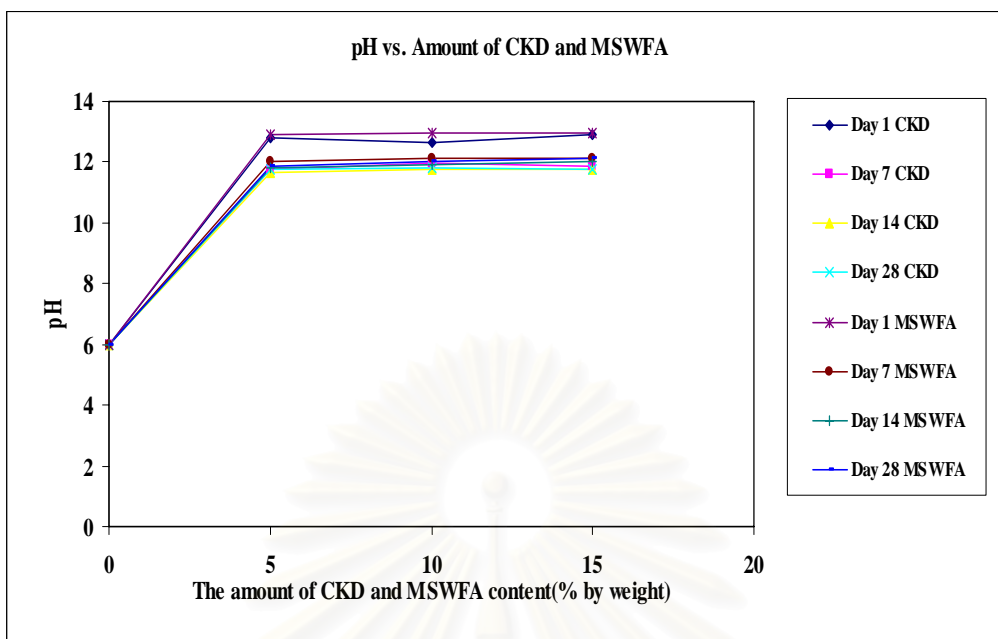
Figure 4.37 Leaching test plots between pH and the amount of CKD or MSWFA content (% by weight)

Table 4.18 Immobilization efficiency of CKD stabilized sample at different curing day.

Day	CKD (%)	Fe immobilization (%)	Mn immobilization (%)
1	5	46.43	98.41
	10	55.83	98.31
	15	57.74	98.01
7	5	50.24	98.05
	10	59.04	98.63
	15	61.81	98.44
14	5	53.00	98.22
	10	62.25	97.63
	15	67.38	98.62
28	5	52.65	97.81
	10	66.04	98.11
	15	71.52	98.31

Table 4.19 Immobilization efficiency of MSWFA stabilized sample.

Day	MSWFA (%)	Fe immobilization (%)	Mn immobilization (%)
1	5	54.76	98.21
	10	66.55	98.71
	15	77.62	98.71
7	5	58.31	97.07
	10	70.36	99.02
	15	77.59	94.15
14	5	58.50	98.42
	10	72.50	98.32
	15	78.00	98.62
28	5	61.90	95.22
	10	75.90	97.91
	15	80.65	98.41

Figures 4.32 to 4.37 show the results of leaching test of CKD or MSWFA stabilized soil. Some important observations are as follows:

1. The increasing of CKD or MSWFA content in stabilized contaminated soil sample can immobile Fe and Mn. It was indicated that MSWFA stabilized contaminated soil has higher efficiency than CKD stabilized contaminated soil in the immobilization of Fe. Both of MSWFA and CKD stabilized contaminated soil can immobile manganese by more than 95 % and less than the100 times of objectionable to consume of Guidelines for Drinking Water Quality of the WHO.

2. The increasing curing time cause increasing immobilization of Fe and Mn. The best recipe for immobilization of Fe is 15 % of MSWFA content in stabilized soil by 80.65 % immobilization. While the immobilization of Mn can use both of CKD and MSWFA stabilized contaminated soil.

3. The leaching test showed that mobility of Fe and Mn in the soil was considerably limited. Leaching of heavy metals was retarded by soil in three ways: by adsorption onto the surface of mineral particles, by adsorption on the organic matter, and by precipitation of the metals. The mechanism of iron (Fe)

and manganese (Mn) interaction with the soil is a mixture of some or all of the above mechanisms, the predominant manner probably depending upon the ingredients and the pH of the stabilized soil sample.

4. The increasing of CKD or MSWFA content caused the pH value increased.

5. The increasing curing times cause the reducing of pH value.

6. For contaminated soil the pH did not increase as curing time increased.

7. The concentration of lead in stabilized sample can not detect by ICP. It can explain that lead can immobile by surface interactions and solution of pH (Dermatas, D., and Meng, X.: 2003). Moreover, hydration reaction with cement in stabilized soil can immobile lead in stabilization soil.

4.4.2 Column Leaching Test

A column leaching test more closely imitates the site condition than a leaching experiment. Furthermore, it contributes detailed information about mobility of the contaminant with respect to time. Hence, additional analysis of the site was carried out by column leaching test in which Fe and Mn concentrations were evaluated. To imitate the worse case of acid rain leaching, this research employed two leaching solutions; namely, distilled water and a leaching solution that is made with sulfuric acid in deionized (DI) water which has a pH of 3. The column soil samples were continuously washed for 48 hours with the leaching solution. The leaching solution was collected by a fractional collector and an aliquot of each sample was then checked for its pH and concentration of heavy metals by the ICP-OES. The results of all recipes are show in Figures 4.38 to 4.51.
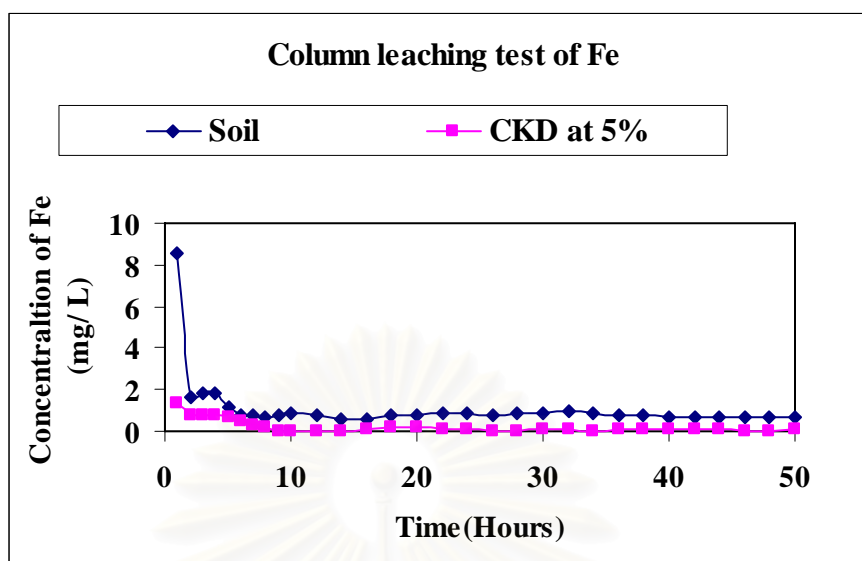
Figure 4.38 Column leaching test of CKD at 5%: concentrations of Fe over time.
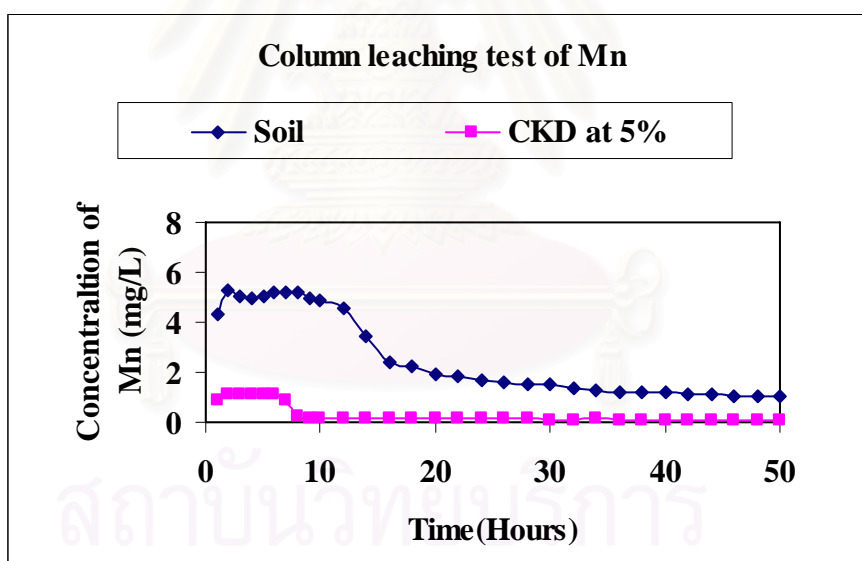
Figure 4.39 Column leaching test of CKD at 5%: concentrations of Mn over time.
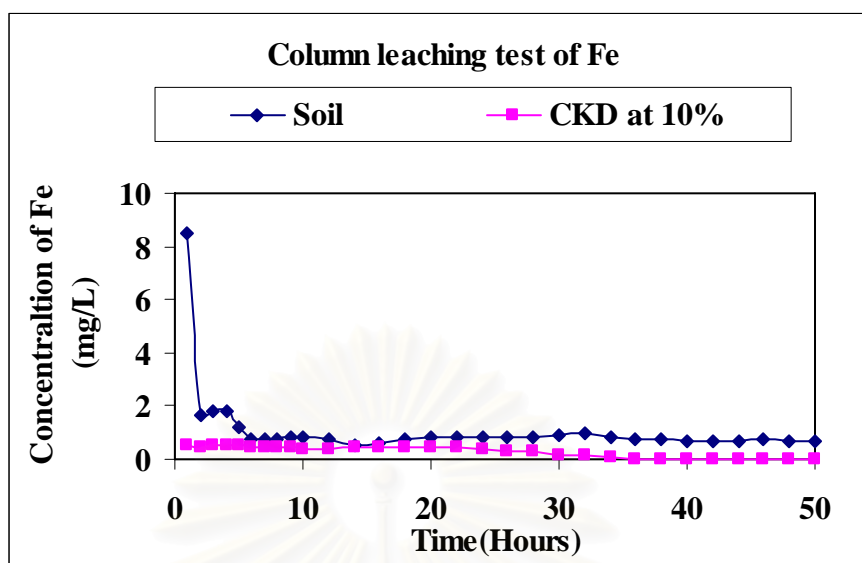
Figure 4.40 Column leaching test of CKD at 10%: concentrations of Fe over time.
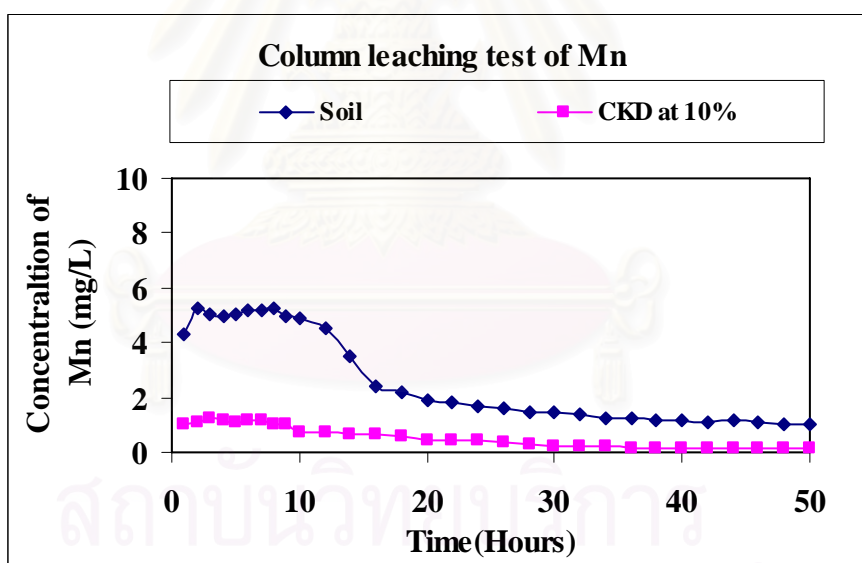
Figure 4.41 Column leaching test of CKD at 10%: concentrations of Mn over time.
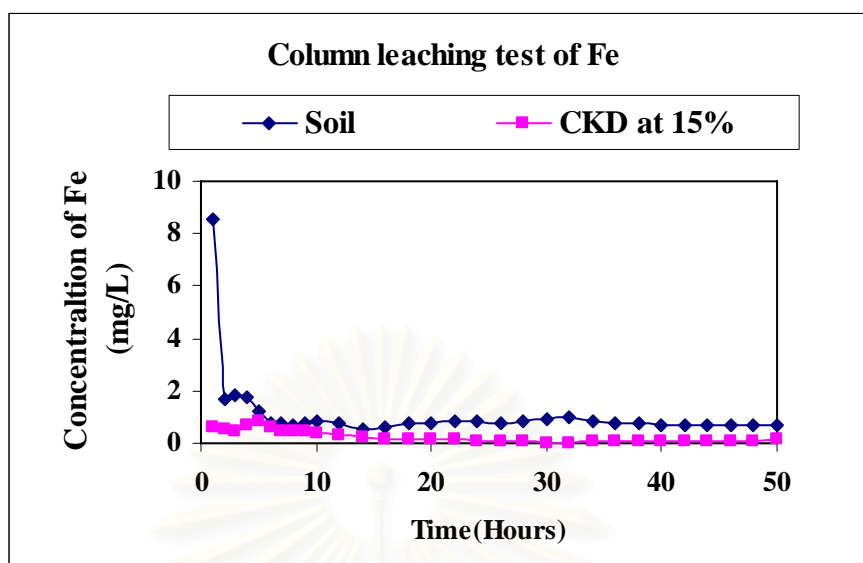
Figure 4.42 Column leaching test of CKD at 15%: concentrations of Fe over time.
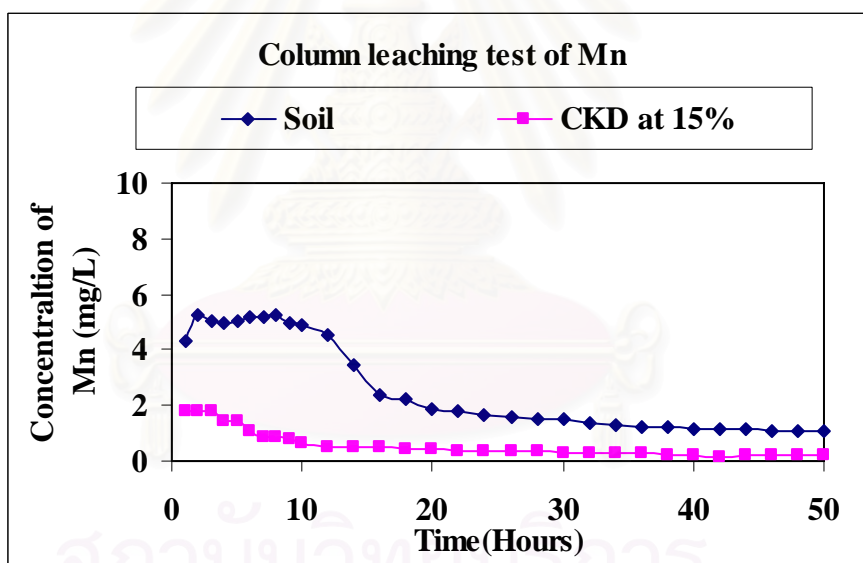
Figure 4.43 Column leaching test of CKD at 15 concentrations of Mn over time.
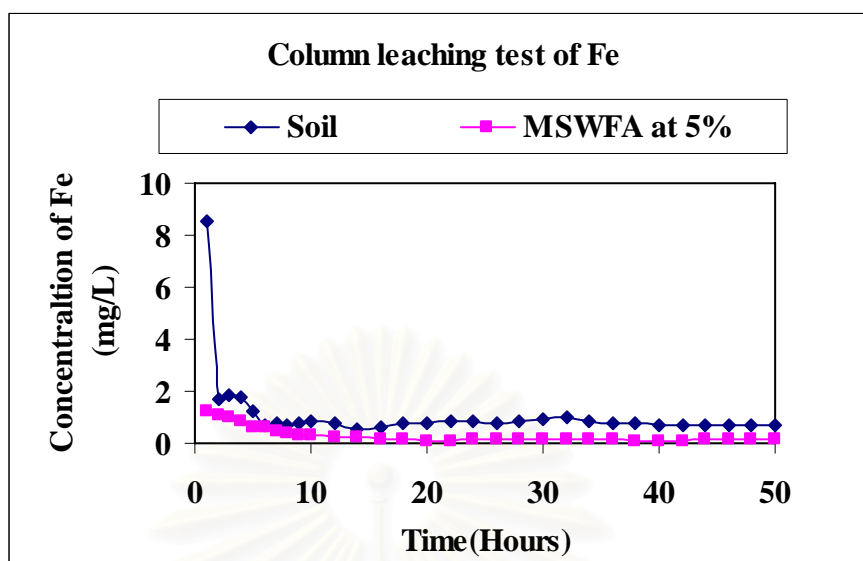
Figure 4.44 Column leaching test of MSWFA at 5%: concentrations of Fe over time.
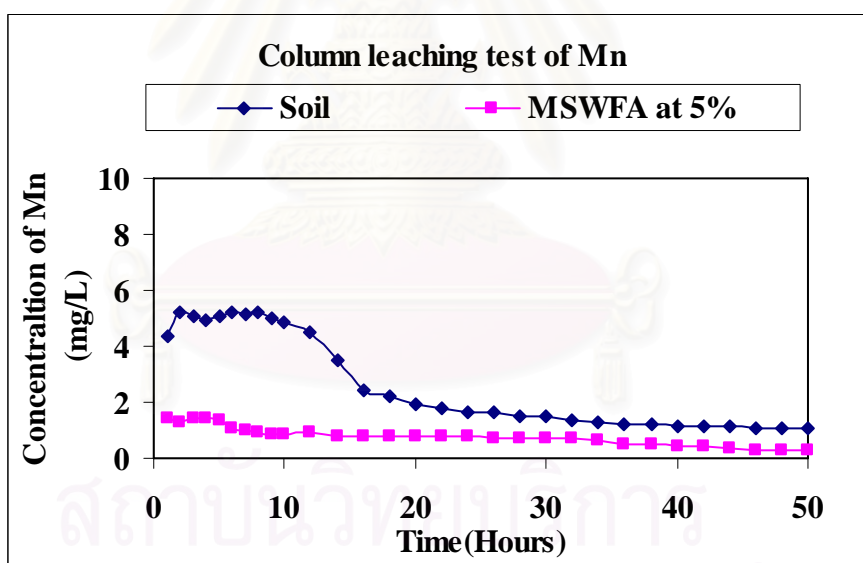
Figure 4.45 Column leaching test of MSWFA at 5%: concentrations of Mn over time.
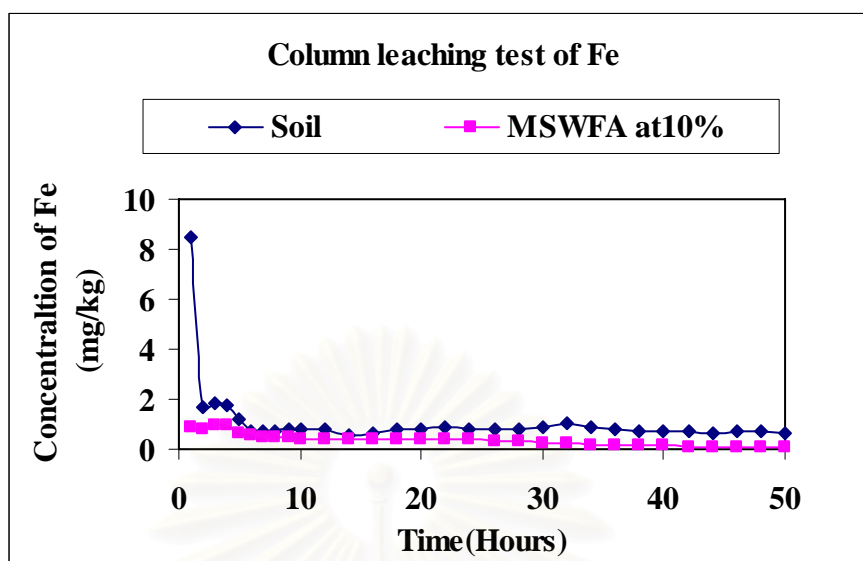
Figure 4.46 Column leaching test of MSWFA at 10%: concentrations of Fe over time.
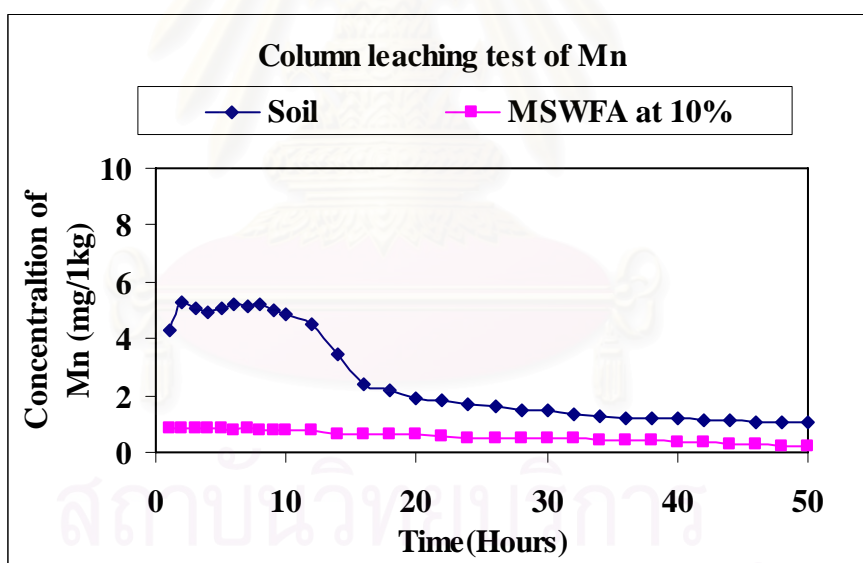
Figure 4.47 Column leaching test of MSWFA at 10%; concentrations of Mn over time.
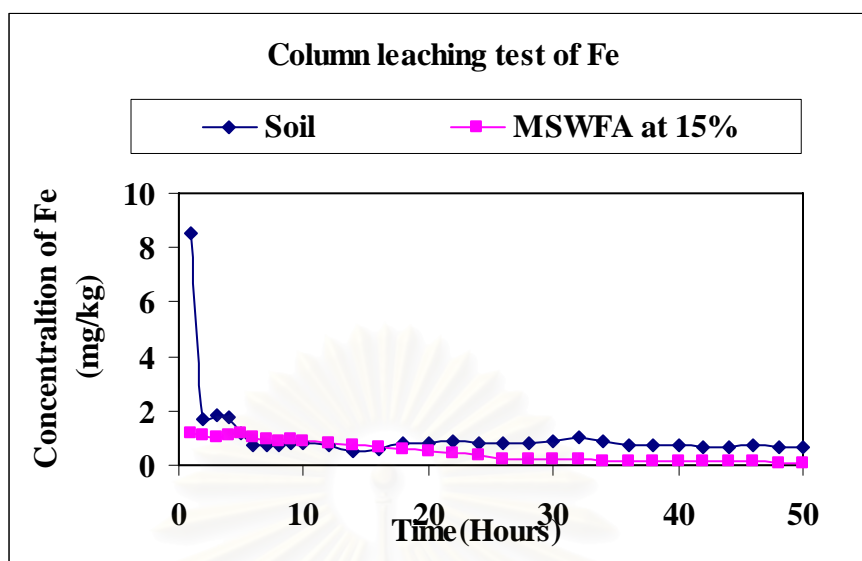
Figure 4.48 Column leaching test of MSWFA at 15%: concentrations of Fe over time.
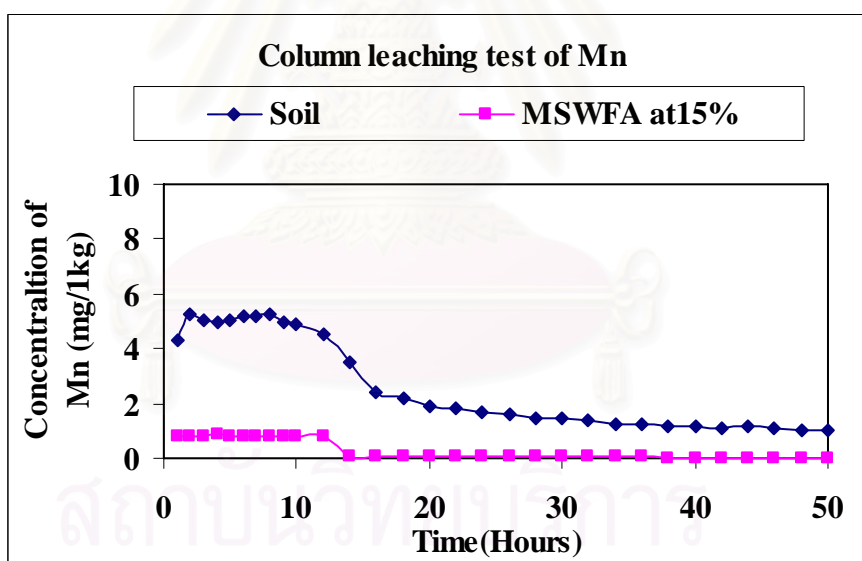
Figure 4.49 Column leaching test of MSWFA at 15%: concentrations of Mn over time.
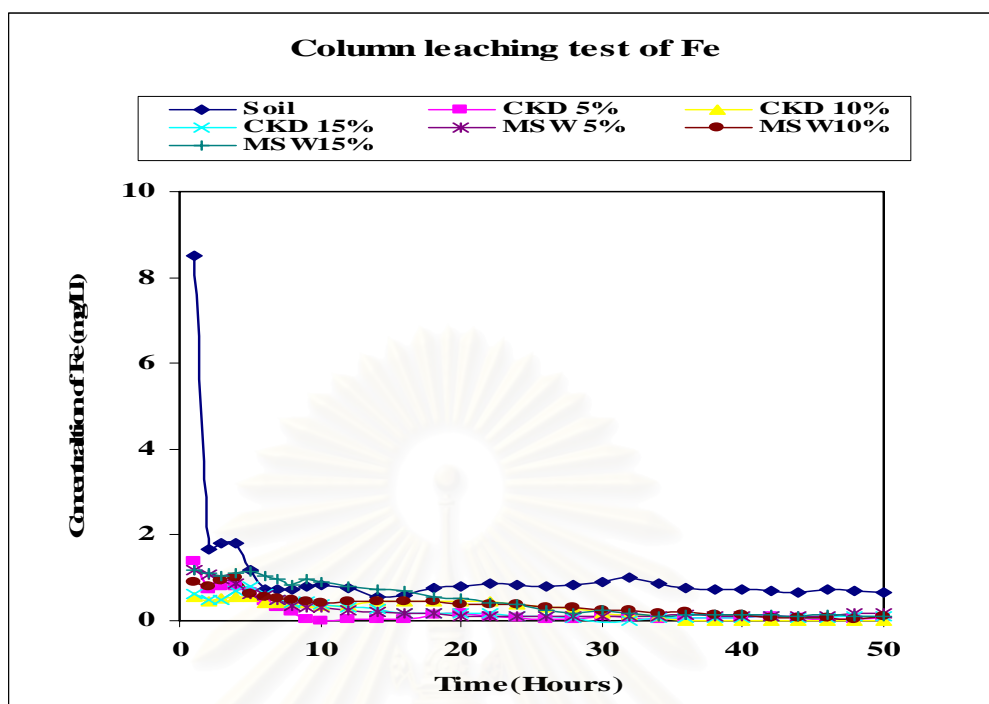
Figure 4.50 Comparison of the Fe concentrations in CKD stabilization and MSWFA stabilization
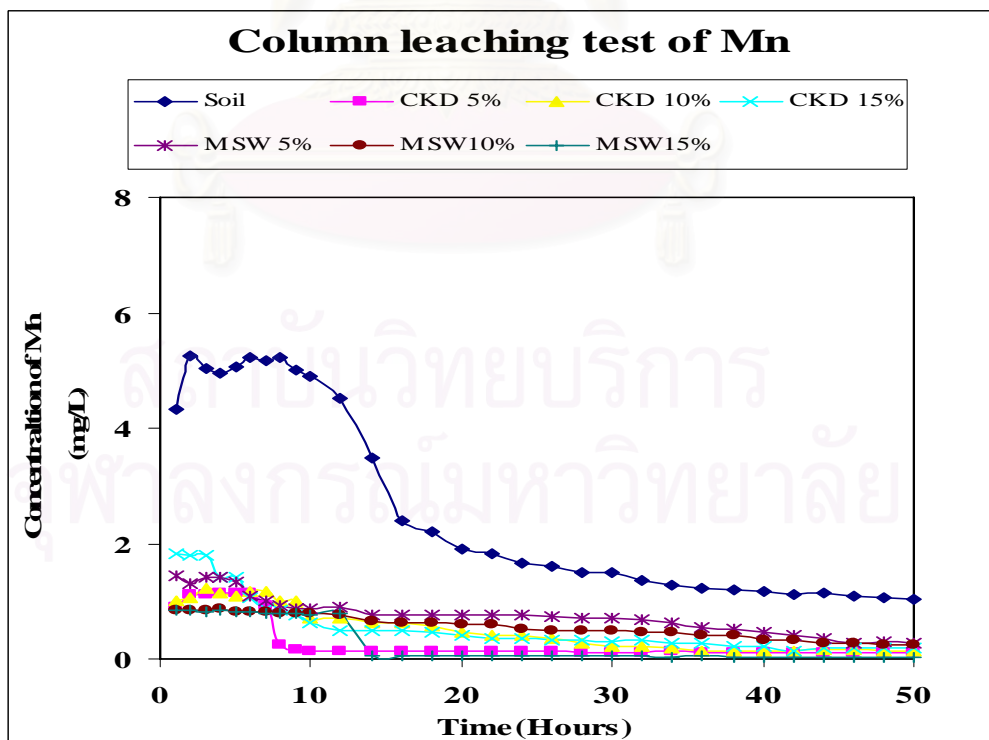
Figure 4.51 Comparison of the Mn concentrations in CKD stabilization and MSWFA stabilization

Figures 4.38 to 4.51 revealed the effects of CKD or MSWFA content in column leaching test on Fe and Mn in the contaminated soil at a pH of 3. The concentration of Fe and Mn could not be determined when DI water was applied as the leaching solution. The column leaching test showed that the concentrations of Fe and Mn in the contaminated soil were considerably similar to the results in the leaching test of stabilized soil samples. The results of column leaching test showed pH 3 leaching solution only. Decrease in the concentrations of Fe and Mn occurred as time progressed. Lower concentrations of Fe and Mn were extracted by a washing solution from the CKD and MSWFA stabilized soil sample than from the contaminated soils. It was ascertained that metal retention using CKD and MSWFA was not primarily due to the adsorption of metals onto either the soil or additive particles. Although not fully characterized, the retention of metals appears to be possibly due to the pH increase and partially, due to the metal hydroxides created.

The column leaching tests explained that the solubility of metals in the stabilized soil samples was considerably limited and the order of decreasing metal leachability.

4.5 Total Cost Analysis

Stabilization and solidification treatment costs generally contain costs for (if treatment is ex situ), chemicals, equipment, utilities, labor, and sampling, and analysis. Excavation employs to sites containing contaminated materials that are to be stabilized by ex-situ mixing. Excavation equipment includes typical earth-moving equipment, which can be rented along with an operator at most sites. Chemical costs are based on the kind of chemicals required for the binder system and the amounts as evaluated by the waste-to-binder ratio, and the transport cost. Equipment costs are dependent on the type of equipment selected for materials handling and processing. Utilities generally include water and electricity. Labor costs are based on the number of equipment operators, supervisory personnel, and managers, and the number of hours of operation. Moreover, an important factor in remediation can be the standby time. Sampling and analysis and quality assurance plan will be provided during

planning. Implementation of the plants may be a significant part of the remediation cost.

This thesis evaluated total cost by using % immobilization from leaching experiment at 28-days curing time of both CKD and MSWFA stabilize sample. There are many assumptions in this case study as follows:

1. The percent of immobilization of Fe applied percent of immobilization at curing time 28 day.

2. Cement cost is approximately 1700 ฿/ tons.

3. Both MSWFA and CKD costs were evaluated from transportation cost since they are considered waste that must be handled properly at the plants. MSWFA cost was calculated using the transportation cost between Lampoon and Phutket (1532 km). While CKD cost was determined by employing the transportation cost between Lampoon and Saraburi (304 km).

4. Truckload is 30 tons per truck.

5. Transportation cost equation is (distance+30) × diesel cost.

6. Others Cost based on literatures describing practices in the USA.

Table 4.20 Total cost analysis of stabilization and solidification in-situ
.

Cost (฿ / 1 Tons)	CKD			MSWFA		
	5%	10%	15%	5%	10%	15%
Chemical Cost	117.11	136.20	157.77	126.65	168.31	209.96
Others Cost	220.00	220.00	220.00	220.00	220.00	220.00
Total	337.11	356.20	377.77	346.65	388.31	429.96

The calculations shown in Table 4.19 indicated that stabilization and solidification employing CKD and MSWFA incurred total cost between 350-400 Bath per 1 ton of contaminated soil.

From Table 4.19, the total cost of CKD is less than the total cost of MSWFA. If the heavy-metals contaminated sites occur in the northern of Thailand, it could be used CKD stabilization. Because the total cost of CKD stabilization will less than MSWFA stabilization. On the other hand, if the heavy-metals contaminated sites

occur in the southern of Thailand, it should be employ the MSWFA stabilization. Because the transportation of MSWFA will less than CKD and the sites is nearly the municipal solid waste incinerator.

From Table 4.21 and 4.22, it helps to decide the best recipe for this site. The best recipe is 5% of CKD stabilized soil. Because the 5% of CKD stabilized soil will reduce volume of wastes in site, reduce the concentration of Mn less than Thai soil standard, and give unconfined compressive strength (UCS) more than 50 psi. Moreover, the 5% of CKD stabilization is the least total cost for this technology. Stabilized CKD and MSWFA soil sample can be applied practically to road embankments and river dike with cover soil in order to avoid additional leachate.

Table 4.21 The comparison of concentration of Fe and Mn between contaminated soil and stabilized contaminated soil sample.

Soil sample	Concentration of heavy metals in soil (mg/L)	
	Fe	Mn
Contaminated soil	79537.00	5019.00
Thai soil standard	-	1800.00
5% CKD at curing time 28 days	37660.77	109.92
10% CKD at curing time 28 days	27010.77	94.86
15% CKD at curing time 28 days	22652.14	84.82
5% MSWFA at curing time 28 days	30303.60	239.91
10% MSWFA at curing time 28 days	19168.42	104.90
15% MSWFA at curing time 28 days	15390.41	79.80

Table 4.22 Conclusion of all stabilized soil samples

Parameter	Sample						
	Contaminated Soil	5% CKD	10% CKD	15% CKD	5% MSWFA	10% MSWFA	15% MSWFA
OMC (%)	9.50	13.00	11.00	11.00	13.00	14.00	13.00
γ dry (KN/m^3)	18.25	18.50	18.64	18.50	18.03	18.11	17.98
Liquid Limit (LL, %)	26.23	30.18	28.81	29.19	26.49	26.06	29.73
Plastic Limit (PL, %)	14.97	16.54	19.78	19.93	16.54	18.01	19.03
Plastic Index (PI, %)	11.26	12.65	10.25	9.03	10.70	9.96	8.08
UCS at 28 curing days (psi)	13.63	123.15	148.72	165.25	91.28	78.97	76.52
UCS (soak) at curing time 28 days (psi)	0.00	123.15	121.47	151.21	69.05	74.37	58.74
% immobilization of Fe at curing time 28 days	-	52.65	66.04	71.52	61.90	75.90	80.65
% immobilization of Mn at curing time 28 days	-	97.81	98.11	98.31	95.22	97.91	98.41
Total concentration of Fe in column test at 50 hours (mg/L)	34.00	6.80	8.63	7.62	9.58	11.62	16.39
Total concentration of Mn in column test at 50 hours (mg/L)	84.37	10.43	16.78	18.65	23.76	17.45	9.74
Total cost analysis (฿ / 1 Tons)	0	337.11	356.20	377.77	346.65	388.31	429.96

CHAPTER V

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORKS

The research was conducted to determine the efficiency and capacity of using municipal solid waste fly ash (MSWFA) and cement kiln dust (CKD) as immobilizing agents for manganese (Mn) and iron (Fe) contained in contaminated soil at a coal mining site in northern Thailand. The research was concerned with evaluating the effectiveness of the use of municipal solid waste fly ash and cement kiln dust for improving engineering properties of soil; such as the unconfined compressive strength (UCS), optimum moisture content (OMC) and maximum dry density of soil. The following conclusions could be drawn from this study:

5.1 Characterization of the soil sample

The contaminated soil can be classified as acidic soil because its pH value was less than 7. The moisture content was 6.65 %. According to the particle size analysis, the soil sample consisted 68.76% of silt and clay, 31.24% of sand, 6.65 meq/100g of cation exchange capacity, and 4.6 %.of organic matter. It was found that both Fe and Mn of contaminated soil were higher than background soil. Also, the concentration of iron and manganese in leaching tests from the contaminated soil were higher than both the Thai Surface Water Quality Standards and Guidelines for Drinking-water Quality from the WHO. In the terms of bulk chemical composition, the soil mainly contained SiO2, AlO_3 and Fe_2O_3 respectively and the most abundant chemical composition in the crystalline phase was SiO_2 (Quartz Low). The results from the Atterberg limit and index were plotted in CL area of the plasticity chart. According to ASTM D 854-92, it was found that the specific gravity of the contaminated soil was 2.68. The soil was classified by the Unified Classification System as fine-grained soil, under the group symbol: CL and group name: sandy lean clay with gravel. The optimum moisture content of the contaminated soil was 9.5 % and the maximum dry density of contaminated soil was 18.25 KN/m^3. Moreover, the unconfined compressive strength of the contaminated soil was measured at the value of 13.63 psi.

5.2 Properties of Municipal Solid Waste Fly Ash (MSWFA) and Cement Kiln Dust (CKD)

The MSWFA and CKD, which passed through a standard sieve No.200 (75-micron openings), was measured for particle size distribution using a particle size analyzer. The moisture of the MSWFA was found to be that of CKD and both of them had higher moisture content than that of Portland cement. However, it was still within the limit of 3%, required by ASTM C 618-95. Both LOI of Phutket MSWFA and CKD were rather higher than the 6% lime for both Class-C and Class-F pozzolan. The chemical composition of CKD mainly contained CaO, SiO_2, AL_2O_3, Fe_2O_3 and MgO, respectively. The composition of MSWFA mostly contained CaO, Cl, K_2O, SO_3, Na_2O and SiO_2. Alite and Belite, are the cement compounds, where are used to compare MSWFA and CKD. The physical and chemical characteristics of MSW and CKD can vary from plant-to plant, depending on the raw materials employed and the type of collection process at the plant. The concentration of heavy metals of MSWFA and CKD were determined and compared. The main heavy metals in MSWFA were Al, Fe, Mn, and Zn, while the concentrations of heavy metals in CKD were Al, Cu, Fe, Mn and Pb.

5.3 Improvement of Engineering Properties

With regard to optimum moisture and maximum dry density, an increase in the OMC and an increase in dry unit weight occurred as the CKD content increased and the effect of CKD on dry density and OMC is a function of the soil and CKD type as well as the process of compaction. The increase in the OMC apparently resulted from the affinity of CKD to water, as maximum dry density occurs because of the aggregation of particles due to the CKD where results in small macropores within the soil. The OMC increased and the maximum dry density decreased as the MSWFA content increased. The addition of fly ash in the soil changes the porosity and void ratio within the range of the void ratio of fly ash and soils. The originate decrease of maximum dry density and an increase in the moisture contents can be ascribed to the capillary tension effect. At lower moisture content, the capillary tension in the pore

water restrains the tendency of the soil particles to move around and be densely compacted.

A deduction in the PI was determined in modest amounts for the use of both of CKD and MSWFA in the contaminated soil. The PL increased and the LL decreased when the CKD or MSWFA content was increased. The plasticity index of CKD and MSWFA stabilized soils decreased mostly due to an increase in the plastic limit. The liquid limit may increase or decrease depending on the type of soil as well. Fly ash mainly reduces the plastic index of high plasticity soil but has little effect on the plasticity index of low plasticity fine soils.

The addition of CKD to soil can substantially improve its unconfined compressive strength. On the other hand, lessening the amount of MSWFA in the soil can improve its unconfined compressive strength. For CKD-stabilized soil and MSWFA- stabilized soil, the most significant strength occurred during the first 7 days. In MSWFA- stabilized soil, the most important strength increase occurred during the first 14 days. The UCS of CKD-stabilized immersed soil sample values were higher than the UCS of MSWFA-stabilized immersed soil sample values. An increase in the UCS of a soaked stabilized soil sample occurred as the curing time increased, and more CKD was add, or when the MSWFA content was reduced. Comparison of the UCS with ASTM D 4609 (50 psi) found that all of the CKD stabilized soil samples have UCS values greater than the ASTM standard, but only 1 day curing time of the MSWFA- stabilized soil samples and 14 curing time of MSWFA- stabilized soaked soil samples have UCS values greater than ASTM standard.

5.4 Leaching test

The addition of CKD and MSWFA to contaminated soil containing Fe and Mn decreased the leachability of the contained metals. Increasing the curing time can assist in increasing the immobilization of heavy metals in contaminated soil. Increasing the amounts of CKD and MSWFA in stabilized samples can reduce the leachability of heavy metals. The degree of heavy metals leaching is highly pH dependent.

With regard to the column leaching tests, both concentrations of Fe and Mn were under the concentration of column leaching test of contaminated soil for CKD-stabilized and MSWFA stabilized samples. Thus, the column leaching test also confirmed the findings of the leaching test.

5.5 Suggestion for future work

1. Others engineering properties such as consolidation, California bearing ratio (CBR) should be tested in the stabilized soil before using it at a site.

2. The leaching test should consider the microstructure of the stabilized soil by using X-ray diffraction and a scanning electron microscope.

REFERENCES

ASTM.(1998). Annual book of ASTM standards section 4.08 West Conshocken.
    USA: American Society for Testing and Materials.

Bahar, R., Berazzoug, M., and Kenai, S. (2004). Performance of compacted cement
    stabilized soil. Cement & Concrete Composites 26: 811-820.

Bell, F.G. (1996). Lime Stabilization of clay minerals and soils. Engineering Geology
    42: 223-237.

Black, C.A. (1965). Method of soil analysis. USA: American Society of Agronomy.

Bowell, R.J., and Bruce, I. (1995). Geochemistry of iron ocheres and mine waters
    from Levant Mine, Cornwell. Applied Geochemistry 10: 237-250.

Bury, N., and Grosell, M. (2003). Review iron acquisition by teleost fish.
    Comparative Biochemistry and Physiology Part C 135: 97-105.

Buurman, P., Van Lagen, B., and Velthorst, E.J. (1996). Manual for soil and water
    analysis. Netherlands: Backhuys Publishers Leiden.

Ciccu, R., Ghiani, M., Serci, A., Fadda, S., Peretti, R., and Zucca, A.(2003). Heavy
    metal immobilization in the mining-contaminated soils using various
    industrial. Minerals Engineering 16: 187-192.

Das, B.M. (1999).Fundamentals of geotechnical engineering. USA: Brooks/Cole.

Dermatas, D., and Meng, X. (2003).Utilization of fly ash for Stabilization/
    solidification of heavy metal contaminated solids. Engineering Geology
    70: 377-394.

Doye, I., and Duchesne, J. (2003). Neutralization of acid mine drainage with alkaline

industrial residual: laboratory investigation using batch-leaching tests. Applied Geochemistry 18: 1197-1213.

Duteré, V., and Vandecasteel, C. (1995). Solidification/ stabilization of hazardous arsenic containing waste from a copper refining process. Journal of Hazardous Masterials 40: 55-68.

Eades, J.L., Grim, R.E. (1969). A quick test to determine lime requirement for lime stabilization. Highway research record 139: 61-72.

Evangelou, V.P. (1995). Pyrite oxidation and its control. USA: CRC Press LLC.

Evagelou,V.P., Zhang, Y.L. (1995). A review: Pyrite Oxidation mechanisms and acid mine drainage prevention. Environmental Science Technology 25: 141-199.

Ferguson, K.D., Erickson, P.M. (1988). Pre-mine prediction of acid mine drainage. In Salomons, W., FÖrstner, U. (ed), Environmental management of soild waste, dredded material and mine tailings, pp 51-72.New York: Springer.

Ferreira, C., Ribeiro, A., and Ottosen, L. (2003). Possible application for municipal solid waste fly ash. Journal of Hazardous Masterials B96: 201-216.

Jacobsen, J.S. (1998). Soil Sampling [PDF file]. Available from: http://www.montana.edu/wwpb/pubs/mt8602.html [2004].

Kamon, M., Katsumi, T., Sano, Y. (2000). MSW fly ash stabilized with coal ash for geotechnical application. Journal of Hazardous Masterials 76: 265-283.

Lee, M.T., and Nicholson, P.G. (1997). An engineering test program of MSW ash mixed with quarry tailing for use as a landfill construction. In Mark A. Wasemiller, Keith B. Hoddinott (ed.), <u>Testing of Soil Mixed with Waste or recycled Materials ASTM STP 1275,</u> pp. 205-218. Fredericksburg: American Society for Testing and Materials.

LaGrega, M.D., Buckingham, P.L., and Evans, J.C. (2001). <u>Hazardous waste management.</u> 2nd ed. Singapore: McGraw-Hill.

Lottermoser, B.G. (2003). <u>Mine Waste</u>. Germany: Springer-Verlag Berlin Heidelberg.

Luther, G.W. (1987). Pyrite oxidation and reduction: Molecular orbital theory considerations. Geochim Cosmochim Acta 51:3193-3199.

Miller, G.A., and Azad, S. (2000). Influence of soil type on stabilization with cement kiln dust. <u>Construction and Building Materials</u> 14: 89-97.

Nicholson, P.G., and Ding, M. (1997). Improvement of tropical soil with waste ash and lime admixtures. In Mark A. Wasemiller, Keith B. Hoddinott (ed.), <u>Testing of Soil Mixed with Waste or recycled Materials ASTM STP 1275,</u> pp. 195-204. Fredericksburg: American Society for Testing and Materials.

Park, C.K. (2000). Hydration and solidification of hazardous wastes containing heavy metals using modified cementitious materials. <u>Cement and Concrete Research</u> 30: 429-435.

Prabaker, J., Dendonkar, N. and, Morchhale, R.K. (2004). Influence of fly ash on strength behavior of typical soils. <u>Construction and Building Materials</u> 18: 263-267. Nalbantoglu, 2. (2004). Effectiveness of class C fly ash as an expansive soil stabilizer. <u>Construction and Building Material</u> 18: 377-381.

Raghu, D., Hsieh, H.N., Basim, S.C., and Morgan,M. (1997). Physical characterization of water treatment plants residual and top soil mixtures. In Mark A. Wasemiller, Keith B. Hoddinott (ed.), Testing of Soil Mixed with Waste or recycled Materials ASTM STP 1275, pp. 3-15. Fredericksburg: American Society for Testing and Materials.

Rivard-Lentz, D.J., Sweeney, L.R., and Dermars, K.R. (1997). Incinerator Bottom Ash as a soil Substitute: Physical and Chemical Behavior. In Mark A. Wasemiller, Keith B. Hoddinott (ed.), Testing of Soil Mixed with Waste or recycled Materials ASTM STP 1275, pp. 246-264. Fredericksburg: American Society for Testing and Materials.

Selim, M., and Sparks, D.L. (2001). Heavy Metals Release in Soil. USA: CRC Press LLC.

Sellers, K. (1999). Fundamentals of hazardous waste site remediation. USA: CRC Press LLC.

Sharma, H.A., and Reddy, K.R. (2004). Geoenvironmental engineering: site remediation, waste contaminant, and emerging waste management technologies. USA: John Wiley & Sons,inc.

Smith, L.A., et al. (1995). Remedial options for metals-contaminated sites. USA: CRC Press LLC.

Stumm, W., and Morga, J.J. (1996). Aquatic chemistry. 3rd ed. New York: A Wiley-Interscience Publication.

The Indiana Department of Transportation. (2002). Design Procedures for Soil Modification or Stabilization. [PDF file]. Available from: http://www.ai.org/dot/business/design/geotech/smod.pdf [2002, October].

Theodoratos, P., Moirou, A., Xenidis, A., and Paspaliaris, I. (2000). The use of municipal sewage sludge for the stabilization of soil contaminated by mining activities. Journal of Hazardous Masterials B77: 177-191.

USEPA. (1986). Test methods for evaluating solid waste laboratory manual physical/chemical methods SW846 Office of Solid Waste and Emergency Response. USA: USEPA.

Wang, Y.M., Chen, T.C., Yeh, K.J., and Shue, M.F. (2001). Stabilization of an elevated heavy metal contaminated site. Journal of Hazardous Masterials B88: 63-74.

Young, R.N., Yaacob, W.Z.W, Bentley, S.P., Harris, C., and Tan, B.K. (2001). Partition of heavy metals on soil samples from column tests. Engineering Geology 60: 307-322.

Yukselen, M.A., and Alpaslan, B. (2001). Case study leaching of metals from soil contaminated by mining activities. Journal of Hazardous Materials B87: 289-300.

APPENDICES

APPENDIX A

Table A-1 Amount of heavy metals in background and contaminated soil using EPA
method 3051 and ICP-OES

Heavy metals	Concentration of Heavy metals (mg/1Kg Soil)				
	Contaminated Soil	Background 1	Background 2	Background 3	Background 4
Ag	11.68	0.27	0	0	0.45
Al	23030.00	8355.80	7982.00	9489.60	8647.40
Cd	10.42	1.55	1.45	1.44	3.13
Cr	59.61	26.08	26.02	26.45	23.63
Cu	56.59	24.42	39.60	37.14	91.12
Fe	79537.00	13307.20	14139.00	10882.60	22212.00
Mn	5019.40	390.98	180.05	186.70	1685.56
Ni	107.81	18.17	20.92	42.64	52.37
Pb	55.06	10.73	1.52	15.09	15.22
Zn	272.92	110.94	73.84	126.79	221.08

Table A-2 Amount of heavy metals in background and contaminated soil from leaching test

Concentration of heavy metals (mg/1kg)	BP2/1
Ag	0.223
Al	4.279
Cd	NA
Cr	0.065
Cu	0.062
Fe	1.178
Mn	3.473
Ni	0.276
Pb	NA
Zn	0.531

FigureA-1 Position of collecting sample in Mining Well 2 (extension)

FigureA-2 Steps of soil sampling in site

APPENDIX B

Table B-1 unconfined compressive strength results of Ratio 1

Ratio	L1	L2	DL	e	Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	sv PSI	AVG.s PSI
Sam1/1d.1	7.2	7.1	0.1	0.014	3.3	1.3	1.345	1.5	15.0	11.15	
Sam1/2d.1	7.1	7.0	0.1	0.014	3.3	1.3	1.345	2.5	25.0	18.58	13.63
Sam1/3d.1	7.0	6.9	0.1	0.014	3.3	1.3	1.345	1.5	15.0	11.15	
Sam1/1d.1S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	
Sam1/2d.1S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	0
Sam1/3d.1S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	
Sam1/1d.7	7.2	7.1	0.1	0.014	3.3	1.3	1.345	1.5	15.0	11.15	
Sam1/2d.7	7.2	7.1	0.1	0.014	3.3	1.3	1.345	2	20.0	14.87	13.63
Sam1/3d.7	7.0	6.9	0.1	0.014	3.3	1.3	1.345	2	20.0	14.86	
Sam1/1d.14	7.0	6.9	0.1	0.014	3.3	1.3	1.345	2	20.0	14.86	
Sam1/2d.14	7.0	6.9	0.1	0.014	3.3	1.3	1.345	1	10.0	7.43	13.63
Sam1/3d.14	7.0	6.9	0.1	0.014	3.3	1.3	1.345	2.5	25.0	18.58	
Sam1/1d.14S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	
Sam1/2d.14S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	0
Sam1/3d.14S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	
Sam1/1d.28	7.0	6.9	0.1	0.014	3.3	1.3	1.345	2	20.0	14.86	
Sam1/2d.28	7.0	6.9	0.1	0.014	3.3	1.3	1.345	2	20.0	14.86	13.63
Sam1/3d.28	7.0	6.9	0.1	0.014	3.3	1.3	1.345	1.5	15.0	11.15	
Sam1/1d.28S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	
Sam1/2d.28S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	0
Sam1/3d.28S	0.0	0.0	0.0	0.000	3.3	1.3	1.326	0	0.0	0.00	

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table B-2 unconfined compressive strength results of Ratio 2

Ratio	L1	L2	DL	e	Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	sv PSI	AVG.s PSI
Sam2/1d.1	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	12.0	120	89.19	
Sam2/2d.1	7.1	7	0.1	0.0141	3.3	1.30	1.35	13.0	130	96.64	91.67
Sam2/3d.1	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	12.0	120	89.19	
Sam1/1d.1S	0.0	0	0.0	0	3.3	1.30	1.33	0.0	0	0.00	
Sam2/2d.1S	0.0	0	0.0	0	3.3	1.30	1.33	0.0	0	0.00	0
Sam2/3d.1S	0.0	0	0.0	0	3.3	1.30	1.33	0.0	0	0.00	
Sam2/1d.7	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	12.0	120	89.24	
Sam2/2d.7	7.2	7.1	0.1	0.0139	3.3	1.30	1.34	13.0	130	96.66	91.70
Sam2/3d.7	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	12.0	120	89.19	
Sam2/1d.14	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	14.0	140	104.05	
Sam2/2d.14	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	14.0	140	104.05	104.05
Sam2/3d.14	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	14.0	140	104.05	
Sam2/1d.14S	7.0	6.9	0.1	0	3.3	1.30	1.33	15.0	150	113.10	
Sam2/2d.14S	7.2	7.1	0.1	0	3.3	1.30	1.33	13.0	130	98.02	103.048
Sam2/3d.14S	7.1	7	0.1	0	3.3	1.30	1.33	13.0	130	98.02	
Sam2/1d.28	7.2	7.1	0.1	0.0139	3.3	1.30	1.34	17.0	170	126.40	
Sam2/2d.28	7.4	7.3	0.1	0.0135	3.3	1.30	1.34	17.0	170	126.45	121.48
Sam2/3d.28	7.5	7.4	0.1	0.0133	3.3	1.30	1.34	15.0	150	111.59	
Sam2/1d.28S	7.3	7.2	0.1	0	3.3	1.30	1.33	16.0	160	120.64	
Sam2/2d.28S	7.3	7.2	0.1	0	3.3	1.30	1.33	18.0	180	135.72	123.154
Sam2/3d.28S	7.3	7.2	0.1	0	3.3	1.30	1.33	15.0	150	113.10	

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table B-3 unconfined compressive strength results of Ratio 3

Ratio	L1	L2	DL	e	Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	sv PSI	AVG.s PSI
Sam3/1d.1	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	13.0	130	96.62	
Sam3/2d.1	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	12.0	120	89.19	94.14
Sam3/3d.1	7.0	6.9	0.1	0.0143	3.3	1.30	1.35	13.0	130	96.62	
Sam3/1d.1S	0.0	0	0.0	0.0000	3.3	1.30	1.33	0.0	0	0.00	
Sam3/2d.1S	0.0	0	0.0	0.0000	3.3	1.30	1.33	0.0	0	0.00	0.00
Sam3/3d.1S	0.0	0	0.0	0.0000	3.3	1.30	1.33	0.0	0	0.00	
Sam3/1d.7	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	14.0	140	104.11	
Sam3/2d.7	7.2	7.1	0.1	0.0139	3.3	1.30	1.34	13.0	130	96.66	101.12
Sam3/3d.7	7.1	6.9	0.2	0.0282	3.3	1.30	1.36	14.0	140	102.59	
Sam3/1d.14	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	15.0	150	111.55	
Sam3/2d.14	7.3	7.1	0.2	0.0274	3.3	1.30	1.36	14.0	140	102.67	108.58
Sam3/3d.14	7.2	7.1	0.1	0.0139	3.3	1.30	1.34	15.0	150	111.53	
Sam3/1d.14S	7.3	7.1	0.2	0.0274	3.3	1.30	1.36	16.0	160	117.34	
Sam3/2d.14S	7.2	7.1	0.1	0.0139	3.3	1.30	1.34	15.0	150	111.53	115.95
Sam3/3d.14S	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	16.0	160	118.99	
Sam3/1d.28	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	20.0	200	148.74	
Sam3/2d.28	7.4	7.3	0.1	0.0135	3.3	1.30	1.34	19.0	190	141.33	148.72
Sam3/3d.28	7.1	7	0.1	0.0141	3.3	1.30	1.35	21.0	210	156.11	
Sam3/1d.28S	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	16.0	160	118.99	
Sam3/2d.28S	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	16.0	160	118.99	121.47
Sam3/3d.28S	7.3	7.2	0.1	0.0137	3.3	1.30	1.34	17.0	170	126.43	

Table B-4 unconfined compressive strength results of Ratio 4

Ratio	L1	L2	DL	e	Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	sv PSI	AVG.s PSI
Sam4/1d.1	7.3	7.2	0.1	0.014	3.3	1.30	1.34	14.0	140	104.11	
Sam4/2d.1	7.2	7.1	0.1	0.014	3.3	1.30	1.34	15.0	150	111.53	109.05
Sam4/3d.1	7.1	7	0.1	0.014	3.3	1.30	1.35	15.0	150	111.51	
Sam4/1d.1S	0.0	0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	
Sam4/2d.1S	0.0	0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	0.00
Sam4/3d.1S	0.0	0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	
Sam4/1d.7	7.0	6.9	0.1	0.014	3.3	1.30	1.35	17.0	170	126.35	
Sam4/2d.7	7.0	6.9	0.1	0.014	3.3	1.30	1.35	16.0	160	118.92	123.87
Sam4/3d.7	7.0	6.9	0.1	0.014	3.3	1.30	1.35	17.0	170	126.35	
Sam4/1d.14	7.0	6.9	0.1	0.014	3.3	1.30	1.35	18.0	180	133.78	
Sam4/2d.14	7.0	6.9	0.1	0.014	3.3	1.30	1.35	17.0	170	126.35	128.83
Sam4/3d.14	7.0	6.9	0.1	0.014	3.3	1.30	1.35	17.0	170	126.35	
Sam4/1d.14S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	19.0	190	141.30	
Sam3/2d.14S4	7.4	7.3	0.1	0.014	3.3	1.30	1.34	18.0	180	133.89	138.81
Sam4/3d.14S	7.1	7	0.1	0.014	3.3	1.30	1.35	19.0	190	141.24	
Sam4/1d.28	7.1	7	0.1	0.014	3.3	1.30	1.35	22.0	220	163.55	
Sam4/2d.28	7.1	7	0.1	0.014	3.3	1.30	1.35	22.0	220	163.55	165.25
Sam4/3d.28	7.3	7.1	0.2	0.027	3.3	1.30	1.36	23.0	230	168.67	
Sam4/1d.28S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	23.0	230	171.05	
Sam4/2d.28S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	20.0	200	148.74	151.21
Sam4/3d.28S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	18.0	180	133.86	

Table B-5 unconfined compressive strength results of Ratio 5

Ratio	L1	L2	DL	e	Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	sv PSI	AVG.s PSI
Sam8/1d.1	7.3	7.2	0.1	0.014	3.3	1.30	1.34	5.0	50	37.18	
Sam8/2d.1	7.1	7.0	0.1	0.014	3.3	1.30	1.35	6.0	60	44.60	39.65
Sam8/3d.1	7.1	7.0	0.1	0.014	3.3	1.30	1.35	5.0	50	37.17	
Sam8/1d.1S	0.0	0.0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	
Sam8/2d.1S	0.0	0.0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	0.00
Sam8/3d.1S	0.0	0.0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	
Sam8/1d.7	7.1	7.0	0.1	0.014	3.3	1.30	1.35	10.0	100	74.34	
Sam8/2d.7	7.1	7.0	0.1	0.014	3.3	1.30	1.35	10.0	100	74.34	79.29
Sam8/3d.7	7.1	7.0	0.1	0.014	3.3	1.30	1.35	12.0	120	89.21	
Sam8/1d.14	7.4	7.3	0.1	0.014	3.3	1.30	1.34	11.0	110	81.82	
Sam8/2d.14	7.3	7.2	0.1	0.014	3.3	1.30	1.34	11.0	110	81.80	81.81
Sam8/3d.14	7.3	7.2	0.1	0.014	3.3	1.30	1.34	11.0	110	81.80	
Sam8/1d.14S	7.1	7.0	0.1	0.014	3.3	1.30	1.35	10.0	100	74.34	
Sam8/2d.14S	7.5	7.4	0.1	0.013	3.3	1.30	1.34	5.0	50	37.20	49.58
Sam8/3d.14S	7.5	7.4	0.1	0.013	3.3	1.30	1.34	5.0	50	37.20	
Sam8/1d.28	7.3	7.2	0.1	0.014	3.3	1.30	1.34	12.0	120	89.24	
Sam8/2d.28	7.3	7.2	0.1	0.014	3.3	1.30	1.34	12.0	120	89.24	91.28
Sam8/3d.28	7.4	7.2	0.2	0.027	3.3	1.30	1.36	13.0	130	95.37	
Sam8/1d.28S	7.3	7.1	0.2	0.027	3.3	1.30	1.36	10.0	100	73.33	
Sam8/2d.28S	7.0	6.9	0.1	0.014	3.3	1.30	1.35	9.0	90	66.89	69.05
Sam8/3d.28S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	9.0	90	66.93	

Table B-6 unconfined compressive strength results of Ratio 5

Ratio	L1	L2	DL	e	Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	sv PSI	AVG.s PSI
Sam9/1d.1	7.3	7.2	0.1	0.014	3.3	1.30	1.34	4.0	40	29.75	
Sam9/2d.1	7.3	7.2	0.1	0.014	3.3	1.30	1.34	5.0	50	37.18	34.70
Sam9/3d.1	7.2	7.1	0.1	0.014	3.3	1.30	1.34	5.0	50	37.18	
Sam9/1d.1S	0.0	0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	
Sam9/2d.1S	0.0	0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	0.00
Sam9/3d.1S	0.0	0	0.0	0.000	3.3	1.30	1.33	0.0	0	0.00	
Sam9/1d.7	7.4	7.3	0.1	0.014	3.3	1.30	1.34	9.0	90	66.94	
Sam9/2d.7	7.4	7.3	0.1	0.014	3.3	1.30	1.34	10.0	100	74.38	69.42
Sam9/3d.7	7.4	7.3	0.1	0.014	3.3	1.30	1.34	9.0	90	66.94	
Sam9/1d.14	7.5	7.4	0.1	0.013	3.3	1.30	1.34	10.0	100	74.40	
Sam9/2d.14	7.5	7.4	0.1	0.013	3.3	1.30	1.34	10.0	100	74.40	74.39
Sam9/3d.14	7.4	7.3	0.1	0.014	3.3	1.30	1.34	10.0	100	74.38	
Sam9/1d.14S	7.6	7.4	0.2	0.026	3.3	1.30	1.36	7.0	70	51.39	
Sam9/2d.14S	7.6	7.5	0.1	0.013	3.3	1.30	1.34	7.0	70	52.09	56.80
Sam9/3d.14S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	9.0	90	66.93	
Sam9/1d.28	7.5	7.4	0.1	0.013	3.3	1.30	1.34	11.0	110	81.83	
Sam9/2d.28	7.4	7.2	0.2	0.027	3.3	1.30	1.36	11.0	110	80.70	78.97
Sam9/3d.28	7.4	7.3	0.1	0.014	3.3	1.30	1.34	10.0	100	74.38	
Sam9/1d.28S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	10.0	100	74.37	
Sam9/2d.28S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	10.0	100	74.37	74.37
Sam9/3d.28S	7.3	7.2	0.1	0.014	3.3	1.30	1.34	10.0	100	74.37	

Table B-7 unconfined compressive strength results of Ratio 7

Ratio	L1	L2	DL	e	Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	sv PSI	AVG.s PSI
Sam10/1d.1	7.1	6.9	0.2	0.03	3.3	1.30	1.36	5.0	50	36.64	
Sam10/2d.1	7.1	6.9	0.2	0.03	3.3	1.30	1.36	4.0	40	29.31	31.75
Sam10/3d.1	7.1	6.9	0.2	0.03	3.3	1.30	1.36	4.0	40	29.31	
Sam10/1d.1S	0.0	0	0.0	0.00	3.3	1.30	1.33	0.0	0	0.00	
Sam10/2d.1S	0.0	0	0.0	0.00	3.3	1.30	1.33	0.0	0	0.00	0.00
Sam10/3d.1S	0.0	0	0.0	0.00	3.3	1.30	1.33	0.0	0	0.00	
Sam10/1d.7	7.1	6.9	0.2	0.03	3.3	1.30	1.36	9.0	90	65.95	
Sam10/2d.7	7.2	7.1	0.1	0.01	3.3	1.30	1.34	8.0	80	59.48	61.64
Sam10/3d.7	7.2	7.1	0.1	0.01	3.3	1.30	1.34	8.0	80	59.48	
Sam10/1d.14	7.0	6.9	0.1	0.01	3.3	1.30	1.35	10.0	100	74.32	
Sam10/2d.14	7.0	6.9	0.1	0.01	3.3	1.30	1.35	10.0	100	74.32	71.85
Sam10/3d.14	7.0	6.9	0.1	0.01	3.3	1.30	1.35	9.0	90	66.89	
Sam10/1d.14S	7.3	7.2	0.1	0.01	3.3	1.30	1.34	5.0	50	37.18	
Sam10/2d.14S	7.5	7.4	0.1	0.01	3.3	1.30	1.34	5.0	50	37.20	44.63
Sam10/3d.14S	7.5	7.4	0.1	0.01	3.3	1.30	1.34	8.0	80	59.52	
Sam10/1d.28	7.4	7.2	0.2	0.03	3.3	1.30	1.36	10.0	100	73.36	
Sam10/2d.28	7.4	7.3	0.1	0.01	3.3	1.30	1.34	10.0	100	74.38	76.52
Sam10/3d.28	7.4	7.3	0.1	0.01	3.3	1.30	1.34	11.0	110	81.82	
Sam10/1d.28S	7.3	7.2	0.1	0.01	3.3	1.30	1.34	9.0	90	66.93	
Sam10/2d.28S	7.2	7.1	0.1	0.01	3.3	1.30	1.34	7.0	70	52.05	54.74
Sam10/3d.28S	7.3	7.3	0.0	0.00	3.3	1.30	1.33	6.0	60	45.24	

Table B-8 unconfined compressive strength Result of Ratio 8

Ratio	L1	L2	L		Dia cm	Dia inc	A inch^2	Stress Reading	Stress*PR lb	v PSI	AVG.s. PSI
Sam10/1d.1	7.1	6.9	0.2	0.03	3.3	1.30	1.36	5.0	50	36.64	
Sam10/2d.1	7.1	6.9	0.2	0.03	3.3	1.30	1.36	4.0	40	29.31	31.75
Sam10/3d.1	7.1	6.9	0.2	0.03	3.3	1.30	1.36	4.0	40	29.31	
Sam10/1d.1S	0.0	0	0.0	0.00	3.3	1.30	1.33	0.0	0	0.00	
Sam10/2d.1S	0.0	0	0.0	0.00	3.3	1.30	1.33	0.0	0	0.00	0.00
Sam10/3d.1S	0.0	0	0.0	0.00	3.3	1.30	1.33	0.0	0	0.00	
Sam10/1d.7	7.1	6.9	0.2	0.03	3.3	1.30	1.36	9.0	90	65.95	
Sam10/2d.7	7.2	7.1	0.1	0.01	3.3	1.30	1.34	8.0	80	59.48	61.64
Sam10/3d.7	7.2	7.1	0.1	0.01	3.3	1.30	1.34	8.0	80	59.48	
Sam10/1d.14	7.0	6.9	0.1	0.01	3.3	1.30	1.35	10.0	100	74.32	
Sam10/2d.14	7.0	6.9	0.1	0.01	3.3	1.30	1.35	10.0	100	74.32	71.85
Sam10/3d.14	7.0	6.9	0.1	0.01	3.3	1.30	1.35	9.0	90	66.89	
Sam10/1d.14S	7.3	7.2	0.1	0.01	3.3	1.30	1.34	5.0	50	37.18	
Sam10/2d.14S	7.5	7.4	0.1	0.01	3.3	1.30	1.34	5.0	50	37.20	44.63
Sam10/3d.14S	7.5	7.4	0.1	0.01	3.3	1.30	1.34	8.0	80	59.52	
Sam10/1d.28	7.4	7.2	0.2	0.03	3.3	1.30	1.36	10.0	100	73.36	
Sam10/2d.28	7.4	7.3	0.1	0.01	3.3	1.30	1.34	10.0	100	74.38	76.52
Sam10/3d.28	7.4	7.3	0.1	0.01	3.3	1.30	1.34	11.0	110	81.82	
Sam10/1d.28S	7.3	7.2	0.1	0.01	3.3	1.30	1.34	9.0	90	66.93	
Sam10/2d.28S	7.2	7.1	0.1	0.01	3.3	1.30	1.34	7.0	70	52.05	54.74
Sam10/3d.28S	7.3	7.3	0.0	0.00	3.3	1.30	1.33	6.0	60	45.24	

APPENDIX C

Table C-1 Thailand soil quality standard

Index	Unit	Standard	Method
1 Volatile Organic Compound			
1) Benzene	Mg/ Kg	Less than 6.5	Gas Chromatography or Gas Chromatography/Mass Spectrometry (GC/MS)
2) Carbon Tetrachloride	"	Less than 2.5	"
3) 1,2-Dichloroethane	"	Less than 3.5	"
4) 1,1-Dichloroethylene	"	Less than 0.5	"
5) cis-1,2-Dichloroethylene	"	Less than 43	"
6) trans-1,2-Dichloroethylene	"	Less than 63	"
7) Dichloromethane	"	Less than 89	"
8) Ethylbenzene	"	Less than 230	"
9) Styrene	"	Less than 1,700	"
10) Tetrachloroethylene	"	Less than 57	"
11) Toluene	"	Less than 520	"
12) Trichloroethylene	"	Less than 28	"
13)1,1,1-Trichloroethan	"	Less than 630	"
14)1,1,2-Trichloroethane	"	Less than 8.4	"
15)Total Xylenes	"	Less than 210	"
2. Heavy metals			
1) Arsenic	Mg/kg	Less than 3.9	Inductively Coupled Plasma-Atomic Emission Spectrometry or Inductively Coupled Plasma-Mass Spectrometry or Atomic Absorption, Furnace Technique or Atomic Absorption, Gaseous Hydride or Atomic Absorption, Borohydride Reduction
2) Cadmium and compounds	"	Less than 37	"
3) Hexavalent Chromium	"	Less than 300	Coprecipitation, Colorimetric Chelation/Extraction

Index	Unit	Standard	Method
4) Lead	"	Less than 400	Inductively Coupled Plasma-Atomic Emission Spectrometry or Inductively Coupled Plasma-Mass Spectrometry or Atomic Absorption, Furnace Technique or Atomic Absorption, Gaseous Hydride or Atomic Absorption, Borohydride
5) Manganese and compounds	"	Less than 1,800	"
6) Mercury and compounds	"	Less than 23	Cold-Vapor Technique
3. Pesticides			
1) Atrazine	mg/Kg	Less than 22	Gas Chromatography
2) Chlordane	"	Less than16	Gas Chromatography/Mass Spectrometry (GC/MS)
3) 2,4-D	"	Less than 690	ใช้วิธี Gas Chromatography หรือวิธี High Performance Liquid Chromatography/Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS)
4) DDT	"	Less than 17	Gas Chromatography or Gas Chromatography/Mass Spectrometry (GC/MS)
5) Dieldrin	"	Less than 0.3	"
6) Heptachlor	"	Less than 1.1	"
7) Heptachlor Epoxide	"	Less than 0.5	"
8) Lindane	"	Less than 4.4	"
9) Pentachlorophenol	"	Less than 30	Gas Chromatography or Gas chromatography /Mass Spectrometry (GC/MS) or Gas Chromatography/Fourier Transform Infrared (GC/FT-IR)Spectrometry

Index	Unit	Standard	Method
4. Others			
1) Benzo (a) pyrene	mg/kg	Less than 0.6	Gas Chromatography/Mass Spectrometry (GC/MS) or Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS) or Gas Chromatography/Fourier Transform Infrared (GC/FT-IR) Spectrometry
2) Cyanide and compounds	"	Less than11	Total and Amenable Cyanide: Distillation or Total Amenable Cyanide (Automated Colorimetric, with off-line Distillation) or Cyanide Extraction Procedure for Solids and Oils
3) PCBs	"	Less than 2.2	Gas Chromatography
4) Vinyl Chloride	"	Less than1.5	Gas Chromatography or Gas Chromatography/Mass Spectrometry (GC/MS)

BIOGRAPHY

Miss Thantip Punmatharith was born on October 26, 1980 in Bangkok, Thailand. She graduated from Mahidol Wittayanusorn School in Nakorn Pathom in 1998. She received her Bachelor of Science Degree in Environmental Science from the Faculty of Science of Silpakorn University in 2002. She pursued her master's degree studies at the International Postgraduate Programs in Environmental Management, Inter-Department of Environmental Management, Chulalongkorn University, Bangkok, Thailand in May 2003. She finished her Master's of Science Degree in Environmental Management in May 2005.