COMPARISON OF LEACHING CONCENTRATIONS OF CHROMIUM FROM SOLIDIFIED SLUDGE IN SEA, BRACKISH, AND FRESH WATER

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In this study, the compressive strengths and the chromium-leaching concentrations from the tannery industrial sludge solidified by type I portland cement were studied. For leaching test, seawater, brackish water, and fresh water were used as leachants. The sludge content was tested at 55%, 65% and 75%, and the curing time was at 3, 7 and 14 days.

The results of this research were analyzed using ANOVA. The results showed that the compressive strength decreased with the increment of sludge content; and it increased with the increment of curing time. When the leaching of chromium from solidified sludge was studied, the results showed that for seawater, there were no proper sludge content and curing time that gave the compressive strength and chromium-leaching concentration that met the Department of Industrial Works Standard. The suitable sludge content and curing time for brackish water were 55% and 7 days. For freshwater, the most appropriate conditions were 55% of sludge content and 3 days curing time. The results of this research also indicated that the mean differences of chromium-leaching concentrations from the three types of leachants, seawater, brackish water, and freshwater, were significantly different. Chromium-leaching concentrations, from high to low, were found in seawater, brackish water and fresh water, respectively. The yielding results were probably due to the type of portland cement used which was not suitable for the saline condition. Thus, if the disposal of solidified waste near the coastal area is necessary, the type V portland cement should be used.

4036219 PHET/M สาขาวิชา : เทคโนโลยีสิ่งแวดล้อม ; วท.ม.(เทคโนโลยีสิ่งแวดล้อม)

อังก์ศิริ กลิ่นมาลี : การเปรียบเทียบการชะละลายของโครเมียมจากก้อนคอนกรีตที่ผ่านกระบวนการหล่อแข็งในน้ำทะเล น้ำกร่อย และน้ำจืด (COMPARISON OF LEACHING CONCENTRATIONS OF CHROMIUM FROM SOLIDIFIED SLUDGE IN SEA, BRACKISH AND FRESH WATER) คณะกรรมการควบคุมวิทยานิพนธ์ : นิภาพรรณ กังสกุลนิติ Dr.P.H. (ENV. H.), กฤษณ์ เฑียรฆประสิทธิ์ M.S. (ENV. H.), ธเรศ ศรีสถิตย์ Ph.D.(ENV. ENG) 135 หน้า. ISBN 974-664-032-1

ในการศึกษานี้ได้ทำการศึกษากำลังรับแรงอัดและความเข้มข้นของโครเมียมที่ถูกชะละลายออกมาจากก้อนคอนกรีตที่ผ่านกระบวนการหล่อแข็งกากตะกอนจากโรงงานฟอกหนังโดยใช้ปูนซีเมนต์พอร์ตแลนด์ชนิดที่ 1 สำหรับการทดสอบการชะละลายนั้น ตัวชะละลายที่ใช้ในการศึกษาครั้งนี้คือ น้ำทะเล น้ำกร่อย และน้ำจืด ปริมาณของกากตะกอนโครเมียมที่ใช้คือ 55% 65% และ 75% ส่วนระยะเวลาบ่มที่ทำการศึกษาคือ 3 วัน 7 วัน และ 14 วัน

ผลการวิจัยนี้ได้ทำการวิเคราะห์โดยใช้สถิติ ANOVA พบว่า ค่ากำลังรับแรงอัดจะลดลงเมื่ออัตราส่วนของกากตะกอนเพิ่มขึ้น แต่กำลังรับแรงอัดจะมีค่าสูงขึ้นเมื่อระยะเวลาในการบ่มคอนกรีตเพิ่มขึ้น เมื่อศึกษาถึงการชะละลายของโครเมียมจากก้อนคอนกรีตพบว่า ในน้ำทะเลไม่มีปริมาณกากตะกอนหรือระยะเวลาบ่มใดที่ให้กำลังรับแรงอัดและความเข้มข้นของโครเมียมได้ตามมาตรฐานของกรมโรงงานอุตสาหกรรม แต่สำหรับในน้ำกร่อยนั้นปริมาณกากตะกอนและระยะเวลาบ่มที่เหมาะสมคือ 55% และ 7 วันตามลำดับ และในน้ำจืดนั้นปริมาณกากตะกอนและระยะเวลาบ่มที่เหมาะสมคือ 55% และ 3 วัน นอกจากนี้จากผลการวิจัยยังชี้ให้เห็นว่า ค่าเฉลี่ยของความเข้มข้นโครเมียมที่ได้จากการทดสอบการชะละลายจากตัวชะละลายทั้ง 3 ชนิดนั้นแตกต่างกันอย่างมีนัยสำคัญ กล่าวคือโครเมียมจะถูกชะละลายออกมามากที่สุดในน้ำทะเล รองลงมาคือน้ำกร่อย และน้ำจืด ตามลำดับ ทั้งนี้อาจเนื่องมาจากชนิดของปูนซีเมนต์ที่ใช้ไม่เหมาะสมสำหรับสภาวะที่มีความเค็ม ดังนั้นหากจำเป็นต้องทำการฝังกลบในบริเวณชายฝั่งทะเลควรใช้ปูนซีเมนต์พอร์ตแลนด์ชนิดที่ 5 แทน

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CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

In Thailand, hazardous waste has been increased with the rapid growth of industrialization. According to the data in 1991, the sludge containing heavy metals was generated about 536,300 tons/yr and predicted to reach 1,658,200 tons/yr in 2001. (1) The large amount of heavy metal sludge causes a problem about the limitation of disposal site. Only a small amount is treated on-site and off-site because of the limited treatment plant capacity and the limited disposal technologies for this type of waste. Parts of them are disposed of by open-dumping or being dumped into the municipal landfill, some are stored in containers and kept within the factory areas (2).

The disposal of heavy metal sludge has to be done in proper way, so contamination of heavy metal to the environment will not cause adverse effects to the environment in the future. At present, it is not economical to recycle heavy metal in the sludge; hence, secured landfill has been adopted for the disposal purpose. Some pre-treatment methods have to be applied to this heavy metal sludge before being disposed of.

The stabilization/solidification techniques are used to minimize the toxicity of wastes. The techniques are employed to improve the physical characteristics of the waste before being dumped into the secured landfill sites. Hence, the release of pollutants from the waste into the environment is reduced..

Due to the rapid growth of industrialization and the limited sites available for landfill, in the future it is possible to use coastal areas or riverside areas for land disposal. When the landfill sites for hazardous waste located near coastal areas or riverside areas, the leaching characteristics of solidified sludge matrics under these conditions are of concern. Therefore, the study of leaching characteristics of solidified sludge on leachants of seawater, brackish water, and fresh water should be undertaken.

1.2 General Objective

The objective of this study is to compare the leaching of chromium from the solidified waste under three different leachants, namely, seawater, brackish water and freshwater.

1.3 Specific Objectives

1.3.1 To study the effect of sludge content on the compressive strength of solidified sludge.

1.3.2 To study the effect of curing time on the compressive strength of solidified sludge.

1.3.3 To study the effect of sludge content on the chromium leaching of solidified sludge.

1.3.4 To study the effect of curing time on the chromium leaching of solidified sludge.

1.3.5 To study the effect of different leachants (seawater, brackish water and freshwater) on the chromium leaching of solidified sludge.

1.4 Research Hypotheses

1.4.1 The compressive strength of solidified sludge decreases when the sludge content increases.

1.4.2 The compressive strength of solidified sludge increases when the curing time increases.

1.4.3 The chromium-leaching concentration of solidified sludge increases when the sludge content increases.

1.4.4 The chromium-leaching concentration of solidified sludge decreases when the curing time increases.

1.4.5 The concentrations of chromium leaching from solidified sludge are different on different leachants.

1.5 Research Variables

1.5.1 Independent Variables

- Sludge content
- Curing time
- Leachants

1.5.2 Dependent Variables

- Compressive strength
- Chromium concentration

1.5.3 Control Conditions

- w/c ratio
- Sand/cement ratio

1.6 Scope of the Study

1.6.1 For this experimental study, the heavy metal sludge samples are taken from Plasap Company, Samutprakarn. The sludge type is of tannery industry sludge containing chromium concentration of 107.4 gCr/kg. Before being used, it was oven dried at 103-105°c for 24 hours and grounded to powder size 0.5-5 mm.

1.6.2 Cementitious binders are the elephant brand ASTM type-I portland cement and coarse sand.

1.6.3 The leachants are seawater, brackish water and freshwater.

1.6.4 Leaching test follows the Extraction Procedure of the Department of Industrial Works.

1.7 Definition of Key Words

1.7.1 **Hazardous sludge** means the sludge containing chromium at high concentration.

1.7.2 **Leachants** mean seawater collected from Suan Son Beach, brackish water and freshwater collected from Maeklong River.

1.7.3 **Supernatant** means the solution above the shaken mixture.

1.7.4 **Curing** means keeping the concrete blocks after molding in the incubator at 23°c and 95% humidity.

1.7.5 **Molding** means placing the mixtures in the cube molds which have the internal size 5x5x5 cm^3.

1.7.6 **Solidification** means a process by which sufficient quantities of solidifying material, including solids, are added to the hazardous materials to result in a solidified mass of material.

1.7.7 **Portland Cement** means a hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition.(3)

1.7.8 **w/c ratio** means the portion between water and cement.

1.7.9 **Compressive strength** means kilograms of force that press on the cubes in the unit of kgf/cm^2

1.7.10 **Solidified sludge** means the hazardous material that added the sufficient quantities of solidifying material to result in a solidified mass of material.

1.8 Conceptual Framework

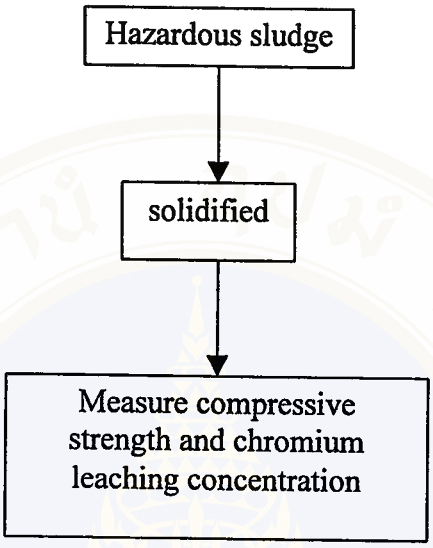


Figure 1 Conceptual Framework.

CHAPTER II

LITERATURE REVIEW

2.1 Hazardous Waste

A solid waste is classified as a hazardous waste if it is not excluded from regulation and it meets any of the description of items below: (4)

1. Ignitable substances

A solid waste that is not excluded from regulation that has any of the following properties:

a). It is a liquid, other than an aqueous solution containing less than 24% alcohol by volume, and has a flash point less than 60 °C (140 °F), as determined by Pensdy Martens Closed Cup Tester (ASTM D-93-79 or D-93-80) or Setaflash Closed Cup Tester (ASTM D-3278-78)

b). It is not a liquid and is capable under standard temperature and pressure, of causing fire through friction, absorption of moisture or spontaneous chemical changes, and when ignited burns so vigorously and persistently that it creates a hazard.

c). It is an ignitable compressed gas. It means any material or mixture having in the container an absolute pressure exceeding 2.81 Kg/cm^2 (40 psi) at 21 °C (70 °F) or, having an absolute pressure exceeding 7.31 kg/cm^2 (104 psi) at 55°C (130 °F) determined by ASTM D-323.

d). It is an oxidizer that yield oxygen readily when involved in a fire, thereby accelerating and intensifying the combustion of organic material. The samples of oxidizers such as chlorate, permanganate, inorganic peroxide and nitrates.

2. Corrosive Substances

A solid waste that is not excluded from regulation that has any of the following properties:

a). It is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5, as determined by US EPA Method 9040.

b). It is a liquid and corrodes steel (SAE 1020) at a rate grater than 6.35 mm (0.250 inch) per year at a test temperature of 55 °C (130 °F) as determined by NACE (National Association of Corrosion Engineers) Standard TM-01-69.

3. Reactive Substances

A solid waste that is not excluded from regulation that has any of the following properties:

a). It is normally unstable and readily undergoes violent change without detonating.

b). It reacts violently with water.

c). It forms potentially explosive mixtures with water.

d). When mixed with water, it generates toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment.

e). It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

4. Toxic Substances

A solid waste that is not excluded from regulation that has any of the following properties:

a). It presents a danger to human health and causes human die by only small quantity as determined by US EPA Toxicity Test Method.

b). It has Oral LD_{50} less than 50 mg/kg of rat weight or has Inhalation LC_{50} less than 100 ppm in gas or vapor phase for rats or has Dermal Rabbit LD_{50} less than 43 mg/kg of rabbit weight LD_{50} means the medium lethal dosage that causes the animals dying of 50%. The unit of LD_{50} is mg toxic substance/kg of animal weight. LC_{50} means medium lethal concentration in the media that cause animal dying of 50%. The unit of LC_{50} is part (by volume or by weight) of toxic substance per million (by volume or by weight) of media.

c). It is generated from Industrial Process that contaminated by carcinogen as identified in 1, 2A and 2B Group of International Agency for Research of Cancer.

d). It has Aquatic LC_{50} less tan 5 mg/l in 96 hours.

e). It has LC_{50} in 96 hours although it is diluted to less than 20%.

5. Leachable Substance

The solid waste that extracted by leachate extraction procedure and analyzed the leachate. The concentration of heavy metal or toxic substance in leachates will equal or more than these follow:

Arsenic (total)	5.0	mg/l
Barium	100.0	mg/l
Benzene	0.5	mg/l
Cadmium (Total)	1.0	mg/l
Carbon tetrachloride	0.5	mg/l
Chlordane	0.03	mg/l
Chlorobenzene	100.0	mg/l
Chloroform	6.0	mg/l
Chromium (total)	5.0	mg/l
ortho-Cresol	200.0	mg/l
meta-Cresol	200.0	mg/l
para-Cresol	200.0	mg/l

Cresol (total)	200.0	mg/l
2-4 d	10.0	mg/l
1,4-Dichlorobenzene	7.5	mg/l
1,4-Dichloroethane	0.5	mg/l
1,1-Dichloroethylene	0.7	mg/l
Endrin	0.02	mg/l
Heptachlor and its epoxide	0.008	mg/l
Hexachlorobenzene	0.13	mg/l
Hexachloroethane	3.0	mg/l
Lead (total)	5.0	mg/l
Lindane	0.4	mg/l
Mercury (total)	0.2	mg/l
Methoxychlor	10.0	mg/l
Methyl ethyl ketone	200.0	mg/l
Nitrobenzene	2.0	mg/l
2,4-Nitrotoluene	0.13	mg/l
Pentachlorophenol	100.0	mg/l
Pyridine	0.5	mg/l
Selenium	1.0	mg/l
Silver	5.0	mg/l
Tetrachloroethlene	0.7	mg/l
Toxaphene	0.5	mg/l
Trichloroethylene	0.5	mg/l

2,4,5-Trichlorophenol	400.0	mg/l
2,4,6-Trichlorophenol	2.0	mg/l
2,4,5-TP (Silvex)	1.0	mg/l
Vinyl chloride	0.2	mg/l

2.2 Metals of Environmental Concern

It seems obvious today why certain metals are of environmental concern (5). They are hazard in one way or another to human and/or other forms of life. The hazard to human may be in the form of acute or chronic toxicity, or the metal may act in more subtle ways, causing cancer and other secondary-effect diseases or damage to fetuses. Aquatic organisms in fresh water or marine environments are often extremely sensitive to very small concentrations of metals. Plant growth may be adversely affected by metals in soils and irrigation water, or may concentrate them in leaves, stems, or roots where they can subsequently affect the food chain. Mammals may be affected both through the food chain and by drinking contaminated water. On the other hand, trace amounts of many metals, including the "toxic metals," are vital to the human diet and that of lower forms of life. Metals exist naturally in the environment, originating from the leaching of soils by rain, ground, and surface water.

2.3 Chromium

Chromium (Cr) is the metal that have atomic weight of 52, specific gravity of 7.20, melting point of 1890 °C and the boiling point of 2482 °C. It is insoluble in water but soluble in dilute sulphuric and hydrochloric acids. It is a hard, brittle, lustrous, steel-grey metal which is very resistant to corrosion (5).

2.3.1 Occurrence

Elemental chromium is not found free in nature, and the only ore of any importance is the spinel ore, chromite or chrome iron stone, which is ferrous chromite (FeO Cr_2O_3), widely distributed over the Earth's surface. In addition to chromic oxide, this ore contains variable quantities of iron oxide, magnesium oxide and silica, as well as trace quantities of other substances. Only ores or concentrates containing more than 40% Cr_2O_3 are used commercially.

2.3.2 Chromium compounds

Chromium forms a number of compounds in various oxidation states. Those of +2 (chromous), +3 (chromic) and +6 (chromate) are the most important; the +2 state is basic, the +3 state amphoteric and the +6 state is acidic. Commercial applications mainly concern compounds in the +6 state, with some interest in +3 state chromium compounds.

The chromous state (+2) is very unstable since it is readily oxidized to the chromic state (+3); this therefore limits the use of chromous compounds. The chromic compounds are very stable and form many compounds which have commercial applications, the principal of which are chromic oxide and basic chromium sulphate.

Chromium in the +6 oxidation state has its greatest industrial application as a consequence of its acidic and oxidant properties, and its ability to form strongly colored and insoluble salts. The most important compound containing chromium in the +6 state are sodium dichromate, potassium dichromate and chromic acid. Most other chromate compounds are produced industrially using sodium dichromate as the source of +6 chromium.

2.3.3 Production

Ferrochrome, a chromium iron alloy, is usually produced by reduction of chromite ores with carbon in an electric furnace. The process leads to production of a high carbon ferrochrome whose use was restricted to high carbon steels. With increasing use of argon-oxygen decarburisation and similar processes in steel manufacture, this limitation is less severe. Sulfur must be kept low as it embattles both Cr metal and nickel base alloys to which Cr is added. The principal source of chromium metal in a pure form is by the reduction of chromic oxide (Cr_2O_3) with aluminium powder by the alumino-thermit process or by electrolysis of various chromium-containing solutions.

2.3.4 Uses

The principal uses of chromium are in the metallurgical processing of ferrochromium and other metallurgical products, chiefly stainless steel, and, to a much lesser extent, in the refractory processing of chrome bricks and chemical processing to make chromic acid and chromates.

Chromates are used for the oxidation of various organic materials, in the purification of chemicals, in inorganic oxidation, and in the production of pigments. A large percentage of chromic acid is used for plating. Dichromate is converted to chromic sulfate for tanning. Fungicides and wood preservatives consume an estimated 1.3 million kg of chromium annually. Chromates are used as rust and corrosion inhibitors, for example, in diesel engines. Because chromite has a high melting point and is chemically inert, it is used in the manufacture of bricks for lining metallurgical furnaces.

The important use of pure chromium is for chromium electroplating a wide range of equipment such as automobile parts and electrical equipment. Chromium is used extensively for alloying with iron and nickel to form stainless steels and with nickel, titanium, niobium, cobalt, copper and other metals, to form special purpose alloys.

2.3.5 Hazards

It is evident that chromium in the +3 oxidation state is considerably less hazardous. It is not readily absorbed from the digestive system and combines with proteins in the superficial layers of skin to form stable complexes.

This property probably accounts for the fact that chromic compounds do not cause dermatitis or chrome ulceration. In the +6 oxidation state, chromium compounds are irritant and corrosive and are absorbed by ingestion, through the skin and by inhalation.

The effects of chromium encountered in occupations where chromium compounds are manufactured and used are due to +6 chromium and involve mainly the skin and respiratory system. Occupational exposure to chromium and its compounds has been found to cause skin and mucous membrane irritation and corrosion, dermatitis and chrome ulceration, and been related to an increase in the incidence of lung cancer.

Typical industrial hazards are inhalation of the dust and fume arising during the manufacture of dichromate from chromite ore and the manufacture of lead and zinc chromates, inhalation of chromic acid mists during the electroplating and surface treatment of metals and skin contact with +6 chromium compounds in manufacture or use.

2.4 Hazardous Waste Treatment and Disposal

There are a lot of processes which can be applied to treat hazardous waste. (2, 4) The main process of waste are shown in Fig. 2.

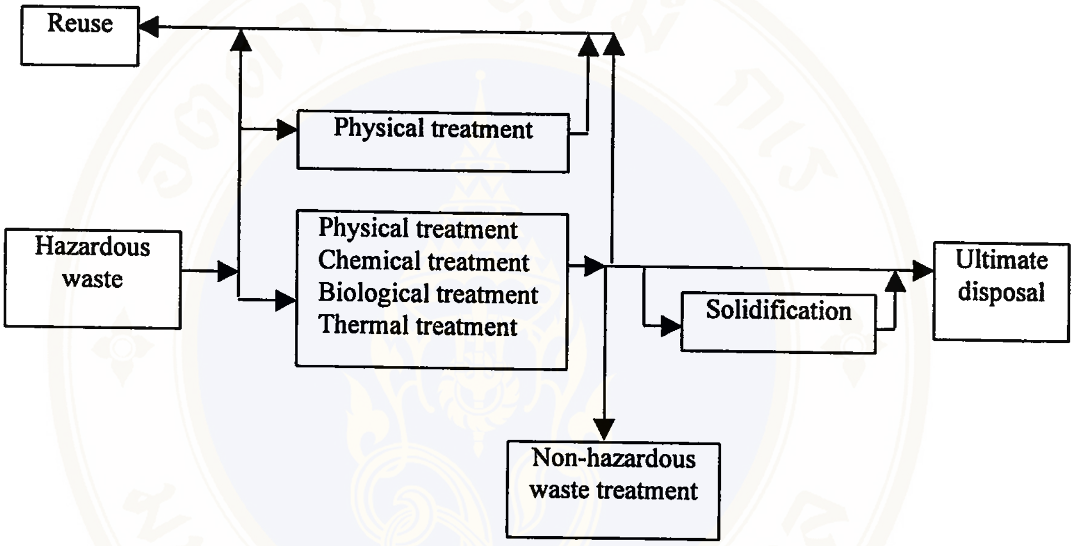


Figure 2 The process of Waste Treatment (2)

2.4.1 Physical Treatment

The physical processes acting in the subsurface determine how a chemical partitions in the subsurface media, which can have a significant effect on the environmental fate of a substance (6). These processes are often grouped together as centrifugation, steam distillation and steam stripping, multi-media filtration, reverse osmosis, micro-/ultra-filtration, evaporation, air floatation, gravity thickening and oil/water separator or coalescence separator. Note that phase changes can be thought of as physical or chemical processed, and are strongly affected by the chemistry of the system.

In 1996, one of physical treatment was studied by Power SE and Zander AK (7). Solar evaporation was used as a pretreatment process of mixed waste containing nitrate, cadmium, chromium and nickel. The waste characteristics were changed to be suitable forms for disposal by solidification technique. They reported that the process will fully develop a solidification process.

2.4.2 Physical/Chemical treatment

In many cases the hazardous and/or toxic material is only a portion of the whole waste, that generally is voluminous and heterogeneous (8). Under these circumstances it seems convenient to use, if possible, a separation process in order to transfer the toxic material to a phase which is more suitable for the successive chemical treatments. In this way the dangerous material is concentrated, and both homogeneity and reduction of mass and volume are also obtained. Among the unit operations, adsorption over activated carbon, leaching, or steam distillation are the most suitable for achieving these goals.

Soil washing, air stripping, activated carbon adsorption, precipitation /flocculation, dissolved air floatation, ion exchange and liquid/liquid extraction, filter press, dewatering, vacuum filtration and belt-press filtration are widely used.

2.4.3 Chemical treatment

It is obvious that, in this class of waste treatments, the major role is played by a reaction between the hazardous and/or toxic substance and a treatment chemical (7). This reaction is performed for the waste to lose both hazardous and toxicity. As for the case of physical/chemical treatments, there is a large number of possible processed, as almost any type of reaction can be performed, depending on the type of transformation needed to destroy the hazardous and toxic substances contained in the waste or to transform them into substances more appropriate for successive treatments and/or disposal.

Neutralization and pH adjustment, oxidation/reduction reactions, ozonation and UV/ozonation, electrodialysis, precipitation, dechlorination, and dehalogenation are widely used.

2.4.4 Biological treatment

Biological treatment of hazardous waste in generally used for removal of organic pollutants from wastewater (9). It is effective with wastewater having low-to-moderate concentrations of simple organic compounds and lower concentrations of complex organics. The biota is generally ineffective in attacking mineral components and is useless against heavy metal constituents.

Biological treatment of toxic organic components requires considerably more sophisticated operational control than is necessary with nontoxic wastewater. The microorganisms used in biological treatment processes can easily be destroyed by shock loading or rapid increases in the rate of feed.

The biological treatment units used for treatment of hazardous waste components in industrial wastewater are similar in configuration and operation to those used in municipal sewage treatment works. They include attached film reactors, activated sludge, anaerobic digestion, composting, stabilization pond, in situ biological decomposition and biological detoxification.

2.4.5 Thermal process for treatment and/or disposal

Organic compounds can be destroyed by thermal processes and, after scrubbing, leave only nontoxic gases to be discharged to the atmosphere; inorganic residues of ash and scrubber sludge to be landfilled; and salt water to be injected into deep wells, evaporated, or diluted and discharged (9).

Heavy metals are not destroyed by any process (thermal or otherwise), but thermal processes will destroy sulfides and cyanides and leave all metals in the form of metal oxides. The ash scrubber sludge can be stabilized, solidified, or converted to glassy slag, which may be safety landfilled.

Liquid injection incineration, cement kiln incineration and rotary kiln incineration and fluidized bed incineration are considered types of thermal treatment processed, although the intent with incineration is to destroy the waste. There are the less conventional methods of thermal treatment, such as wet-air oxidation and solar evaporation.

2.4.6 Land treatment and/or disposal

Land treatment is term that has been used to label the practice of spreading hazardous wastes on the land surface (9). The practice ostensibly uses the interaction between plants and the soil surface to stabilize the waste. There have been successful applications of the practice in the treatment and disposal of hydrocarbon waste from the petroleum industry and domestic sewage sludge. Chlorinated and other persistent compounds and wastes bearing heavy metals are not suitable for land applications for treatment or disposal. Sewage sludge containing heavy metals is similarly unsuitable. The practice requires very careful monitoring and controls to prevent contamination of surface and groundwater.

Land farming, spray irrigation, engineered, secured landfill, above ground long-term storage and deepwell injection are widely used.

2.5 Solidification and Stabilization

Solidification has been widely applied in the management of hazardous wastes (10). The technologies are being applied to a) the remediation of hazardous waste sites; b) the treatment of residue from other treatment process (e.g., the ash from thermal treatment); and c) the treatment of contaminated land where large quantities of soil containing contaminant are encountered.

In general terms, stabilization is process where additives are mixed with waste to minimize the rate of contaminant migration from the waste and to reduce the toxicity of the waste. Thus, stabilization may be describe as a process by which contaminants are fully or partially bound by the addition of supporting media, binders, or other physical nature of the waste (as measured by the engineering properties of strength, compressibility, and/or permeability) is altered during the process. Thus, objectives of stabilization and solidification would encompass both the reduction in waste toxicity and mobility as well as an improvement in the engineering properties of the stabilized material.

Stabilization and solidification are physiochemical process. This allows for more detailed examination of these widely employed hazardous waste management techniques include presentation of stabilization mechanisms, techniques, and design considerations along with the tests used to evaluate the treatment effectiveness.

2.5.1 Definition

Stabilization is a process employing additives (reagents) to reduce the hazardous nature of a waste by converting the waste and its hazardous constituents into a form :

a) to minimize the rate of contaminant migration into the environment,

or b) to reduce the level of toxicity.

Fixation is often used synonymously with stabilization. Stabilization is accomplished through the addition of reagents that :

a) improve the handling and physical characteristics of waste,

b) decrease the surface area across which transfer or loss of contaminants can occur,

c) limit the solubility of any pollutants contaminated in the waste, and

d) reduce the toxicity of the contaminants.

In contrast, **solidification** is described as a process by which sufficient quantities of solidifying material, including solids, are added to the hazardous materials to result in a solidified mass of material. Solidifying the mass is accomplished through the addition of reagents that :

a) Increase the strength,

b) decrease the compressibility, and

c) decreased the permeability of the waste.

The potential for contaminant loss from a solidified mass is usually determined by leaching tests. **Leaching** is the process by which contaminants are transferred from a solidified matrix to a liquid medium such as water.

2.5.2 Solidification Techniques

Solidification is a technology where a waste material is mixed with materials that tend to set into a solid, thus capturing or fixing the waste within the solid structure (2). The prime objective is to convert toxic waste streams into an inert, physically stable mass, having very low leachability and with sufficient mechanical strength to use for land reclamation, landfill, or other purpose. It is necessary that the solidified material obtained has "historic" stability properties. "Ten-year" stability or less as found in construction and public works, is not acceptable. One must aim at stabilizing waste for hundreds of years or more.

Solidification process used for waste disposal include : cement-based techniques; lime-based techniques; thermoplastic techniques (bitumen, paraffin, or polyethylene); thermosetting techniques); encapsulation; self-cementing techniques; and glassification (vitrification). The first two methods are commonly used and suitable for a large majority of inorganic wastes. Treatment costs for the remaining processes are generally higher; these latter techniques are reserved for problematic wastes, such as radioactive or those with a high organic content. Table 1 shows how to choose the best solidification technique for a given type of waste (11).

2.5.3 Cement-based Techniques

In these techniques, Ordinary Portland Cement (OPC) with pozzolanic materials such as fly ash, rice husk ash, cement kiln dust are generally used to improve the physical characteristics and decrease the leachate from the resulting solidified sample (2). The term "pozzolanic matreial" refers to the one which possesses high silica content. This term, originated by ancient Greeks and Romans, is also called puzzolana, pozzolan, puzzuolana and pozzolana. The concrete obtained from that process is called pozzolanic concrete and has pozzolanic properties, namely strength increases with time. The pozzolanic reactions present a problem for modern construction methods: they are slow, hence the use of portland cement which sets much more quickly.

The interpretation of cement-pozzolanic material reaction is that the formation of new hydrated compounds, namely, the tricalcium silicate hydrate during the hydration of cement. The net effect, it is claimed, is that the waste particles are micro-encapsulated within a largely gel matrix (2). Another interpretation is that the pozzolanic materials affect leaching rates by reducing the permeability of the hardened paste. It can also chemically react with the heavy metals to form complexes.

Special additives such as clay and sodium silicate are also used in an attempt to decrease the migration troublesome contaminants to the environment. Clay has been found to be successful adsorbent that can be incorporated into cement-waste structure. Sodium silicate has been used successfully to bind contaminants in cement fixation process.

Table 1 Solidification Techniques (11)

Technology	Solidification Process	Applicable Waste	Advantages	Disavantages
Cement and silicate based solidification/fixation	Chemical fixation/ Solidification	Dry or wet (generally inorganic)	Employs inexpensive materials Tolerant of diverse chemical conditions Very effective with heavy metal wastes Represents highly developed technology	Some organics detrimental to setting of concrete Uncoated cement/sludge mixtures subject to degradation and leaching under condition of low pH Increased weight and size of waste increase transport and landfilling costs
Lime based solidification/ fixation	Chemical fixation/ Solidification	Dry or wet (generally inorganic)	Employ in expensive materials Represents highly developed technology Addition of flyash allows disposal of two waste products in one process	Same as for cement and lilicate based solidification.fixation
Self-cementing techniques	Chemical fixation/ Solidification	Dry or wet	Process requires few additives Cement mixture sets very quickly	Some organics detrimental to setting of concrete Uncoated cement/sludge mixtures subject to degradation and leaching under condition of low pH Increased weight and size of waste increase transport and landfilling costs

Table 1 Solidification Techniques (continue)

Technology	Solidification Process	Applicable Waste	Advantages	Disavantages
				Requires expensive equipment and skill labor Processs restricted to wastes with a high calcium sulfite/sulfate content
Thermoplastic based solidification/fixation	Physical fixation	Dry (generally inorganic)	Vety effective in reducing chemical migration Leaching solutions have little effect on products	Requires expensive equipment and skill labor Wet waste reduce effectiveness of process Cannot be used with strong oxidants, dehydrated salts or thermoplastic solvents
Organic polymer processes	Physical fixation	Dry or wet (primarily toxic organics)	Only a small amount of fixative is required to form the polymer's matrix Relatively low density of product reduces transportation costs	Waste is held very loosely in the polymer Low pH of catalysis tends to make metals more soluble Biodegradability of some polymers may create landfilling problems
Vitrification	Physical fixation	Dry	Vitrified material has an extremely low leach rate Provides a high degree of containment Employs in expensive materials	High temperatures may vaporize some hazardous waste constituents before they are fixed Requires large heat expenditure, expensive equipment, and skilled personnel

Table 1 Solidification Techniques (continue)

Technology	Solidification Process	Applicable Waste	Advantages	Disavantages
				Costs prohibitive to all but high level radioactive and extremely toxic wastes
Encapsulation	Chemical containment	Dry or wet	Product is very water resistant Virtually leach-free as long as the inner jacket is intact Life cycle cost is competitive or lower than other technologies	Leaching will commence if jacket is damaged Not demonstrated on a large scale

2.5.4 Cement

Solidification of hazardous wastes frequently employs cement as the principal reagent (10). The most common cement is portland cement which is made by firing a mixture of limestone and clay (or other silicate) in a kiln at high temperatures. The kiln produces a clinker which is ground to a powder which is mixture of calcium, silicate, aluminium and iron oxides. The main constituents are tri- and di- calcium silicates. For cement-based solidification, waste materials are mixed with cement followed by the addition of water for hydration, if necessary because the waste does not have enough water. The hydration of the cement forms a crystalline structure consisting of calcium alumino-silicate. This results in a rock-like, monolithic, hardened mass. Concrete, by definition, is a particulate composite consisting of hydrated cement and aggregate.

In its simplest form, the reaction of the tricalcium silicate can be expressed by the reaction equation:

$$2(3CaO \cdot SiO_2) + 6H_2O \longrightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2$$

and the reaction of dicalcium silicate by:

$$2(2CaO \cdot SiO_2) + 4H_2O \longrightarrow 3CaO \cdot 2SiO_2 . 3H_2O + 3Ca(OH)_2$$

The resulting silicate gel is termed tobomorite. These reactions are quite slow, contributing to the lengthy time associated with portland cement concrete.

Cement-based solidification is best suited for inorganic wastes, especially those containing heavy metals. As a result of high pH of the cement, the metals are retained in the form of insoluble hydroxide or carbonate salts with in the hardened structure. Studies have shown that lead, copper, zinc, tin, and cadmium are likely bound in the matrix by chemical fixation, forming insoluble compounds while mercury is predominantly held by physical microencapsulation.

It is difficult to determine precisely where a specific contaminant will react within the solidified cement matrix. In a study of the binding chemistry of hazardous waste in cement, the locations of the heavy metals lead and chromium were studied. The results indicated that the lead precipitates on the outer surface of the hydrated cement particles whereas chromium was widely and more uniformly dispersed through the hydrated cement particles.

Solidification with cement has shown considerable promise and utilization for the fixation of inorganic wastes such as metal hydroxide sludges from the plating industry. The side use of solidification of inorganic derives from a) the lack of better alternatives (for example, metals do not biodegrade and do not change in atomic structure when incinerated) and b) available and understood physiochemical mechanisms such as precipitation and adsorption.

2.5.5 Portland Cement

Portland Cement is a finely ground material consisting primarily of compounds of lime, silica, alumina and iron (12). When mixed with water, it forms a paste which hardens and binds the aggregates (such as sand, gravel or crushed rock) to form a hard durable mass called concrete.

2.5.5.1. Setting and Hardening

When portland cement is mixed with water, a paste is formed. Which first sets (becomes firm) and then hardens. The setting and hardening are due to the chemical reaction between the cement and water. This reaction is called hydration and results in concrete, which has a strong internal structure and is hart, durable and watertight. The set and subsequent hardening process are the same whether the cement is used alone or in combination with aggregates. If the concrete is kept moist, the hydration reaction will continue for years and the concrete will become progressively stronger and more durable.

2.5.5.2. Type of Portland Cement

Portland cement is a type of cement, not a brand name. Each cement manufacturer makes portland cement. All portland cements are hydraulic cements. This means that they will set and harden under water.

Type I cement, normal portland cement, is a general-purpose cement suitable for all uses not requiring the special properties of the other types of cement. Type I cement is used in pavement and sidewalk construction, reinforced concrete buildings and bridges, railway structures, tanks and reservoirs, culverts, water pipe and masonry units. It is used for all cement or concrete construction not subject to sulfate attack from soil or water, or where the rise in temperature due to the heat generated by the hydration of the cement is not objectionable.

Type II cement, modified portland cement, has a lower heat of hydration than Type I cement and thus generates heat at a slower rate. It also has improved resistance to sulfate attack. It may be used to minimize the temperature rise in structures of considerable size such as large piers, heavy retaining walls. This is especially important when the concrete is placed in warm weather. In cold weather, when the heat generated is an advantage, Type I or II cement may be preferable. Type II cement is used when the added precaution against moderate sulfate attack is important, such as in drainage strictures where the sulfate concentration in the ground water are higher than normal but are not unusually severe.

Type III cement, high-early-strength portland cement, is used when high strengths are desired at very early periods, from one to three days after the concrete is placed this cement is used when it is desired to remove the forms as soon as possible, or to put the concrete into service quickly, In addition, it is used in cold weather constriction to reduce the necessary period of protection against low temperatures. Type III cement is also used when the high strengths desired at early periods can be obtained more satisfactorily or more economically with this cement than with richer mixes of Type I cement. Most prestressed concrete plants use this type of cement.

Type IV cement, low-heat portland cement, is a special cement for use where the amount and rate of heat generated must be kept to a minimum. The development of strength in this cement is also at a slower rate. Type IV cement is used for those types of construction in which large masses of concrete are placed, such as for large gravity dams where the temperature rise resulting from the heat generated during hardening is a critical factor.

Type V cement, sulfate-resistant portland cement, is a special cement to be used only in construction exposed to severe sulfate action, such as in some western states where the soil or water may have a high alkali content. Type V cement has a slower rate of strength gain than normal portland cement.

Different types of cement provide different results of solidification of waste. The differences of solidification efficiency between the two types of portland cement, type I and type II, were studied by Yang (13). The results showed that type II portland cement provided more solidification efficiency than that of type I. Pozzolanic cement and blast furnace cement in solidification process compared to portland cement were studied by Caludio and Sorbrinho in 1990 (14). The results showed that at start of curing time portland cement had more compressive strength than that of blast furnace cement and pozzolanic cement respectively. The pozzolanic cement showed the best result in 90 days. For the fixing efficiency, portland cement demonstrated the best result while blast furnace slag cement was the opposite (14).

2.5.6 Other binders

In general, cement has always been used as a binder. However, there are several types of binders being used in solidification press, such as fly ash, blast furnace slag, red mud, silica fume and rice husk ash. Adding some waste binders such as fly ash caused increasing heavy metal concentration and decreasing compressive strength of the solidified waste. The use of waste binders in solidification process was studied by Shin et al (15) and Kilinckale et al in 1997 (16). Rice husk ash, lignite fly ash, and cement were studied and compared for the best compressive strength. The results from the experiment demonstrated that lignite fly ash gave the best compressive strength. Furthermore, other research results demonstrated that the suitable ratio of lignite fly ash added to the waste was 35% (17). In addition, fly ash was also studied and compared to silica fume in the same way by Fuessle and Taylor (1994). They reported that fly ash gave the higher compressive strength than silica fume at a short term curing time (60 days). However, the result was the opposite for the long term curing time (335 days) (18). From these studies, it could be concluded that proper binder content and curing time would give good heavy metal fixing efficiency and the strengths that meet the standard. The advantage of waste binder addition is cost saving for waste disposal by solidification process.

2.5.7 Mixing Water

Water is used in concrete making for three different purposes: a) as mixing water; b) for curing of concrete; and c) for washing. The quality requirements for the water depend on the type of the use (19).

The mixing water, that is, the free water encountered in freshly mixed concrete, has three main functions: a) it reacts with the cement powder, thus producing hydration; b) it acts as a lubricant, contributing to the workability of the fresh mixture; and c) it secures the necessary space in the paste for the development of hydration products.

Impurities can be either dissolved in the water or present in the form of suspensions. Some of these impurities, above certain levels, may interfere with the hydration of the cement, thus changing setting times and reducing the strength of the concrete. Impurities may also cause staining on the concrete surface or increase the risk of corrosion of the reinforcement.

2.6 Extraction and Leaching Test

Wastes disposed on land are exposed to the liquid percolating through the cover or bottom liner material provided (10). This liquid comes from the surface drainage, rainfall and ground water. It leads to the decomposition of the wastes and the formation of a dark colored liquid containing suspended or dissolved waste. This liquid is called "leachate". The amount of hazardous constituents in the liquid plays the major role on the characteristics of the liquid whether it will deteriorate to the environment.

The extraction procedures for leaching test are divided into two groups: batch (shake) test and column test. In the batch test, the samples are continuously contacted with the same extract solution in a reaction vessel (2). In the column test, the fresh extract solutions are intermittent introduced to contact with a column packed sample. The advantages and disadvantages of both column and batch (shake) tests are compared in Table 2.

Regarding the difference between batch and column tests, Jackson et al. (1984) concluded that leachate generated by the column method was more of a simulated leachate from a disposal site than that of from the batch method. Besides, they reported that all organic compound concentrations in the first leachate subfraction from the column method were greater than those of the subsequent subfraction; which was in contrast to the batch method. They said that this trend implies that retardation in wetting of the hydrophobic waste limited the initial analyte concentrations. Furthermore, the total leaching capacity of analytes was much less when the column method was used, indicating a decrease in contact of leaching media with the waste material (20).

The column method was used by Shively et al. in 1986 (21) for testing the leaching of heavy metals stabilized with portland cement. They reported that there were small amounts of the metal at first three extractions, and increased during the next extractions. This finding corresponded to that of Bishop's study in 1988 (22).

Currently, various procedures of extraction and leaching tests are use in different laboratories; and it is therefore difficult to relate published results from these tests. Table 3 shows the comparison of extraction tests.

Table 2 Advantages and Disadvantages of Column and Batch Tests (2)

Advantages	Disadvantages
Batch (Shake) Test	
Edge effect in column test is avoided Time required for test is generally less than column test Results are more reproducible	Do not simulate the leaching environment in a landfill site Do not measure true leachate but equilibrium concentration A standard filtering procedure is required
Column test	
It simulates the waste-leachate content (except around the column) and the slow leachate migration found in landfill Good prediction of the release pattern with time	Channeling and non-uniform packing Clogging Biological growth Edge effects Time requirement Reproducibility

Table 3 Comparison of Extraction Tests (2)

Laboratory Procedure	Standard Leach Test	Toxicant Extraction Procedures	ASTM Method A	EP Tox (EPA Method 1310)
Amount of sample	28.6 g sample (solid fraction)	no minimum weight	350 g	100 g minimum (0.5 g solids)
Sample preparation	liquid separation, 0.45 µm pressure filtration	liquid separation, centrifugation/ filtration	anticipated field form	grind to 9.5 mm or subject to structural integrity test
Liquid/solid ratio	10:1 to 7:1	10:1 (8:1 initially)	4:1	20:1 (16:1 initially)
Extraction solution	buffered acetic acid/distilled water	acetic aced or sodium hydroxide	ASTM Type IV water	0.5 N acetic acid;maximum 4ml/g of sample
pH control	varied	4.9 to 5.2	none	4.8 to 5.2
Extraction vessel	closed container	none specified	wide mouth bottle (closed)	stirring device or equivalent
Method of mixing and time	rotating shaker 24 h	mechanical stirring 24 h	reciprocating shaker 48 h	continuous agitation 24 h
Liquid/solid separation	filter through 0.45 µm filter	centrifugation/ filtration, 0.45 µm x10 volume adjusted to fractions weight	0.45 µm filtration	0.45µm filtration
Number of elution	3	2	1	1
Moisture content addressed	yes	no	no	no

Table 4 EPToxicity Characteristic, Maximum Concentration of Contaminants (2)

EPA hazardous waste number	Contaminant	Maximum Concentration, mg/l
D004	Arsenic	5.0
D005	Barium	100.0
D006	Cadmium	1.0
D007	Chromium	5.0
D008	Lead	5.0
D009	Mercury	0.2
D010	Selenium	1.0
D011	Silver	5.0
D012	Endrin (1,2,3,4,10,10-hexachloro-1,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-5,8-dimethano-naphthalene)	0.02
D013	Lindane (1,2,3,4,5,6-hexa-chlorocyclohexane,gamma isomer)	0.4
D014	Methoxychlor (1,1,1-trichloro-2,2-bis[p-mehtoxyphenyl-ethane])	10.0
D015	Toxaphene (C10H10Cl8, technical polychloroinated camphene, 67-69% chlorine)	0.5
D016	2,4-D (2,4-dichlorophemoxyacetic acid)	10.0
D017	2,4,5-trichlorophenoxypropionic acid)	1.0

The sorption of different heavy metals yielded the different results for leaching test. A study by Cheng and Bishop in 1992 (23). They found that in the acidic solution (pH 5) 90% of Cd, 70% of Pb and 60% of As were desorped; but in the basic solution (pH 9) there was no desorption of any heavy metals (23). Besides, they also reported that the distribution of heavy metal after leaching occurred within the surface layer of the samples only (24).

2.7 Stabilization of Chromium in Solidified Waste

Leaching characteristics of heavy metal, chromium, from solidified sludge under seawater conditions were studied in 1990 by Shin et al (15). Seawater, acidic water and distilled water were used as a leachant. They reported that the chromium concentrations in the leachate samples were found under the Standard for all of the three leachants. This finding corresponded to Machutrakull's study in 1995 (25). Leaching of chromium from solidified sludge was studied in another condition. In 1995, Boy et al. studied the use of cement based systems for chromium stabilization and solidification of hazardous waste (26). They used blast furnace slag as a binder. The results showed that the replacement of 25% of the portland cement by blast furnace slag was found to decrease chromium concentrations (26). Another binder, fly ash, was used for stabilization of chromium in solidified sludge. This was the study of Teoprasong (1996) which reported that addition of fly ash was found to decrease chromium concentrations in the leachate (27).

2.8 Concrete in Seawater

Concrete is one of the main materials used in sea defence works and in the construction of docks ad harbours, and is subject to destructive activity both from physical pounding by the sea and from chemical attack by the salts contained in it.

The action of sea waves in causing extensive destruction of sea defense works during storms is well known. It is not always realized, however, that chemical attack may help physical destruction as well as physical destruction assisting the rate of chemical attack. Cracking leads to the penetration of seawater into the concrete; with reinforced concrete, corrosion of the reinforcement follows, and with plain concrete the depth of chemical attack is increased.

The chemical attack by seawater consists essentially of two part attacks of the concrete which is submerged, and attack of that which is just above the water level. In concrete which is just above high water level the seawater rises by capillary attraction. No concrete has zero absorption, so that by absorption and evaporation a strong concentration of salts is formed, with eventual crystallization. The salts react with the cement, and the growth of crystals physically disrupts the concrete.

Below water level, concrete is subject only to the chemical attack with perhaps some abrasion due to sand and gravel, depending upon the coastal situation. A few feet below the sea surface the impact force of waves is very much reduced, so that physical erosion and pounding is no as great.

The chemical attack by seawater is more complex than that of simple sulphate solutions, due to the presence of other chemicals. Chlorides tend to retard any swelling of the concrete which could result from reaction with sulphates only. In addition free lime is more soluble in seawater than plain water. The combined chemical and physical attack of seawater leads to more aggressive leaching than would take place in ground water containing a similar concentration of sulphates.

The chemical action of seawater on concrete is mainly due to the presence of magnesium sulphate (28). Magnesium sulphate reacts with the free calsium hydroxide in set Portland cement to form calcium sulphate, at the same time precipitating magnesium hydroxide; it also reacts with hydrated calcium aluminate to form calcium sulphoaluminate. These have often been assumed to be the actions primarily responsible for the chemical attack of concrete by seawater. It is, for instance, a common observation that deterioration of concrete in seawater is often not characterized by the expansion found in concrete exposed to sulphate solutions, but takes more the form of an erosion or less of constituents from the mass. Laboratory tests show that the presence of chlorides much retarded the swelling of concrete in sulphate solutions. It is also found that concrete that have suffered deterioration have lost part of their lime content. Both calcium hydroxide and calcium sulphate are considerably more soluble in seawater than in plain water and this, when combined with the conditions produced by wave motion, much lead to an increased leaching action.

Another factor that has attracted some attention is the effect of carbon dioxide. In normal seawater only small amounts of carbonate and bicarbonate are present, about 10 and 80 parts per million respectively, and small amount of free dissolved carbon dioxide. The pH varies between about 7.5 and 8.4, an average value for seawater in equilibrium with the carbon dioxide in the atmosphere being 8.2. In normal seawater some gradual carbonation of set cement occurs, and may indeed help by the formation of a protective surface skin, but it is doubtful if the free carbon dioxide content plays more than a minor part in the leaching of lime form concrete. Under exceptional conditions, seawater contain abnormal amount of dissolved carbon dioxide and then become much more aggressive, for carbonic acid behaves as a much stronger acid in seawater than in plain water. These conditions can arise in sheltered bays and estuaries if the sea-bed is covered by organic matter which in its decay produces carbon dioxide.

CHAPTER III

MATERIALS AND METHODS

3.1 Materials

3.1.1 Binder

The cementitious binder of elephant brand ASTM type-I portland cement manufactured by Siam Cement Company Ltd. was used.

3.1.2 Hazardous Sludges

The sludge samples were obtained from the Plasup Company, a tannery industry in Samutprakarn.

Characteristics of Sludge

a) blue in color
b) friable
c) low moisture content
d) chromium concentration was 107.4 g Cr/kg

The raw sludge was oven dried at 103-105 °c for 24 hours and ground to powder form. Then, the powdered-form sludge was mixed together in order to homogenize the sludge texture. After mixing, the homogenized sludge was passed through No.8 sieve (effective size 0.5-5 mm) before being used in the solidification process.

3.1.3 Sand

Natural river sand passing No. 8 sieve (generally called coarse sand)

3.1.4 Mixing Water

Ordinary tap water was used.

3.1.5 Leachants

3.1.5.1 seawater (salinity in the range of 29-35 ppt)
3.1.5.2 brackish water (salinity in the range of 7-13 ppt)
3.1.5.3 freshwater (salinity of 0 ppt)
3.1.5.4 distilled water

The pH of all leachants was adjusted in the range of 5.8-6.3.

3.1.6 Chemicals

3.1.6.1 Nitric acid

3.1.6.2 Hydrochloric acid

3.1.6.3 Sodium hydroxide

3.2 Equipment

3.2.1 Equipment for Mixing Sludge and Binder (29, 30)

a) Two decimal notation balance (Mettler PM 34, Delta)

b) The 2-inch or [50 mm] cube mold. The mold was made of hard metal not attacked by the cement mortar, as recommended by ASTM C 109

c) Mechanical Mixer that was an electrically driven mechanical mixer of the epicyclic type, which imparted both a planetary and a revolving motion to the mixer paddle.

d) Mixing Bowl. The removable mixing bowl giving a norminal capacity 4.73 L and made of stainless steel.

e) Paddle. The paddle was readily removable, made of stainless steel.

f) Tamper made of a non-absorption, non-abrassive, non-brittle material. The tamping face will be flat and at right angles to the length of the tamper.

g) Trowel, having a steel blade 4 to 6 inch [100 to 150 mm] in length, with straight edges.

h) Soiltest engineering test equipment.

i) Incubator (3949, Forma Scientific Inc.)

j) Flow Table and Frame. The apparatus was consisted of an integrally cast rigid iron frame and a circular rigid table top 10 ± 0.1 inch [254 ± 2.5 mm.] in diameter.

3.2.2 Equipment for Compressive Strength Test

Testing machine (UMH-50, SHIMADZU)

3.2.3 Equipment for Leaching Test

a) Sieve No.8 (effective size 0.5-5 mm.) (200 digit, Restch)

b) PP plastic bottles

c) Five decimal notation balance

d) Volumetric flask 500 ml

e) Erlenmayer flask 250 ml

f) Shaker (Physcrotherm, NEW BRUNSWICK)

g) Paper filter (Watman No.42)

h) Atomic absorption spectrophotometer (Spectra AA 640, VARIAN)

i) Salinity meter (S – 28, ATAGO)

j) pH meter (pH Scan I, EUTECH CYBERNETICS)

3.3 Methods

3.3.1 Composition of Mortar :

The ratio of cement to sand was 1:2 with replacing cement by 55%, 65%, and 75% of sludge. The water to cement ratio (w/c) was 1.8, 2.55 and 3.98 respectively. The amount of mixing water was added to produce a flow of 110 ± 5%.

3.3.2 Preparation of Mortar :

Procedure for Mixing Mortar was performed following the steps outline in C350-94 ASTM Standard (30).

Procedure : Place dry paddle and the dry bowl in the mixing position in the mixer. Then introduce the materials for a batch into the bowl and mix in the following manner.

a) Place all the mixing water in the bowl.

b) Add the mixture of cement and sludge in the water; then start the mixer and mix at the slow speed (140 ± 5 r/m) for 30 seconds.

c) Add the sand slowly over a 30-seconds period, while mixing at slow speed.

d) Stop the mixer, change to medium speed (285 ± 10 r/m), and mix for 30 seconds.

e) Stop the mixer and let the mortar stand for 1.5 minute. During the first 15 seconds if this interval, quickly scrape down into the batch any mortar that may have collected on the side of the bowl; then for the remainder for this interval, cover the bowl with the lid.

f) Finish by mixing for 1 min at medium speed (285 ± 10 r/m).

3.3.3 Determination of Flow :

Determination of flow was performed according to C109/109M-95 ASTM Standard (29).

Procedure : Carefully wipe the flow-table top clean and dry, and place the flow mold at the center. Place a layer of mortar about 1 inch or [25 min] in thickness in the mold and tamp 20 times with the tamper. The tamping pressure will be just sufficient to ensure uniform filling of the mold. Then fill the mold with mortar and tamp as specified for the first layer. Cut off the mortar to a plane surface, flush with the top of the mold, by drawing the straight edge of a trowel (held nearly perpendicular to the mold) with a sawing motion across the top of the mold. Wipe the table top clean and dry, being especially careful to remove any water from around the edge of the flow mold. Lift the mold away from the mortar 1 minute after completing the mixing operation. Immediately, drop the table through a height of 1/2 inch or [13 mm] 25 times in 15 seconds. Using the calipers, determine the flow by measuring the diameters of the mortar along the lines scribed in the table top, adding the four readings. The total of the four readings from the calipers equals the percent increase of the original diameter of the mortar. Make trial mortars with varying percentage of water until the specific flow is obtained.

3.3.4 Molding Test Specimens :

The following procedure was performed as outlined in C109/109M-95 ASTM Standard (31).

Procedure :

a) Immediately following completion of the flow test, return the mortar from the flow table to the mixing bowl. Quickly scrape the bowl sides and transfer into the batch the mortar that have collected on the side of the bowl and then remix the entire batch 15 s at medium speed. Upon completion of mixing, the mixing paddle will be shaken to remove excess mortar into the mixing bowl.

b) Start molding the specimens within a total elapsed time of not more than 2 min and 30 s after completion of the original mixing of the mortar batch. Place a later of mortar about 1 inch or [25 min] (approximately one half of the depth of the mold) in all of the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 seconds in 4 rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen. The tamping pressure will be just sufficient to ensure uniform filling of the mold. The 4 rounds of tamping (32 strokes) of mortar will be completed in one cube before going to the next. When the tamping of the first later in all of the cube compartments is completed, fill the compartments with the remaining mortar and then tamp as specified for the first later. Cut off the mortar to a plane surface flush with the top of the mold by drawing the straight edge of the trowel (held nearly perpendicular to the mold) with a sawing motion over the length of the mold.

3.3.5 Storage of Test Specimens

Immediately upon completion of molding, place the test specimen in the incubator at 23 °C, 95% humidity and then remove the specimens from the mold after 48 hours. Cured the specimens for 3, 7 and 14 days.

3.3.6 Extraction Procedure

The solidified samples, after testing for compressive strength, were tested for leaching using the Standard Procedure from the Department of Industrial Works (4) as follow :

a) The solidified samples are crushed and sieved to about 0.5-5 mm size.

b) Add 50 g of crushed sample to the 500 ml of leachant, seawater, brackish water and freshwater (for extraction procedure of the Department of Industrial Works using the distilled water) adjusted pH in the range of 5.8-6.3 in a 1,000 ml PP plastic bottles.

c) The bottles are shaken on the shaker, which is operated at 200 rpm at ambient temperature for 6 hours.

d) The solutions are filtrated through the paper filters No.42

e) Pipette100 ml of filtrated solution and acidify by adding nitric acid 3-5 ml. After adding, the solutions are digested to about 50 ml.

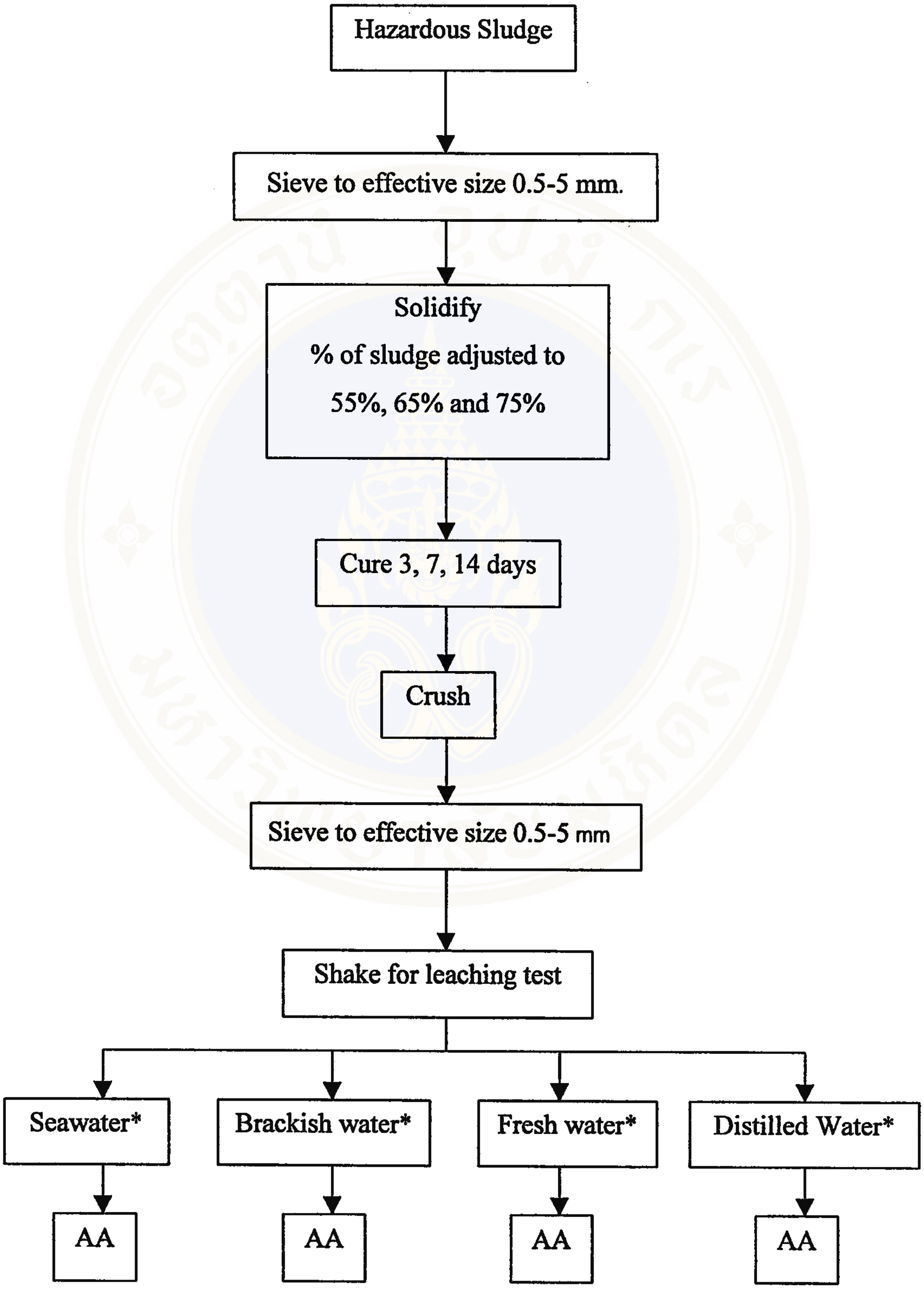
f) Adjust the volume of the digested solution to 100 ml by using distilled water.

g) After that, analyze the chromium concentration of the samples by using atomic absorption spectrophotometer.

3.4 Statistical Methods

ANOVA was used for explain the effect of sludge content and curing time on compressive strength and chromium-leaching concentration at P-value = 0.05. This statistical analysis was run on SPSS Program.

3.5 Experimental Strategy



* with adjusted pH in the range of 5.8-6.3

Figure 3 Experiment Strategy

CHAPTER IV

RESULTS

This research was conducted on the solidification of heavy metal sludge, which was a tannery industry sludge having the chromium concentration around 107.4 gCr/kg. The leaching concentrations of chromium from the solidified sludge in different leachants were investigated.

Type I portland cement and coarse sand were used in the solidification process. The contents of sludge were varied to be 55%, 65% and 75%. Chromium concentrations in the solidified samples were found to be around 34.39 g/kg, 41.27 g/kg and 41.39 g/kg respectively. The w/c ratios were 1.8, 2.55 and 3.98 respectively; and the curing times were 3, 7 and 14 days. After solidification process, the solidified cubes were measured for the compressive strength and chromium leaching concentrations in three leachants, seawater, brackish water and freshwater. Furthermore, the solidified sludge was also tested for chromium leaching in distilled water with adjusted pH in the range of 5.8-6.3 (the standard leachant as delineated in the Extraction Procedure of the Department of Industrial Works).

The results of these experiments were:

4.1 Effect of Sludge Content and Curing Time on Compressive Strength of Solidified Samples

Table 5 shows the compressive strength of solidified samples at 55%, 65% and 75% sludge content and 3, 7 and 14 days curing time.

Table 5 and Figure 4 show that the compressive strength decreased when sludge content increased. The mean compressive strength at 3 days curing time was 22.2407 kgf/cm^2 (S.D. = 0.8584) at 55% sludge content and decreased to 11.6364 kgf/cm^2 (S.D.= 0.6615) and 9.8422 kgf/cm^2 (S.D.= 0.5214) at 65% and 75% sludge content respectively. While the mean compressive strength at 7 days curing time was 22.3048 kgf/cm^2 (S.D.= 1.9530) and decreased to 10.8112 kgf/cm^2 (S.D.= 0.8246) and 5.8252 kgf/cm^2 (S.D.= 0.7108) at 55%, 65% and 75% sludge content respectively. Similarly, at 14 days curing time, the mean compressive strength was 37.6402 kgf/cm^2 (S.D.= 2.0515) and decreased to be 15.3894 kgf/cm^2 (S.D.= 0.8841) and 8.3780 kgf/cm^2 (S.D.= 0.8741) respectively.

Table 5 Compressive Strength of Samples

Sludge content (%)	Curing time (days)	*Compressive Strength (kgf/cm^2)				
		1	2	3	4	mean
55	3	21.5684	22.2087	22.4648	22.7209	22.2407
	7	23.3616	19.2633	23.4893	23.1051	22.3048
	14	35.0149	37.9603	38.8567	38.7287	37.6402
65	3	12.1009	11.9087	10.6271	11.9087	11.6364
	7	11.3234	10.9392	11.3234	9.6586	10.8112
	14	14.6530	16.4459	15.2933	15.1653	15.3894
75	3	10.1786	10.1145	10.0504	9.0252	9.8422
	7	6.5211	5.4966	5.1124	6.8617	5.8252
	14	9.3456	8.6407	7.5514	7.1669	8.3780

*Department of Industrial Works Standard is not less than 14 kgf/cm^2

When the curing time was considered, it was found that at all percentage of sludge content, the maximum compressive strength occurred at 14 days curing time and decreased at 3 days and 7 days curing time as shown in Table 5 and Figure 5.

Firstly, at 55% sludge content, the compressive strengths were 22.2407 kgf/cm^2 (S.D. = 0.8584), 22.3048 kgf/cm^2 (S.D. = 1.9530) and 37.6402 kgf/cm^2 (S.D. = 2.0515) at 3, 7 and 14 days curing time respectively. For 65% sludge content, the compressive strengths were 11.6364 kgf/cm^2 (S.D. = 0.6615), 10.8112 kgf/cm^2 (S.D. = 0.8245) and 15.3894 kgf/cm^2 (S.D. = 0.8841), respectively. Lastly, at 75% sludge content, the compressive strengths were 9.8422 kgf/cm^2 (S.D. = 0.5214), 5.8252 kgf/cm^2 (S.D. = 0.7108) and 8.3780 kgf/cm^2 (S.D. = 0.8741), respectively.

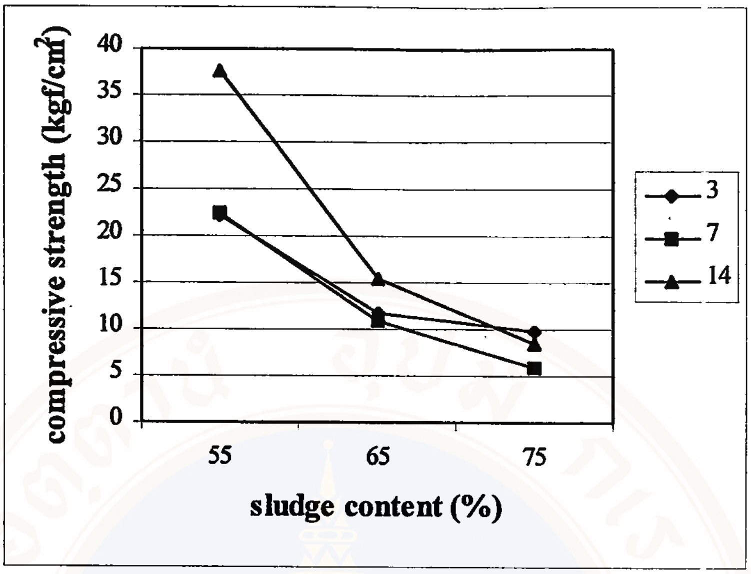


Figure 4 Effect of Sludge Content on Compressive Strength

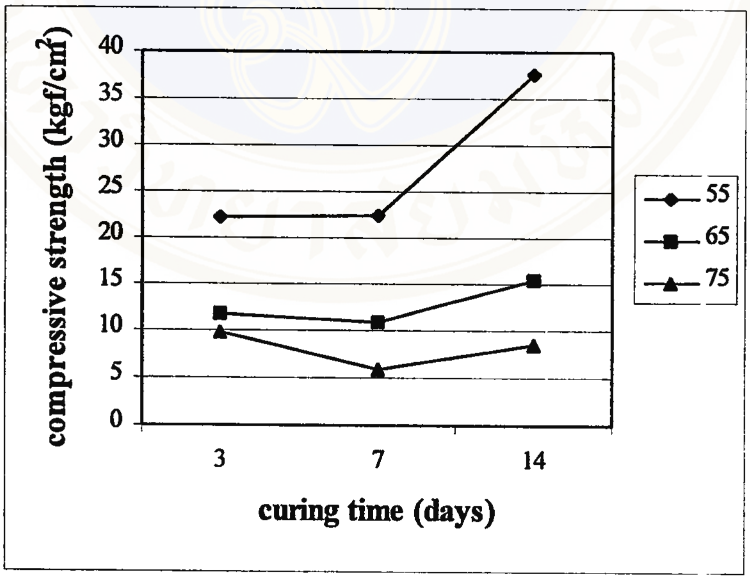


Figure 5 Effect of Curing Time on Compressive Strength

Statistical analysis "ANOVA" was employed to test whether sludge content and curing time had an effect on the compressive strength; and whether there was an interaction between the independent variables. The statistical analysis at P-value of <0.05 demonstrated that there was an effect from sludge content and curing time on the compressive strength and there was an interaction between the pair (sludge content and curing time). The results are shown in Table 6.

Table 6 Effect of Sludge Content and Curing Time on the Compressive Strength of the Samples and the Interaction between each Pair

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9178.484[b]	8	1147.311	827.826	0.000
Intercept	26496.5	1	26496.5	19118.2	0.000
Sludge Content	7101.511	2	3550.755	2561.998	0.000
Curing Time	1055.080	2	527.540	380.639	0.000
Sludge Content * Curing Time	972.762	4	243.190	175.471	0.000
Error	131.664	95	1.386		
Total	37112.0	104			
Corrected Total	9310.148	103			

a. Computed using alpha = .05

b. R Squared = .986 (Adjusted R Squared = .985)

* means the interaction

Because sludge content and curing time were found to affect the compressive strength; the mean difference of the compressive strength of the samples should be determined. For this purpose, Post Hoc Tests (Tukey) were done at 0.05 level of significance. The results are shown in Table 7 and 8.

In order to determine the effect of sludge content on the compressive strength; the curing time was fixed was fixed in this analysis.

Table 7 Multiple Comparisons of Mean Difference of the Compressive Strength : Sludge Content

Sludge Content (I)	**Sludge Content (II)**	**Curing Time = 3 days**		**Curing Time = 7 days**		**Curing Time = 14 days**	
		DF	**Sig.**	**DF**	**Sig.**	**DF**	**Sig.**
55	65	10.6043*	.000	11.4937*	.000	22.2508*	.000
	75	12.3895*	.000	16.4796*	.000	29.2622*	.000
65	55	-10.6043*	.000	-11.4937*	.000	-22.251*	.000
	75	1.7942*	.000	4.9860*	.000	7.0114*	.000
75	55	-12.3985*	.000	-16. 4796*	.000	-29.262*	.000
	65	-1.7942*	.000	-4.9860*	.000	-7.0114*	.000

DF means the mean difference between sludge content (I) and (II)

* The mean difference is significant at the 0.05 level.

The results from Table 7 show that there was significant difference of the mean compressive strength between each pair of sludge content (P<0.05) at each level of curing time. Moreover, the statistical analysis at P-value of 0.05 demonstrated that the mean compressive strength of the samples at 55% sludge content was greater than at 65% and 75% sludge content respectively.

When the curing time was considered, the results from Table 8 show that the mean compressive strength of the samples were significantly different (P<0.05). The mean difference between the three pairs at the P-value of 0.05 indicated that the maximum mean compressive strength of the samples occurred at 14 days curing time and decreased at 3 days and 7 days. This occurs only at 55% and 65% sludge content but at 75% the results are not in the same way.

Table 8 Multiple Comparisons of Mean Difference of the Compressive Strength : Curing Time

Curing Time (I)	**Curing Time (II)**	**Sludge Content = 55%**		**Sludge Content = 65%**		**Sludge Content = 75%**	
		DF	**Sig.**	**DF**	**Sig.**	**DF**	**Sig.**
3	7	-6.41E-02	.995	0.8252*	.041	4.0170*	.000
	14	-15.3995*	.000	-3.7530*	.000	1.4642*	.000
7	3	6.41E-02	.995	-0.8252*	.041	-4.0170*	.000
	14	-15.3353*	.000	-4.5782*	.000	-2.5528*	.000
14	3	15.3995*	.000	3.7530*	.000	-1.4642*	.000
	7	15.3353*	.000	4.5782*	.000	2.5528*	.000

DF means the mean difference between curing time (I) and (II)

* The mean difference is significant at the 0.05 level.

4.2 Effect of Sludge Content and Curing Time on Chromium-Leaching Concentration of Solidified Samples in Different Leachants

The chromium-leaching concentrations in leachate at sludge content of 55%, 65% and 75%, at 3, 7 and 14 days curing time were shown in Table 9, 10, and 11 and 12. Seawater, brackish water, freshwater and distilled water were used as a leachant.

4.2.1 Seawater

The results in Table 9 show that at 3 days curing time, chromium leaching concentrations were 6.9383 mg/l (S.D. = 0.04), 2.5513 mg/l (S.D. = 0.2911) and 4.8170 mg/l (S.D. = 0.031) for 55%, 65% and 75% sludge content respectively. For 7 days curing time, chromium-leaching concentrations were 5.2753 mg/l (S.D. = 0.065), 3.5300 mg/l (S.D. = 0.093) and 6.8053 mg/l (S.D. = 0.1034), respectively. At last, 14 days curing time, chromium-leaching concentrations were 8.0040 mg/l (S.D. = 0.1837), 8.5090 mg/l (S.D. = 0.056) and 8.0847 mg/l (S.D. = 0.035), respectively. Figure 6 and 7 show the effect of sludge content and curing time on chromium-leaching concentration as described above.

Table 9 Chromium-leaching Concentration in Seawater

Curing time (days)	Sludge content (%)	*Chromium-Leaching Concentration (mg/l)			
		1	2	3	mean
3	55	6.976	6.897	6.942	6.9383
	65	2.749	2.688	2.217	2.5513
	75	4.580	4.788	4.813	4.8170
7	55	5.204	3.439	6.769	5.2753
	65	5.331	3.527	6.725	3.5300
	75	5.291	3.642	6.922	6.8053
14	55	7.826	7.993	8.193	8.0040
	65	8.456	8.504	8.567	8.5090
	75	7.975	8.325	8.325	8.0847

*Department of Industrial Works Standard is not more than 5 mg/l

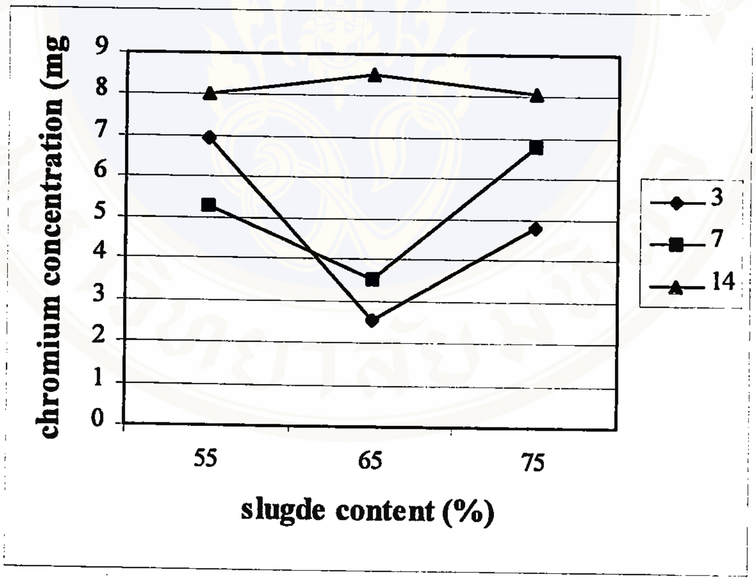


Figure 6 Effect of Sludge Content on Chromium-Leaching Concentration in Seawater

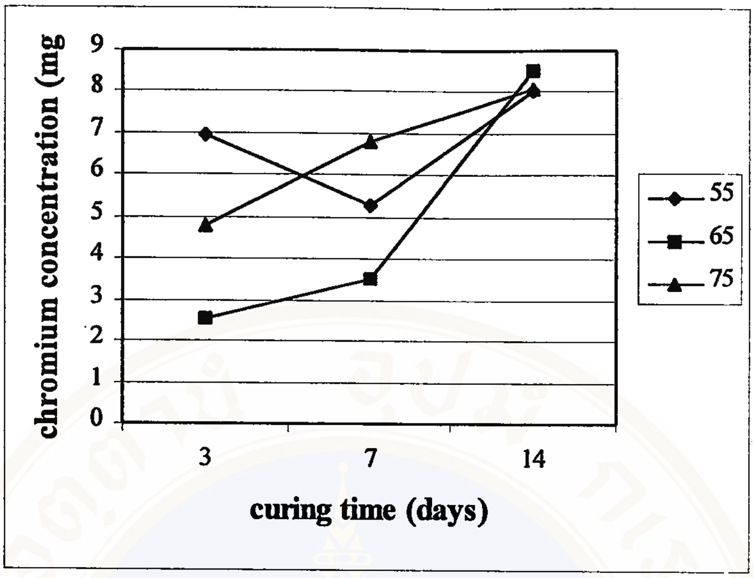


Figure 7 Effect of Curing Time on Chromium-leaching Concentration in Seawater

4.2.2 Brackish Water

At 3 days curing time, chromium-leaching concentrations were 5.9273 mg/l (S.D. = 0.2852), 2.3653 mg/l (S.D. = 0.1495) and 5.5057 mg/l (S.D. = 0.1425) for 55%, 65% and 75% sludge content respectively. For 7 days curing time, chromium-leaching concentrations were 3.2698 mg/l (S.D. = 0.1384), 3.1502 mg/l (S.D. = 0.2970) and 5.7048 mg/l (S.D. = 0.3525), respectively. At last, 14 days curing time, chromium-leaching concentrations were 6.0085 mg/l (S.D. = 0.026), 6.4452 mg/l (S.D. = 0.1764) and 7.0945 mg/l (S.D. = 0.1681), respectively. As shown in Table 10, Figure 8 and Figure 9.

Table 10 Chromium-leaching Concentrations in Brackish Water

Curing time (days)	Sludge content (%)	*Chromium-leaching Concentration (mg/l)			
		1	2	3	mean
3	55	5.616	6.176	5.990	5.9273
	65	2.538	2.281	2.277	2.3653
	75	5.510	5.361	5.646	5.5057
7	55	3.339	3.111	3.3605	3.2698
	65	2.951	3.492	3.009	3.1502
	75	5.572	6.105	5.439	5.7048
14	55	6.008	5.984	6.035	6.0085
	65	6.242	6.550	6.545	6.4452
	75	6.936	7.078	7.271	7.0945

*Department of Industrial Works Standard is not more than 5 mg/l

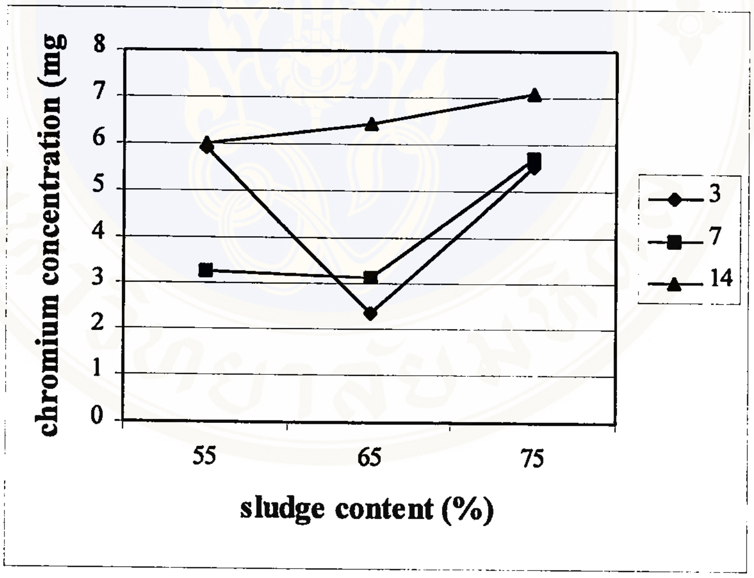


Figure 8 Effect of Sludge Content on Chromium-leaching Concentration in Brackish Water

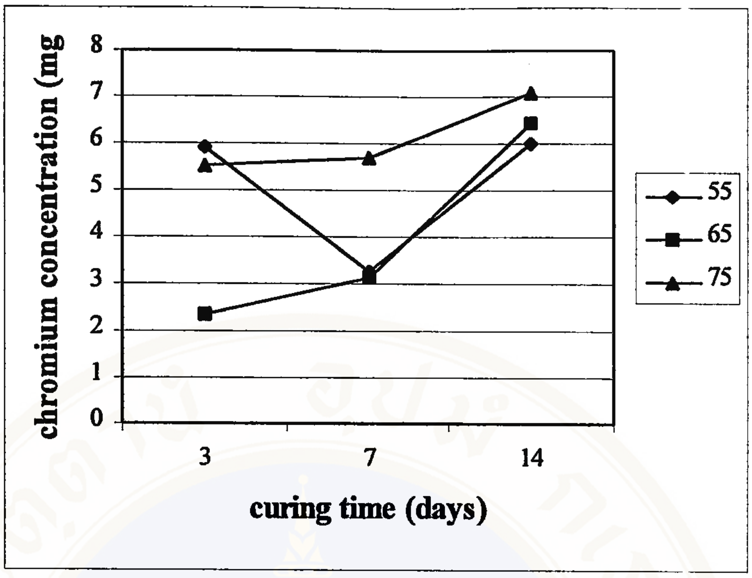


Figure 9 Effect of Curing Time on Chromium-leaching Concentration in Brackish Water

4.2.3 Freshwater

Chromium-leaching concentration at 3 days curing time were 0.7187 mg/l (S.D. = 0.018), 0.6067 mg/l (S.D. = 0.02) and 1.9840 mg/l (S.D. = 0.1697) for 55%, 65% and 75% sludge content respectively. For 7 days curing time, chromium-leaching concentration were 0.6332 mg/l (S.D. = 0.024), 0.6658 mg/l (S.D. = 0.021) and 1.5558 mg/l (S.D. = 0.0032), respectively. The last, 14 days curing time, chromium-leaching concentration were 0.8977 mg/l (S.D. = 0.037), 1.3513 mg/l (S.D. = 0.035) and 2.7293 mg/l (S.D. = 0.1395), respectively. These are shown in Table 11 and demonstrated by Figure 10 and Figure 11.

Table 11 Chromium-leaching Concentrations in Freshwater

Curing time (days)	Sludge content (%)	*Chromium-leaching concentration (mg/l)			
		1	2	3	mean
3	55	0.698	0.725	0.7333	0.7187
	65	0.585	0.625	0.610	0.6067
	75	2.138	2.012	1.802	1.9840
7	55	0.650	0.645	0.606	0.6332
	65	0.674	0.643	0.682	0.6658
	75	1.555	1.554	1.560	1.5558
14	55	0.930	0.905	0.858	0.8977
	65	0.139	1.352	1.316	1.3513
	75	2.774	2.573	2.841	2.7293

*Department of Industrial Works Standard is not more than 5 mg/l

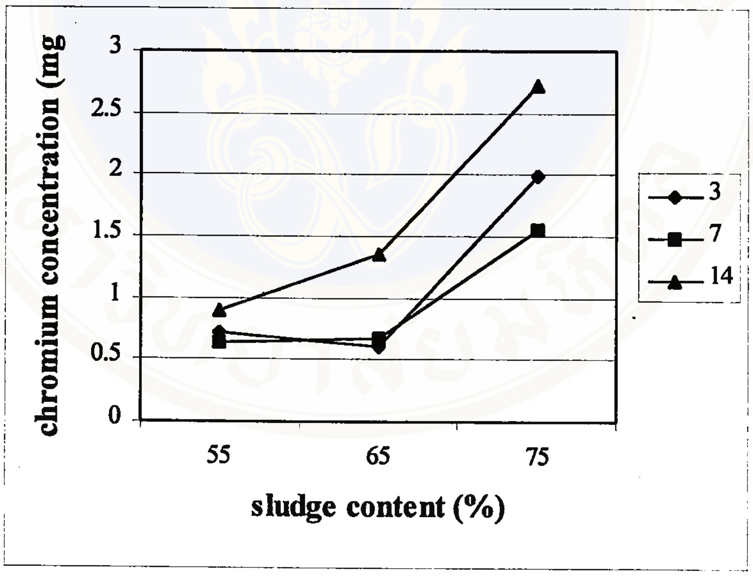


Figure 10 Effect of Sludge Content on Chromium-Leaching Concentration in Freshwater

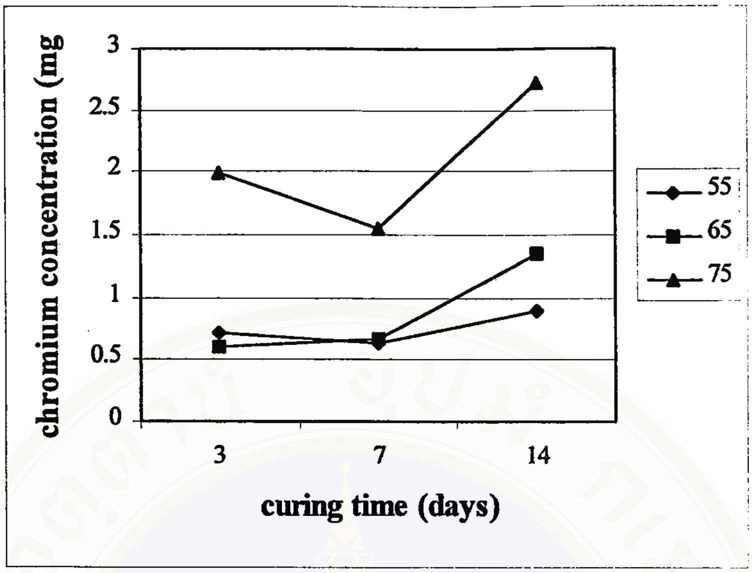


Figure 11 Effect of Curing Time on Chromium-leaching Concentration in Freshwater

4.2.4 Distilled Water

In this section of the experiment, the same curing time and sludge content were used as the previous section but the leachant was changed to be distilled water with adjusted pH in the range of 5.8-6.3. This was the standard leachant as delineated in the Extraction Procedure of the Department of Industrial Works.

When chromium-leaching concentration of the samples was considered, (Table 12 Figure 12 and Figure 13), at 3 days curing time, the chromium-leaching concentration of the samples were 0.7773 mg/l (S.D. = 0.092), 0.6717 mg/l (S.D. = 0.022) and 2.5443 mg/l (S.D. = 0.061) at 55%, 65% and 75% sludge content respectively. At 7 days curing time, the chromium-leaching concentrations of the samples were 0.5673 mg/l (S.D. = 0.0049), 0.6380 mg/l (S.D. = 0.011) and 1.5093 mg/l (S.D. = 0.3831), respectively. At 14 days curing time, the chromium-leaching concentrations of samples were 0.7610 mg/l (S.D. = 0.0092), 1.2477 mg/l (S.D. = 0.014) and 2.4223 mg/l (S.D. = 0.032), respectively.

Table 12 Chromium-leaching Concentration in Distilled Water

Sludge content (%)	Curing time (days)	*Chromium-leaching Concentration (mg/l)			
		1	2	3	mean
55	3	0.751	0.880	0.701	0.7773
	7	0.565	0.573	0.564	0.5673
	14	0.759	0.771	0.753	0.7610
65	3	0.656	0.697	0.662	0.6717
	7	0.645	0.625	0.644	0.6380
	14	1.248	1.234	1.261	1.2477
75	3	2.597	2.477	2.559	2.5443
	7	1.067	1.737	1.724	1.5093
	14	2.432	2.448	2.387	2.4223

*Department of Industrial Works Standard is not more than 5 mg/l

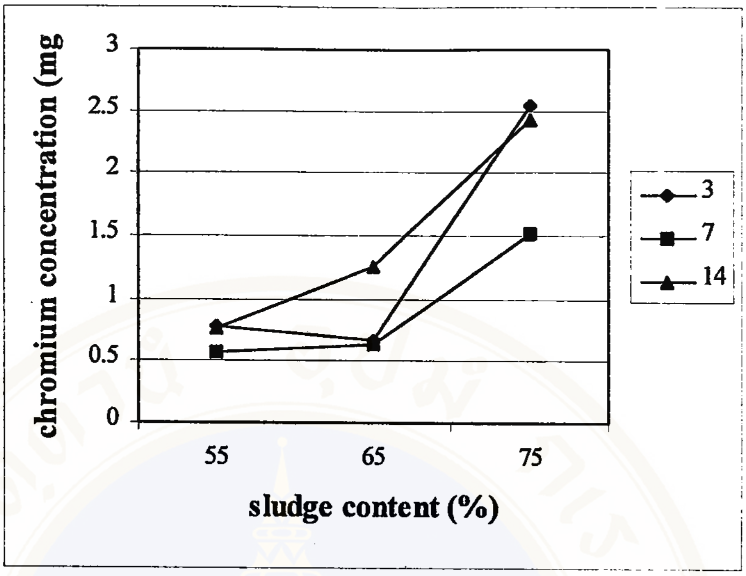


Figure 12 Effect of Sludge Content on Chromium-leaching Concentration in Distilled Water

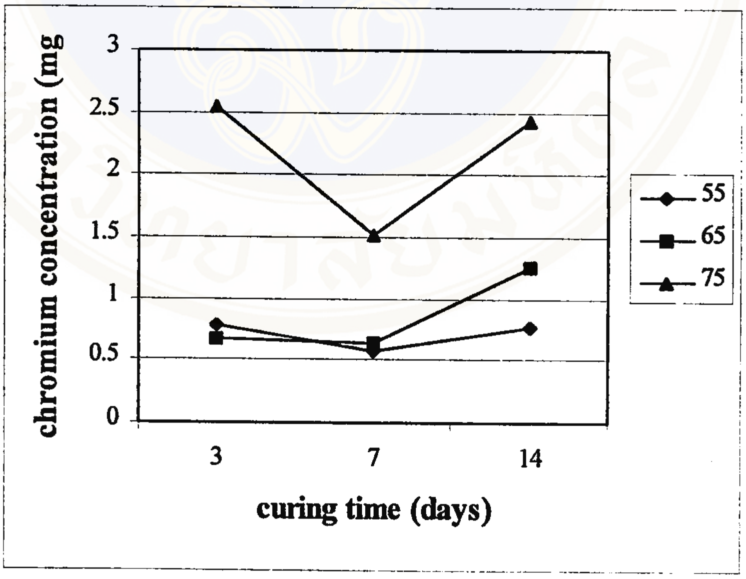


Figure 13 Effect of Curing Time on Chromium-leaching Concentration in Distilled Water

The effect of sludge content, curing time and type of leachant on chromium-leaching concentration and the interaction between the three pairs (sludge content-curing time, sludge content-leachant and curing time-leachant) were tested by ANOVA in the same way as previous section. The results indicated that there was an effect from each factor on the chromium-leaching concentration and there was an interaction between each pair of the three factors at 0.05 level of significance (Table 13).

Table 13 Effect of Sludge Content, Curing Time and Type of Leachant on the Chromium-leaching Concentrations of the Samples and the Interaction between each Pair

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	696.704[b]	23	30.291	103.222	0.000
Intercept	1245.785	1	1245.79	4245.191	0.000
Sludge Content	45.602	2	22.801	77.698	0.000
Curing Time	61.985	2	30.993	105.612	0.000
Leachant	516.801	3	172.297	587.025	0.000
Sludge Content * Curing Time	21.785	4	5.446	18.559	0.000
Sludge Content * Leachant	15.311	6	2.552	8.696	0.000
Curing Time * Leachant	35.219	6	5.870	20.002	0.000
Error	24.650	84	0.293		
Total	1967.139	108			
Corrected Total	721.354	107			

a. Computed using alpha = .05

b. R Squared = .966 (Adjusted R Squared = .956)

* means the interaction

The following section is the results of an effect of sludge content on chromium-leaching concentration. For this purpose, the curing time and type of leachant had to be fixed while the statistical analysis was employed. The differences between the means of the chromium-leaching concentrations were compared. The results are shown in Table 14.

Table 14 Multiple Comparisons of Mean Difference of Chromium-leaching Concentrations : Effect of Sludge Content

Leachant	Curing Time (days)	Results of Comparison between the Chromium-Leaching Concentration
Seawater	3	55 > 75 > 65
	7	75 > 55 > 65
	14	65 > [55 = 75]
Brackish Water	3	[55 = 75] > 65
	7	75 > [55 = 65]
	14	75 > 65 > 55
Freshwater	3	75 > [55 = 65]
	7	75 > [55 = 65]
	14	75 > 65 > 55
Distilled Water	3	75 > [55 = 65]
	7	75 > [55 = 65]
	14	75 > [55 = 65]

Note : a) 55 > 65 means the mean of chromium-leaching concentration at 55% sludge content was significantly greater than at 65% sludge content

b) 55 = 65 means the mean of chromium-leaching concentration at 55% and 65% sludge content were not statistically different.

c) the full Post-Hoc Test (Tukey) is shown in the appendix

From Table 14, it can be concluded that the chromium-leaching concentration tends to increase with the increment of sludge content.

When the effect of curing time was studied, the sludge content and type of leachant have to be fixed while the statistical analysis was employed. The differences between the means of the chromium-leaching concentrations were compared. The results are shown in the Table 15.

Table 15 Multiple Comparisons of Mean Difference of Chromium-leaching Concentrations : Effect of Curing Time

Leachant	Curing Time (days)	Results of Comparison between the Chromium-Leaching Concentration
Seawater	55	14 > 3 > 7
	65	14 > 7 > 3
	75	14 > 7 > 3
Brackish Water	55	[14 = 3] > 7
	65	14 > 7 > 3
	75	14 > [3 = 7]
Freshwater	55	14 > 3 > 7
	65	14 > [3 = 7]
	75	14 > 3 > 7
Distilled Water	55	[3 = 14] > 7
	65	14 > [3 = 7]
	75	[3 = 14] > 7

Note : a) 14 > 7 means the mean of chromium-leaching concentration at 14 days curing time was significantly greater than at 7 days curing time

b) 3 = 7 means the mean of chromium-leaching concentration at 3 and 7 days curing time were not statistically different.

c) the full Post-Hoc Test (Tukey) is shown in the appendix

The results from Table 15 indicat that chromium-leaching concentration was found to be increased with the increment of curing time

4.3 Effect of Type of Leachants on Chromium-leaching Concentration of Solidified Samples

The objective of this experiment was to study whether the chromium-leaching concentrations were greater than the Department of Industrial Works Standard, 5 mg/l when waste was solidified and disposed of in a secure landfill located near coastal or riverside areas. Seawater, brackish water and freshwater were used to represent natural area condition of coastal, estuary and riverside areas, respectively.

The chromium-leaching concentrations of solidified sludge obtained from extraction procedure using seawater, brackish water and freshwater as a leachant are shown in Table 16 and Figure 14.

Table 16 Chromium-leaching Concentration (mg/l) from Solidified Samples

curing time (days)	3			7			14		
sludge content / leachant	55%	65%	75%	55%	65%	75%	55%	65%	75%
Seawater	6.9838	2.5513	4.8170	5.2753	3.5300	6.8053	8.0040	8.5090	8.0847
Brackish water	5.9273	2.3653	5.5057	3.2698	3.1502	5.7048	6.0085	6.4452	7.0945
Freshwater	0.7187	0.6067	1.9840	0.6332	0.6658	1.5558	0.8977	1.3513	2.7293

Department of Industrial Works Standard is not more than 5 mg/l

The chromium-leaching concentration in seawater at 3 days curing time and 55% sludge content was 6.9383 mg/l (S.D. = 0.04) and decreased to be 5.9273 mg/l (S.D. = 0.2852) and 0.7187 mg/l (S.D. = 0.018) in brackish water and freshwater respectively. When the sludge content was 65% the concentration of chromium at 3 days curing time was 2.5513 mg/l (S.D. = 0.2911) in seawater and decreased to be 2.3653 mg/l (S.D. = 0.1495) and 0.6067 mg/l (S.D. = 0.02) in brackish water and freshwater respectively. When 75% sludge content was considered, chromium-leaching concentration in seawater was 4.8170 mg/l (S.D. = 0.031) and increased to be 5.5057 mg/l (S.D. = 0.1425) in brackish water; then decreased to be 1.9840 mg/l (S.D. = 0.1697) in freshwater.

The chromium-leaching concentrations at 7 days curing time and 55% sludge content in seawater, brackish water and freshwater were 5.2753 mg/l (S.D. = 0.065), 3.2698 mg/l (S.D. = 0.1384) and 0.6332 mg/l (S.D. = 0.024), respectively. When sludge content increased to be 65% the chromium-leaching concentration in seawater was 3.5300 mg/l(S.D. = 0.093) and increased to be 3.1502 mg/l (S.D. = 0.2970) and 0.6658 mg/l (S.D. = 0.021) in brackish water and freshwater respectively. The last 75% sludge content, chromium-leaching concentrations were 6.8053 mg/l (S.D. = 0.1034), 5.7048 mg/l (S.D. = 0.3525) and 1.5558 mg/l (S.D. = 0.0032) in seawater, brackish water and freshwater respectively.

When 14 days curing time was considered, at 55% sludge content, chromium-leaching concentration in seawater was 8.0040 mg/l (S.D. = 0.1837) and decreased to be 6.0085 mg/l (S.D. = 0.026) and 0.8977 mg/l (S.D. = 0.037) in brackish water and freshwater respectively. At 65% sludge content, chromium-leaching concentrations were 8.5090 mg/l (S.D. = 0.056), 6.4452 mg/l (S.D. = 0.1764) and 1.3513 mg/l (S.D. = 0.035) in seawater, brackish water and freshwater respectively. For 75% sludge content, chromium-leaching concentration was 8.0847 mg/l (S.D. = 0.2084) in seawater, 7.0945 mg/l (S.D. = 0.1681) in brackish water and 2.7293 mg/l (S.D. = 0.1395) in freshwater.

The results from Post Hoc Tests (Table 17) show that the chromium-leaching concentrations leached from the solidified samples in seawater, brackish water and freshwater were significantly different (P<0.05). The maximum chromium-leaching concentrations occurred in seawater and decreased in brackish water and freshwater, respectively.

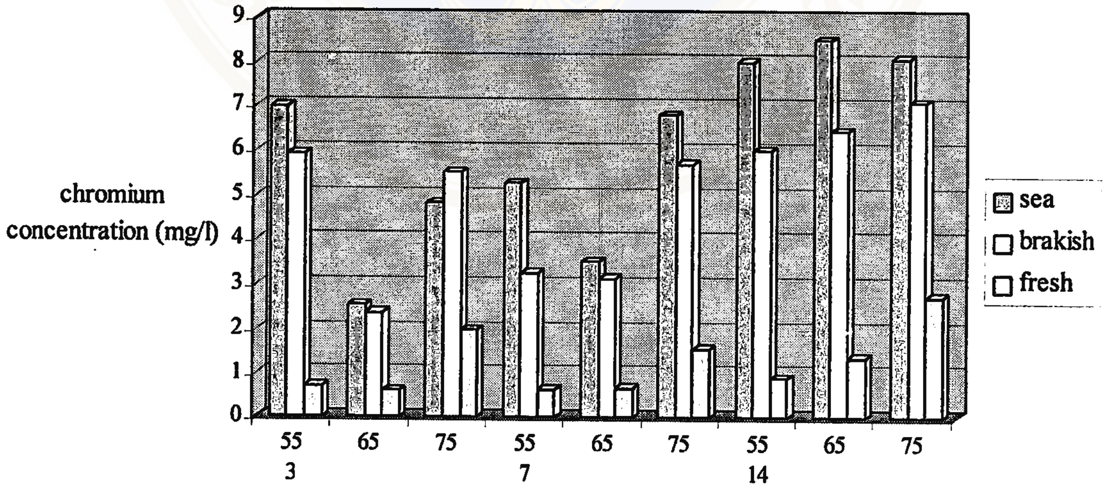


Figure 14 Effect of Sludge Content and Curing Time on Chromium-leaching Concentration in Different Leachants

This section was to determine the effect of leachant on chromium-leaching concentration. For this purpose, the sludge content and curing time had to be fixed while the statistical analysis was employed. The differences between the means of the chromium-leaching concentrations were compared. The results are shown in Table 17.

Table 17 Multiple Comparisons of Mean Difference of Chromium-leaching Concentrations : Effect of Leachant

Curing Time	Sludge Content	Results of Comparison between the Chromium-Leaching Concentration
3	55	S > B > [F = D]
	65	[S = B] > [F = D]
	75	B > S >D > F
7	55	S > B > [F = D]
	65	[S = B] > [F = D]
	75	S > B > [F = D]
14	55	S > B > [F = D]
	65	S > B > [F = D]
	75	S > B > [F = D]

Note : a) S = seawater, B = brackish water, F = freshwater and D = distilled water

b) S > B means the mean of chromium-leaching in seawater was significantly greater than in brackish water

c) S = B means the mean of chromium-leaching concentration in seawater and in brackish water were not statistically different.

d) the full Post-Hoc Test (Tukey) is shown in the appendix

The results from Table 17 demonstrate that the chromium-leaching concentration was found to be increased with the increment of the salinity of leachant.

CHAPTER V

DISCUSSION

The solidification experiment was done to study the effect of sludge content, curing time and type of leachant on the compressive strength and chromium-leaching concentration of the solidified sludge.

The results from the experiment and the statistical analysis could be discussed as follows:

5.1 Effect of Sludge Content and Curing Time on the Compressive Strength of the Solidified Samples

When sludge content and curing time were considered, the results indicated that the compressive strength of the samples was found to be inversely associated with the sludge content but directly associated with the curing time. These findings were in agreement with the first and the second hypotheses which stated that the compressive strength of solidified sludge decreased when the sludge content increased and the compressive strength of solidified sludge increased when the curing time increased. These finding corresponded to Srisukho's study (1997).

However, the results of 75% sludge content were exceptional. The compressive strength of 75 % sludge content did not corresponded to the second hypothesis which stated that the compressive strength of solidified sludge increased when curing time increased. The results can be explained by the sludge powder size that was not as homogeneous as cement. When the inhomogeneous sludge was solidified the force that pressed on the solidified cube may not be uniform. This was more clearly when high quantity of sludge was applied (this was obtained from the experiment).

The maximum compressive strength at 55% sludge content occurred at 14 days curing time. The compressive strength at all of the curing time were found to be better than the Department of Industrial Works Standard; therefore if time saving was required, the curing time at 3 days would be the most suitable at this content of sludge. The result of 65% sludge content was consistent with 55% sludge content but the compressive strength of the samples at 3 days and 7 days curing time were lower than the standard. If cost saving of disposal was the purpose, 65% sludge content and 14 days curing time should be used because the compressive was better than the standard.

5.2 Effect of Sludge Content and Curing Time on Chromium-leaching Concentration of Solidified Samples in Different Leachants

The results from statistical analysis mentioned in Chapter IV indicated that the chromium-leaching concentrations of the samples tend to increase with the increment of sludge content. This finding was consistent with the third hypothesis which stated that the chromium-leaching concentration of solidified sludge increased when the sludge content increased. This finding corresponded to the study of Youn (1990) and Srisukho (1997).

When the effect of curing time on chromium-leaching concentration was considered, the results of the experiment indicated that the chromium-leaching concentration was found to be increased with the increment of curing time. This finding was not in agreement with the fourth hypothesis which stated that the chromium-leaching concentration of solidified sludge decreased when the curing time increased. The reason for this result could be explained by the reaction of dicalcium silicate and tricalcium silicate contained in the cement. When cement reacts with water, calcium hydroxide is formed. Calcium hydroxide dissolved in the water provides high pH of solution (as explained by the equation below). In terms of chromium, it forms soluble anionic species at high pH as well (34). So, the more calcium silicate transformed to calcium hydroxide, the higher concentrations of chromium will be leached from the solidified waste. At 14 days curing time calcium silicate would change to calcium hydroxide more completely than 3 days curing time; hence the chromium-leaching concentration would be greater than at 3 days.

The reaction of the tricalcium silicate can be expressed by the reaction equation:

$$2(3CaO\,.\,SiO2) + 6H2O \longrightarrow 3CaO\,.\,2SiO2\,.\,3H2O + 3Ca(OH)2$$

and the reaction of dicalcium silicate by:

$$2(2CaO \cdot SiO_2) + 4H_2O \longrightarrow 3CaO \cdot 2SiO_2\,.\,3H_2O + 3Ca(OH)_2$$

The effect of sludge content and curing time on the chromium-leaching concentration were explained by the type of leachant, seawater, brackish water and freshwater as follows:

5.2.1 Seawater

At 3 days curing time the maximum chromium-leaching concentration occurred at 55 % sludge content and the minimum was at 65 % sludge content. Only the concentration of 55 % exceeded the standard, 5 mg/l. These are shown in Table 9. When the compressive strength of 65 % and 75 % sludge content were considered, it was found that the compressive strength of the two did not meet the standard (14 kgf/cm2) as depicted in Table 5. So, it could be noted that at 3 days curing time the study ratio of sludge content was not suitable for solidification under the given condition.

The Chromium-leaching concentration at 7 days curing time was analyzed in the same way. The results from Table 9 demonstrate that although the maximum and minimum concentration occurred at 75 % and 65 % respectively, only chromium-leaching concentration of 65 % met the standard. When the compressive strength of the sample was also considered, it was found that 65 % of sludge contents did not meet the standard for compressive strength either. Hence, the study sludge contents was not appropriate for solidification.

For 14 days curing time, it was found that there was no suitable percentage of sludge content for solidification because the chromium-leaching concentrations of all samples were greater than the standard.

5.2.2 Brackish water

The maximum chromium-leaching concentration at 3 days curing time occurred at 55 % sludge content and the minimum was at 65 % (Table 10). Only the chromium-leaching concentration at 65 % sludge content was found to meet the standard. However, the compressive strength of 65 % sludge content did not meet the standard. Thus, there was no suitable percentage of sludge content for this level of curing time.

At 7 days curing time, the maximum leaching concentration occurred at 75 % and the minimum was at 65 % sludge content. The leaching concentration of both 55 % and 65 % sludge content did meet the standard. When the compressive strength was also considered, only that of the 55 % sludge content met the standard. Hence, at 55 % sludge content was applicable to the conditions of brackish water at 7 days curing time (Table 5).

At last, the chromium-leaching concentrations of all sludge contents exceeded the standard for the 14 days curing time.

5.2.3 Freshwater

For this type of water, the chromium-leaching concentration of each percentage of sludge content and curing time all met the standard (Table 11). However, the compressive strength of samples at 55 % sludge content for all levels of curing time; and at 65 % sludge content for 14 days curing time did meet the standard. (see Table 5). The compressive strengths of 65 % sludge content was only slightly above the standard; therefore, it is not a suitable choice for this sludge ratio. Hence, at 55 % sludge content and 3 days curing time should by good for solidification due to safety and time saving.

5.2.4 Distilled Water

This section of the study was done to determine whether the chromium-leaching concentration from the solidified sludge of all conditions was greater than the standard. Distilled water with adjusted pH in the range of 5.8-6.3 used in this study was the standard leachant according to the leaching test of the Department of Industrial Works. The results from Chapter IV indicated that the chromium-leaching concentration of each percentage of sludge content and curing time all met the standard (Table 12). This finding demonstrated that hazardous sludge being treated by the conditions of this experiment yielded the chromium-leaching concentration at the safety level after the treatment.

5.3 Effect of Type of Leachants on Chromium-leaching Concentration of Solidified Samples

The results from statistical analysis as mentioned in Chapter IV (Table 17) indicated that the chromium-leaching concentration leached from seawater, brackish water, fresh water and distilled water were significantly different ($P<0.05$). This finding confirmed the fifth hypothesis which stated that the concentrations of chromium-leaching of solidified sludge were different on different leachants. The results from Table 15 show that the chromium-leaching concentration of seawater are more than brackish water and freshwater respectively.

The greater amount of chromium leached from the seawater condition could be due to the type of cement used for solidification process. The type I portland cement used in this study was not appropriate for seawater condition because sulfates presented in seawater are known to be the cause of attack on concrete. The principal sulphates in seawater are calcium sulphate (gypsum), magnesium sulphate (Epsom salts) and sodium sulphate (Glauber's salts). These sulphates react with calcium aluminate and the free lime in type I Portland Cement concrete (35). The suitable type of Portland cement for seawater condition should be Type V because of its sulfate-resistance.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 The compressive strength of the samples at all level of sludge contents increased when the sludge content decreased. The compressive strengths of the samples at 55% sludge content were significantly higher than those of 65% and 75% sludge content respectively. Hence, the best percentage of sludge contents for the compressive strength was 55%.

6.1.2 The compressive strength of samples at 55% and 65% sludge content were found to be increased with the increment of the curing time. The compressive strength of the sample at 14 days curing time was significantly higher than those of 3 days and 7 days at 55% and 65% sludge content. Hence, the best curing time was 14 days for these two percentages of sludge content.

6.1.3 For seawater, there was no suitable sludge content and curing time that give the compressive strength and chromium-leaching concentration that met the Department of Industrial Works Standard.

6.1.4 The appropriate sludge content and curing time for brackish water was 55% and 7 days when both the compressive strength and chromium-leaching concentration of the samples were considered.

6.1.5 For fresh water, the suitable condition were at 55% sludge content and 3 days curing time for solidification in order to meet the standards for both compressive strength and chromium-leaching concentration.

6.1.6 The mean difference of chromium-leaching concentration from the three type of leachants seawater, brackish water and freshwater, was significantly different. The chromium-leaching concentrations from high to low were in seawater, brackish water and freshwater, respectively.

6.1.7 The higher salinity of the disposal area for solidified sludge, the greater risk of leaching if inappropriate binder was used for solidification.

6.2 Recommendations

6.2.1 Recommendations for Application

6.2.1.1 If disposal of chromium-containing waste in the coastal areas is necessary, the lower percentage of sludge content than in this should be used.

6.2.1.2 Type V Portland Cement should be used when solidified hazardous waste being disposed of in coastal areas, and riverside areas with brackish water conditions.

6.2.2 Recommendations for Further Study

6.2.2.1 The leaching of other heavy metals from the solidified sludge at these study conditions should be investigated.

6.2.2.2 The proper sludge content and curing time of the samples for seawater condition should be further investigated.

6.2.2.3 Other binders such as rice husk ash and lignite fly ash should be investigated the feasibility of using in the mixture for chromium fixation and increase of compressive strength.

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APPENDIX A

DATA OF THE EXPERIMENT

Table A-1 Mixtures

	Control	55%	65%	75%
Sludge (g)	-	366	433	500
Cement (g)	666	300	235	166
Sand (g)	1332	1332	1332	1332
Water (ml)	320	540	600	660
w/c ratio	0.48	1.80	2.55	3.98
Flow (%)	105	106	110.5	109

Note : The amount of mixing water was used to produce a flow of 110 ± 5%

Table A-2 Background Conditions of the Leachants

Parameter / leachants	pH	Salinity (ppb)	Chromium Concentration (mg/l)
Seawater	5.8-6.3	30	0.039
Brackish Water	5.8-6.3	10	ND
Fresh water	5.8-6.3	0	ND

Note : ND means not detectable at 0.001 mg/l

Table A-3 Chromium Concentration in Samples

Samples	Chromium Concentrations (gCr/kg)			
	1	2	3	Means
Control	0.015	0.016	0.018	0.016
Sludge	107.60	107.85	106.75	107.40
55% Sludge	33.79	36.17	33.21	34.39
65% Sludge	42.23	40.77	40.82	41.27
75% Sludge	41.01	42.62	40.55	41.39

Table A-4 Compressive Strengths and Chromium-leaching Concentrations of Control Samples

No.	Leachants	Curing Time (days)	Compressive Strength (kgf/cm2)	Chromium Concentrations (mg/l)
1	seawater	3	247.68	0.327
2	seawater	3	238.34	0.349
3	seawater	3	234.47	0.371
4	brackish water	3	312.74	0.148
5	brackish water	3	276.97	0.146
6	brackish water	3	291.04	0.144
7	freshwater	3	280.96	0.030
8	freshwater	3	279.41	0.028
9	freshwater	3	296.85	0.023
10	seawater	7	300.72	0.170
11	seawater	7	322.04	0.164
12	seawater	7	363.11	0.157
13	brackish water	7	348.38	0.100
14	brackish water	7	343.35	0.099
15	brackish water	7	320.49	0.097
16	freshwater	7	353.03	0.012
17	freshwater	7	361.56	0.013
18	freshwater	7	346.83	0.014
19	seawater	14	394.91	0.162
20	seawater	14	398.75	0.164
21	seawater	14	377.60	0.143
22	brackish water	14	385.29	0.113
23	brackish water	14	396.83	0.114
24	brackish water	14	392.98	0.116
25	freshwater	14	354.54	0.013
26	freshwater	14	358.38	0.010
27	freshwater	14	367.99	0.016

Table A-5 Compressive Strengths and Chromium-leaching Concentrations of 55% Sludge Content Samples

No.	Leachants	Curing Time (days)	Compressive Strength (kgf/cm2)	Cromium Concentrations (mg/l)
1	seawater	3	21.44031	6.976
2	seawater	3	20.671938	6.897
3	seawater	3	22.592868	6.942
4	brackish water	3	21.44031	5.616
5	brackish water	3	21.824496	6.176
6	brackish water	3	23.36124	5.99
7	freshwater	3	23.36124	0.698
8	freshwater	3	21.44031	0.725
9	freshwater	3	22.592868	0.733
10	distilled water	3	22.5928682	0.751
11	distilled water	3	22.9770543	0.88
12	distilled water	3	22.5928682	0.701
13	seawater	7	23.362403	5.204
14	seawater	7	22.592868	5.331
15	seawater	7	24.129612	5.291
16	brackish water	7	19.51938	3.3385
17	brackish water	7	19.51938	3.1105
18	brackish water	7	18.751008	3.3605
19	freshwater	7	23.36124	0.6495
20	freshwater	7	23.745426	0.6445
21	freshwater	7	23.36124	0.6055
22	distilled water	7	24.5137984	0.565
23	distilled water	7	22.5928682	0.573
24	distilled water	7	22.2086822	0.564
25	seawater	14	36.807752	7.826
26	seawater	14	33.734264	7.993
27	seawater	14	34.502636	8.193

Table A-5 Compressive Strengths and Chromium-leaching Concentrations of 55% Sludge Content Samples (continue)

No.	Leachants	Curing Time (days)	Compressive Strength (kgf/cm2)	Cromium Concentrations (mg/l)
28	brackish water	14	40.265426	6.0075
29	brackish water	14	37.191938	5.9835
30	brackish water	14	36.423566	6.0345
31	freshwater	14	37.96031	0.93
32	freshwater	14	38.728682	0.905
33	freshwater	14	39.88124	0.858
34	distilled water	14	37.576124	0.759
35	distilled water	14	39.1128682	0.771
36	distilled water	14	39.4970543	0.753

Table A-6 Compressive Strengths and Chromium-leaching Concentrations of 65% Sludge Content Samples

No.	Leachants	Curing Time (days)	Compressive Strength (kgf/cm2)	Cromium Concentrations (mg/l)
1	seawater	3	11.588295	2.749
2	seawater	3	12.357236	2.688
3	seawater	3	12.357236	2.217
4	brackish water	3	11.972764	2.538
5	brackish water	3	11.780512	2.281
6	brackish water	3	11.972764	2.277
7	freshwater	3	10.819353	0.585
8	freshwater	3	10.242651	0.625
9	freshwater	3	10.819353	0.61
10	distilled water	3	11.7805116	0.656
11	distilled water	3	11.9727636	0.697
12	distilled water	3	11.9727636	0.662
13	seawater	7	11.067287	3.439
14	seawater	7	11.835659	3.527
15	seawater	7	11.067287	3.624
16	brackish water	7	11.067287	2.9505
17	brackish water	7	11.067287	3.4915
18	brackish water	7	10.683101	3.0085
19	freshwater	7	10.683101	0.6735
20	freshwater	7	11.067287	0.6425
21	freshwater	7	12.219845	0.6815
22	distilled water	7	9.53054264	0.645
23	distilled water	7	9.91472868	0.625
24	distilled water	7	9.53054264	0.644
25	seawater	14	14.909147	8.456
26	seawater	14	13.756589	8.504
27	seawater	14	15.293333	8.567

Table A-6 Compressive Strengths and Chromium-leaching Concentrations of 65% Sludge Content Samples (continue)

No.	Leachants	Curing Time (days)	Compressive Strength (kgf/cm2)	Cromium Concentrations (mg/l)
28	brackish water	14	16.445891	6.2415
29	brackish water	14	16.445891	6.5495
30	brackish water	14	16.445891	6.5445
31	freshwater	14	16.061705	1.386
32	freshwater	14	14.909147	1.352
33	freshwater	14	14.909147	1.316
34	distilled water	14	16.0617054	1.248
35	distilled water	14	14.5249612	1.234
36	distilled water	14	14.9091473	1.261

Table A-7 Compressive Strengths and Chromium-leaching Concentrations of 75% Sludge Content Samples

No.	Leachants	Curing Time (days)	Compressive Strength (kgf/cm2)	Cromium Concentrations (mg/l)
1	seawater	3	10.434884	4.85
2	seawater	3	10.050415	4.788
3	seawater	3	10.050415	4.813
4	brackish water	3	10.242651	5.51
5	brackish water	3	10.050415	5.361
6	brackish water	3	10.050415	5.646
7	freshwater	3	10.050415	2.138
8	freshwater	3	10.050415	2.012
9	freshwater	3	10.050415	1.802
10	distilled water	3	9.08923643	2.597
11	distilled water	3	9.28147287	2.477
12	distilled water	3	8.70476744	2.559
13	seawater	7	6.6491473	6.769
14	seawater	7	6.4570543	6.725
15	seawater	7	6.4570543	6.922
16	brackish water	7	5.6886822	5.5715
17	brackish water	7	5.3044961	6.1045
18	brackish water	7	5.4965891	5.4385
19	freshwater	7	5.3044961	1.5545
20	freshwater	7	5.1124031	1.5535
21	freshwater	7	4.9203101	1.5595
22	distilled water	7	break	1.067
23	distilled water	7	break	1.737
24	distilled water	7	6.86170543	1.724
25	seawater	14	9.0892364	7.975
26	seawater	14	9.4737093	7.954
27	seawater	14	9.4737093	8.325

Table A-7 Compressive Strengths and Chromium-leaching Concentrations of 75% Sludge Content Samples (continue)

No.	Leachants	Curing Time (days)	Compressive Strength (kgf/cm2)	Cromium Concentrations (mg/l)
28	brackish water	14	8.7048837	6.9355
29	brackish water	14	8.8970039	7.0775
30	brackish water	14	8.3202984	7.2705
31	freshwater	14	7.743593	2.774
32	freshwater	14	7.3591202	2.573
33	freshwater	14	7.5513566	2.841
34	distilled water	14	7.1668876	2.432
35	distilled water	14	break	2.448
36	distilled water	14	break	2.387

APPENDIX B

STATISTICAL ANALYSIS

Table B-1 Tests of between-Subjects Effects of Compressive Strength

Tests of Between-Subjects Effects

Dependent Variable: COM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Corrected Model	9178.484[b]	8	1147.311	827.826	.000	6622.608	1.000
Intercept	26496.5	1	26496.5	19118.2	.000	19118.164	1.000
CONTENT	7101.511	2	3550.755	2561.998	.000	5123.997	1.000
TIME	1055.080	2	527.540	380.639	.000	761.278	1.000
CONTENT * TIME	972.762	4	243.190	175.471	.000	701.883	1.000
Error	131.664	95	1.386				
Total	37112.0	104					
Corrected Total	9310.148	103					

[a] Computed using alpha = .05

[b] R Squared = .986 (Adjusted R Squared = .985)

Table B-2 Post Hoc Test for Compressive Strength of Curing Time (55% Sludge Content)

Multiple Comparisons

Dependent Variable: COM
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	-6.41E-02	.698	.995	-1.77594	1.647658
	14	-15.39946*	.698	.000	-17.1113	-13.6877
7	3	6.414E-02	.698	.995	-1.64766	1.775941
	14	-15.33532*	.698	.000	-17.0471	-13.6235
14	3	15.399458*	.698	.000	13.6877	17.1113
	7	15.335317*	.698	.000	13.6235	17.0471

*. The mean difference is significant at the .05 level.

Table B-3 Post Hoc Tests for Compressive Strength of Curing Time (65% Sludge Content)

Multiple Comparisons

Dependent Variable: COM
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	.825208*	.325	.041	2.8E-02	1.622225
	14	-3.753008*	.325	.000	-4.55002	-2.95599
7	3	-.825208*	.325	.041	-1.62222	-2.8E-02
	14	-4.578217*	.325	.000	-5.37523	-3.78120
14	3	3.753008*	.325	.000	2.955992	4.550025
	7	4.578217*	.325	.000	3.781200	5.375233

*. The mean difference is significant at the .05 level.

Table B-4 Post Hoc Tests for Compressive Strength of Curing Time (75% Sludge Content)

Multiple Comparisons

Dependent Variable: COM
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	4.016958*	.302	.000	3.271431	4.762485
	14	1.464178*	.302	.000	.718651	2.209705
7	3	-4.016958*	.302	.000	-4.76249	-3.27143
	14	-2.552780*	.315	.000	-3.33146	-1.77410
14	3	-1.464178*	.302	.000	-2.20971	-.718651
	7	2.552780*	.315	.000	1.774102	3.331458

*. The mean difference is significant at the .05 level.

Table B-5 Post Hoc Test for Compressive Strength of Sludge Content (3 Days Curing Time)

Multiple Comparisons

Dependent Variable: COM
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	10.604333*	.283	.000	9.908786	11.2999
	75	12.398542*	.283	.000	11.7030	13.0941
65	55	-10.60433*	.283	.000	-11.2999	-9.90879
	75	1.794208*	.283	.000	1.098661	2.489756
75	55	-12.39854*	.283	.000	-13.0941	-11.7030
	65	-1.794208*	.283	.000	-2.48976	-1.09866

*. The mean difference is significant at the .05 level.

Table B-6 Post Hoc Test for Compressive Strength of Sludge Content (7 Days Curing Time)

Multiple Comparisons

Dependent Variable: COM
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	11.493683*	.539	.000	10.1678	12.8196
	75	16.479642*	.565	.000	15.0890	17.8703
65	55	-11.49368*	.539	.000	-12.8196	-10.1678
	75	4.985958*	.565	.000	3.595315	6.376602
75	55	-16.47964*	.565	.000	-17.8703	-15.0890
	65	-4.985958*	.565	.000	-6.37660	-3.59531

*. The mean difference is significant at the .05 level.

Table B-7 Post Hoc Test for Compressive Strength of Sludge Content (14 Days Curing Time)

Multiple Comparisons

Dependent Variable: COM
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	22.250783*	.576	.000	20.8324	23.6691
	75	29.262178*	.604	.000	27.7746	30.7498
65	55	-22.25078*	.576	.000	-23.6691	-20.8324
	75	7.011395*	.604	.000	5.523814	8.498976
75	55	-29.26218*	.604	.000	-30.7498	-27.7746
	65	-7.011395*	.604	.000	-8.49898	-5.52381

*. The mean difference is significant at the .05 level.

Table B-8 Tests of between-Subjects Effects of Chromium-leaching Concentration

Tests of Between-Subjects Effects

Dependent Variable: CR

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Corrected Model	696.704[b]	23	30.291	103.222	.000	2374.117	1.000
Intercept	1245.785	1	1245.785	4245.191	.000	4245.191	1.000
CONTENT	45.602	2	22.801	77.698	.000	155.396	1.000
TIME	61.985	2	30.993	105.612	.000	211.223	1.000
LEACHANT	516.801	3	172.267	587.025	.000	1761.075	1.000
CONTENT * TIME	21.785	4	5.446	18.559	.000	74.234	1.000
CONTENT * LEACHANT	15.311	6	2.552	8.696	.000	52.176	1.000
TIME * LEACHANT	35.219	6	5.870	20.002	.000	120.013	1.000
Error	24.650	84	.293				
Total	1967.139	108					
Corrected Total	721.354	107					

[a] Computed using alpha = .05

[b] R Squared = .966 (Adjusted R Squared = .956)

Table B-9 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (3 Days Curing Time and Seawater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
55	65	4.387000*	.139	.000	3.959618	4.814382
	75	2.121333*	.139	.000	1.693952	2.548715
65	55	-4.387000*	.139	.000	-4.81438	-3.95962
	75	-2.265667*	.139	.000	-2.69305	-1.83829
75	55	-2.121333*	.139	.000	-2.54871	-1.69395
	65	2.265667*	.139	.000	1.838285	2.693048

*. The mean difference is significant at the .05 level.

Table B-10 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (3 Days Curing Time and Brackish Water)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	3.562000*	.166	.000	3.052607	4.071393
	75	.421667	.166	.097	-8.8E-02	.931060
65	55	-3.562000*	.166	.000	-4.07139	-3.05261
	75	-3.140333*	.166	.000	-3.64973	-2.63094
75	55	-.421667	.166	.097	-.931060	8.8E-02
	65	3.140333*	.166	.000	2.630940	3.649726

*. The mean difference is significant at the .05 level.

Table B-11 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (3 Days Curing Time and Freshwater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	.112000	.081	.407	-.136667	.360667
	75	-1.265333*	.081	.000	-1.51400	-1.01667
65	55	-.112000	.081	.407	-.360667	.136667
	75	-1.377333*	.081	.000	-1.62600	-1.12867
75	55	1.265333*	.081	.000	1.016667	1.514000
	65	1.377333*	.081	.000	1.128667	1.626000

*. The mean difference is significant at the .05 level.

Table B-12 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (3 Days Curing Time and Distilled Water with pH 5.8-6.3)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	.105667	.053	.197	-5.8E-02	.269193
	75	-1.767000*	.053	.000	-1.93053	-1.60347
65	55	-.105667	.053	.197	-.269193	5.8E-02
	75	-1.872667*	.053	.000	-2.03619	-1.70914
75	55	1.767000*	.053	.000	1.603473	1.930527
	65	1.872667*	.053	.000	1.709140	2.036193

*. The mean difference is significant at the .05 level.

Table B-13 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (7 Days Curing Time and Seawater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	1.745333*	.072	.000	1.523738	1.966929
	75	-1.530000*	.072	.000	-1.75160	-1.30840
65	55	-1.745333*	.072	.000	-1.96693	-1.52374
	75	-3.275333*	.072	.000	-3.49693	-3.05374
75	55	1.530000*	.072	.000	1.308404	1.751596
	65	3.275333*	.072	.000	3.053738	3.496929

*. The mean difference is significant at the .05 level.

Table B-14 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (7 Days Curing Time and Brackish Water)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

					95% Confidence Interval	
(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
55	65	.119667	.227	.861	-.576422	.815755
	75	-2.435000*	.227	.000	-3.13109	-1.73891
65	55	-.119667	.227	.861	-.815755	.576422
	75	-2.554667*	.227	.000	-3.25076	-1.85858
75	55	2.435000*	.227	.000	1.738911	3.131089
	65	2.554667*	.227	.000	1.858578	3.250755

*· The mean difference is significant at the .05 level.

Table B-15 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (7 Days Curing Time and Freshwater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

					95% Confidence Interval	
(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
55	65	-3.27E-02	.015	.155	-7.9E-02	1.3E-02
	75	-.922667*	.015	.000	-.968748	-.876586
65	55	3.267E-02	.015	.155	-1.3E-02	7.9E-02
	75	-.890000*	.015	.000	-.936081	-.843919
75	55	.922667*	.015	.000	.876586	.968748
	65	.890000*	.015	.000	.843919	.936081

*· The mean difference is significant at the .05 level.

Table B-16 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (7 Days Curing Time and Distilled Water with pH 5.8-6.3)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	-7.07E-02	.181	.920	-.625109	.483775
	75	-.942000*	.181	.005	-1.49644	-.387558
65	55	7.067E-02	.181	.920	-.483775	.625109
	75	-.871333*	.181	.007	-1.42578	-.316891
75	55	.942000*	.181	.005	.387558	1.496442
	65	.871333*	.181	.007	.316891	1.425775

*. The mean difference is significant at the .05 level.

Table B-17 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (14 Days Curing Time and Seawater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	-.505000*	.134	.021	-.914852	-9.5E-02
	75	-8.07E-02	.134	.823	-.490518	.329185
65	55	.505000*	.134	.021	9.5E-02	.914852
	75	.424333*	.134	.044	1.4E-02	.834185
75	55	8.067E-02	.134	.823	-.329185	.490518
	65	-.424333*	.134	.044	-.834185	-1.4E-02

*. The mean difference is significant at the .05 level.

Table B-18 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (14 Days Curing Time and Brackish Water)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	-.436667*	.116	.021	-.791081	-8.2E-02
	75	-1.086000*	.116	.000	-1.44041	-.731586
65	55	.436667*	.116	.021	8.2E-02	.791081
	75	-.649333*	.116	.003	-1.00375	-.294919
75	55	1.086000*	.116	.000	.731586	1.440414
	65	.649333*	.116	.003	.294919	1.003748

*. The mean difference is significant at the .05 level.

Table B-19 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (14 Days Curing Time and Freshwater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	-.453667*	.070	.002	-.668271	-.239062
	75	-1.831667*	.070	.000	-2.04627	-1.61706
65	55	.453667*	.070	.002	.239062	.668271
	75	-1.378000*	.070	.000	-1.59260	-1.16340
75	55	1.831667*	.070	.000	1.617062	2.046271
	65	1.378000*	.070	.000	1.163395	1.592605

*. The mean difference is significant at the .05 level.

Table B-20 Post Hoc Test for Chromium-leaching Concentration of Sludge Content (14 Days Curing Time and Distilled Water with pH 5.8-6.3)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) CONTENT	(J) CONTENT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
55	65	-.486667*	.017	.000	-.538145	-.435189
	75	-1.661333*	.017	.000	-1.71281	-1.60986
65	55	.486667*	.017	.000	.435189	.538145
	75	-1.174667*	.017	.000	-1.22614	-1.12319
75	55	1.661333*	.017	.000	1.609855	1.712811
	65	1.174667*	.017	.000	1.123189	1.226145

*. The mean difference is significant at the .05 level.

Table B-21 Post Hoc Test for Chromium-leaching Concentration of Curing Time (55% Sludge Content and Seawater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	1.663000*	.094	.000	1.375352	1.950648
	14	-1.065667*	.094	.000	-1.35331	-.778019
7	3	-1.663000*	.094	.000	-1.95065	-1.37535
	14	-2.728667*	.094	.000	-3.01631	-2.44102
14	3	1.065667*	.094	.000	.778019	1.353314
	7	2.728667*	.094	.000	2.441019	3.016314

*. The mean difference is significant at the .05 level.

Table B-22 Post Hoc Test for Chromium-leaching Concentration of Curing Time (55% Sludge Content and Brackish Water)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
3	7	2.657500*	.150	.000	2.197467	3.117533
	14	-8.12E-02	.150	.854	-.541200	.378866
7	3	-2.657500*	.150	.000	-3.11753	-2.19747
	14	-2.738667*	.150	.000	-3.19870	-2.27863
14	3	8.117E-02	.150	.854	-.378866	.541200
	7	2.738667*	.150	.000	2.278634	3.198700

*. The mean difference is significant at the .05 level.

Table B-23 Post Hoc Test for Chromium-leaching Concentration of Curing Time (55% Sludge Content and Freshwater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
3	7	8.550E-02*	.022	.020	1.7E-02	.154155
	14	-.179000*	.022	.000	-.247655	-.110345
7	3	-8.55E-02*	.022	.020	-.154155	-1.7E-02
	14	-.264500*	.022	.000	-.333155	-.195845
14	3	.179000*	.022	.000	.110345	.247655
	7	.264500*	.022	.000	.195845	.333155

*. The mean difference is significant at the .05 level.

Table B-24 Post Hoc Test for Chromium-leaching Concentration of Curing Time (55% Sludge Content and Distilled Water with pH 5.8-6.3)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	.210000*	.044	.007	7.6E-02	.344435
	14	1.633E-02	.044	.927	-.118102	.150769
7	3	-.210000*	.044	.007	-.344435	-7.6E-02
	14	-.193667*	.044	.011	-.328102	-5.9E-02
14	3	-1.63E-02	.044	.927	-.150769	.118102
	7	.193667*	.044	.011	5.9E-02	.328102

*. The mean difference is significant at the .05 level.

Table B-25 Post Hoc Test for Chromium-leaching Concentration of Curing Time (65% Sludge Content and Seawater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	-.978667*	.146	.001	-1.42781	-.529521
	14	-5.957667*	.146	.000	-6.40681	-5.50852
7	3	.978667*	.146	.001	.529521	1.427813
	14	-4.979000*	.146	.000	-5.42815	-4.52985
14	3	5.957667*	.146	.000	5.508521	6.406813
	7	4.979000*	.146	.000	4.529854	5.428146

*. The mean difference is significant at the .05 level.

Table B-26 Post Hoc Test for Chromium-leaching Concentration of Curing Time (65% Sludge Content and Brackish Water)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	-.784833*	.177	.011	-1.32931	-.240357
	14	-4.079833*	.177	.000	-4.62431	-3.53536
7	3	.784833*	.177	.011	.240357	1.329310
	14	-3.295000*	.177	.000	-3.83948	-2.75052
14	3	4.079833*	.177	.000	3.535357	4.624310
	7	3.295000*	.177	.000	2.750524	3.839476

*. The mean difference is significant at the .05 level.

Table B-27 Post Hoc Test for Chromium-leaching Concentration of Curing Time (65% Sludge Content and Freshwater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	-5.92E-02	.021	.073	-.124783	6.4E-03
	14	-.744667*	.021	.000	-.810283	-.679050
7	3	5.917E-02	.021	.073	-6.4E-03	.124783
	14	-.685500*	.021	.000	-.751116	-.619884
14	3	.744667*	.021	.000	.679050	.810283
	7	.685500*	.021	.000	.619884	.751116

*. The mean difference is significant at the .05 level.

Table B-28 Post Hoc Test for Chromium-leaching Concentration of Curing Time (65% Sludge Content and Distilled Water with pH 5.8-6.3)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	3.367E-02	.013	.099	-7.2E-03	7.5E-02
	14	-.576000*	.013	.000	-.616902	-.535098
7	3	-3.37E-02	.013	.099	-7.5E-02	7.2E-03
	14	-.609667*	.013	.000	-.650569	-.568765
14	3	.576000*	.013	.000	.535098	.616902
	7	.609667*	.013	.000	.568765	.650569

*. The mean difference is significant at the .05 level.

Table B-29 Post Hoc Test for Chromium-leaching Concentration of Curing Time (75% Sludge Content and Seawater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	-1.988333*	.111	.000	-2.32784	-1.64883
	14	-3.267667*	.111	.000	-3.60717	-2.92816
7	3	1.988333*	.111	.000	1.648827	2.327840
	14	-1.279333*	.111	.000	-1.61884	-.939827
14	3	3.267667*	.111	.000	2.928160	3.607173
	7	1.279333*	.111	.000	.939827	1.618840

*. The mean difference is significant at the .05 level.

Table B-30 Post Hoc Test for Chromium-leaching Concentration of Curing Time (75% Sludge Content and Brackish Water)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	-.199167	.196	.594	-.800453	.402119
	14	-1.588833*	.196	.000	-2.19012	-.987547
7	3	.199167	.196	.594	-.402119	.800453
	14	-1.389667*	.196	.001	-1.99095	-.788381
14	3	1.588833*	.196	.000	.987547	2.190119
	7	1.389667*	.196	.001	.788381	1.990953

*. The mean difference is significant at the .05 level.

Table B-31 Post Hoc Test for Chromium-leaching Concentration of Curing Time (75% Sludge Content and Freshwater)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	.428167*	.104	.014	.110370	.745963
	14	-.745333*	.104	.001	-1.06313	-.427537
7	3	-.428167*	.104	.014	-.745963	-.110370
	14	-1.173500*	.104	.000	-1.49130	-.855703
14	3	.745333*	.104	.001	.427537	1.063130
	7	1.173500*	.104	.000	.855703	1.491297

*. The mean difference is significant at the .05 level.

Table B-32 Post Hoc Test for Chromium-leaching Concentration of Curing Time (75% Sludge Content and Distilled Water with pH 5.8-6.3)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
3	7	1.035000*	.184	.003	.471927	1.598073
	14	.122000	.184	.791	-.441073	.685073
7	3	-1.035000*	.184	.003	-1.59807	-.471927
	14	-.913000*	.184	.006	-1.47607	-.349927
14	3	-.122000	.184	.791	-.685073	.441073
	7	.913000*	.184	.006	.349927	1.476073

*· The mean difference is significant at the .05 level.

Table B-33 Post Hoc Test for Chromium-leaching Concentration of Leachant (55% Sludge Content and 3 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.011000*	.124	.000	.614923	1.407077
	3	6.219667*	.124	.000	5.823590	6.615743
	4	6.161000*	.124	.000	5.764923	6.557077
2	1	-1.011000*	.124	.000	-1.40708	-.614923
	3	5.208667*	.124	.000	4.812590	5.604743
	4	5.150000*	.124	.000	4.753923	5.546077
3	1	-6.219667*	.124	.000	-6.61574	-5.82359
	2	-5.208667*	.124	.000	-5.60474	-4.81259
	4	-5.87E-02	.124	.963	-.454743	.337410
4	1	-6.161000*	.124	.000	-6.55708	-5.76492
	2	-5.150000*	.124	.000	-5.54608	-4.75392
	3	5.867E-02	.124	.963	-.337410	.454743

*· The mean difference is significant at the .05 level.

Table B-34 Post Hoc Test for Chromium-leaching Concentration of Leachant (55% Sludge Content and 7 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	2.005500*	.063	.000	1.803037	2.207963
	3	4.642167*	.063	.000	4.439704	4.844630
	4	4.708000*	.063	.000	4.505537	4.910463
2	1	-2.005500*	.063	.000	-2.20796	-1.80304
	3	2.636667*	.063	.000	2.434204	2.839130
	4	2.702500*	.063	.000	2.500037	2.904963
3	1	-4.642167*	.063	.000	-4.84463	-4.43970
	2	-2.636667*	.063	.000	-2.83913	-2.43420
	4	6.583E-02	.063	.732	-.136630	.268296
4	1	-4.708000*	.063	.000	-4.91046	-4.50554
	2	-2.702500*	.063	.000	-2.90496	-2.50004
	3	-6.58E-02	.063	.732	-.268296	.136630

*. The mean difference is significant at the .05 level.

Table B-35 Post Hoc Test for Chromium-leaching Concentration of Leachant (55% Sludge Con tent and 14 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.995500*	.077	.000	1.748015	2.242985
	3	7.106333*	.077	.000	6.858848	7.353819
	4	7.243000*	.077	.000	6.995515	7.490485
2	1	-1.995500*	.077	.000	-2.24299	-1.74801
	3	5.110833*	.077	.000	4.863348	5.358319
	4	5.247500*	.077	.000	5.000015	5.494985
3	1	-7.106333*	.077	.000	-7.35382	-6.85885
	2	-5.110833*	.077	.000	-5.35832	-4.86335
	4	.136667	.077	.353	-.110819	.384152
4	1	-7.243000*	.077	.000	-7.49049	-6.99551
	2	-5.247500*	.077	.000	-5.49499	-5.00001
	3	-.136667	.077	.353	-.384152	.110819

*. The mean difference is significant at the .05 level.

Table B-36 Post Hoc Test for Chromium-leaching Concentration of Leachant (65% Sludge Con tent and 3 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.186000	.134	.540	-.243701	.615701
	3	1.944667*	.134	.000	1.514965	2.374368
	4	1.879667*	.134	.000	1.449965	2.309368
2	1	-.186000	.134	.540	-.615701	.243701
	3	1.758667*	.134	.000	1.328965	2.188368
	4	1.693667*	.134	.000	1.263965	2.123368
3	1	-1.944667*	.134	.000	-2.37437	-1.51497
	2	-1.758667*	.134	.000	-2.18837	-1.32897
	4	-6.50E-02	.134	.960	-.494701	.364701
4	1	-1.879667*	.134	.000	-2.30937	-1.44997
	2	-1.693667*	.134	.000	-2.12337	-1.26397
	3	6.500E-02	.134	.960	-.364701	.494701

*. The mean difference is significant at the .05 level.

Table B-37 Post Hoc Test for Chromium-leaching Concentration of Leachant (65% Sludge Con tent and 7 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.379833	.127	.068	-2.8E-02	.787719
	3	2.864167*	.127	.000	2.456281	3.272052
	4	2.892000*	.127	.000	2.484115	3.299885
2	1	-.379833	.127	.068	-.787719	2.8E-02
	3	2.484333*	.127	.000	2.076448	2.892219
	4	2.512167*	.127	.000	2.104281	2.920052
3	1	-2.864167*	.127	.000	-3.27205	-2.45628
	2	-2.484333*	.127	.000	-2.89222	-2.07645
	4	2.783E-02	.127	.996	-.380052	.435719
4	1	-2.892000*	.127	.000	-3.29989	-2.48411
	2	-2.512167*	.127	.000	-2.92005	-2.10428
	3	-2.78E-02	.127	.996	-.435719	.380052

*. The mean difference is significant at the .05 level.

Table B-38 Post Hoc Test for Chromium-leaching Concentration of Leachant (65% Sludge Con tent and 14 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	2.063833*	.077	.000	1.817079	2.310588
	3	7.157667*	.077	.000	6.910912	7.404421
	4	7.261333*	.077	.000	7.014579	7.508088
2	1	-2.063833*	.077	.000	-2.31059	-1.81708
	3	5.093833*	.077	.000	4.847079	5.340588
	4	5.197500*	.077	.000	4.950745	5.444255
3	1	-7.157667*	.077	.000	-7.40442	-6.91091
	2	-5.093833*	.077	.000	-5.34059	-4.84708
	4	.103667	.077	.563	-.143088	.350421
4	1	-7.261333*	.077	.000	-7.50809	-7.01458
	2	-5.197500*	.077	.000	-5.44425	-4.95075
	3	-.103667	.077	.563	-.350421	.143088

*. The mean difference is significant at the .05 level.

Table B-39 Post Hoc Test for Chromium-leaching Concentration of Leachant (75% Sludge Con tent and 3 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.688667*	.095	.000	-.992098	-.385236
	3	2.833000*	.095	.000	2.529569	3.136431
	4	2.272667*	.095	.000	1.969236	2.576098
2	1	.688667*	.095	.000	.385236	.992098
	3	3.521667*	.095	.000	3.218236	3.825098
	4	2.961333*	.095	.000	2.657902	3.264764
3	1	-2.833000*	.095	.000	-3.13643	-2.52957
	2	-3.521667*	.095	.000	-3.82510	-3.21824
	4	-.560333*	.095	.002	-.863764	-.256902
4	1	-2.272667*	.095	.000	-2.57610	-1.96924
	2	-2.961333*	.095	.000	-3.26476	-2.65790
	3	.560333*	.095	.002	.256902	.863764

*. The mean difference is significant at the .05 level.

Table B-40 Post Hoc Test for Chromium-leaching Concentration of Leachant (75% Sludge Con tent and 7 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.100500*	.217	.004	.406592	1.794408
	3	5.249500*	.217	.000	4.555592	5.943408
	4	5.296000*	.217	.000	4.602092	5.989908
2	1	-1.100500*	.217	.004	-1.79441	-.406592
	3	4.149000*	.217	.000	3.455092	4.842908
	4	4.195500*	.217	.000	3.501592	4.889408
3	1	-5.249500*	.217	.000	-5.94341	-4.55559
	2	-4.149000*	.217	.000	-4.84291	-3.45509
	4	4.650E-02	.217	.996	-.647408	.740408
4	1	-5.296000*	.217	.000	-5.98991	-4.60209
	2	-4.195500*	.217	.000	-4.88941	-3.50159
	3	-4.65E-02	.217	.996	-.740408	.647408

*. The mean difference is significant at the .05 level.

Table B-41 Post Hoc Test for Chromium-leaching Concentration of Leachant (75% Sludge Con tent and 14 Days Curing Time)

Multiple Comparisons

Dependent Variable: CR
Tukey HSD

(I) LEACHANT	(J) LEACHANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.990167*	.124	.000	.593284	1.387049
	3	5.355333*	.124	.000	4.958451	5.752216
	4	5.662333*	.124	.000	5.265451	6.059216
2	1	-.990167*	.124	.000	-1.38705	-.593284
	3	4.365167*	.124	.000	3.968284	4.762049
	4	4.672167*	.124	.000	4.275284	5.069049
3	1	-5.355333*	.124	.000	-5.75222	-4.95845
	2	-4.365167*	.124	.000	-4.76205	-3.96828
	4	.307000	.124	.139	-9.0E-02	.703882
4	1	-5.662333*	.124	.000	-6.05922	-5.26545
	2	-4.672167*	.124	.000	-5.06905	-4.27528
	3	-.307000	.124	.139	-.703882	9.0E-02

*. The mean difference is significant at the .05 level.

APPENDIX C

FIGURES OF THE EXPERIMENT

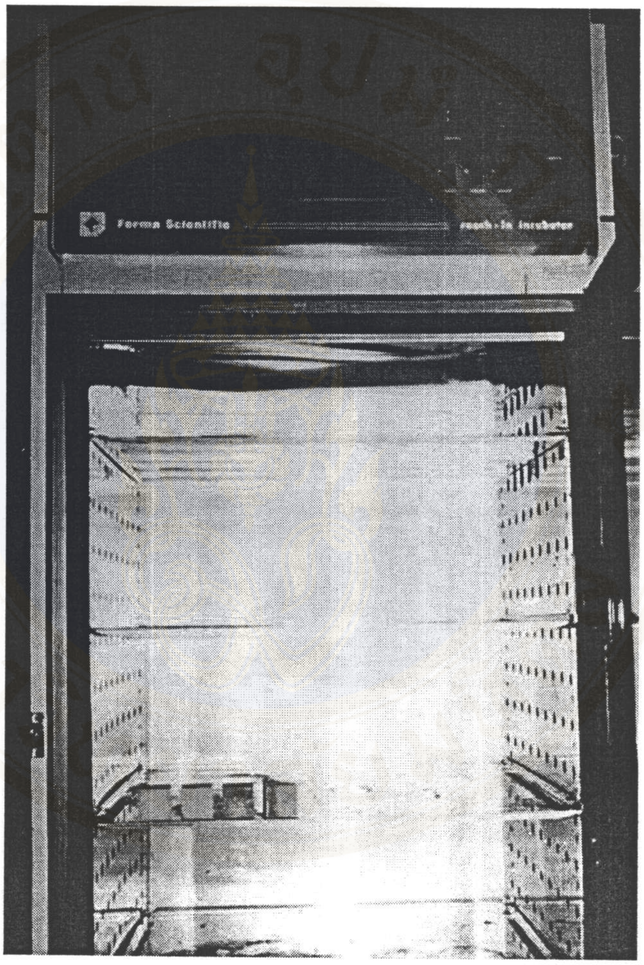

Figure C-1 Incubator

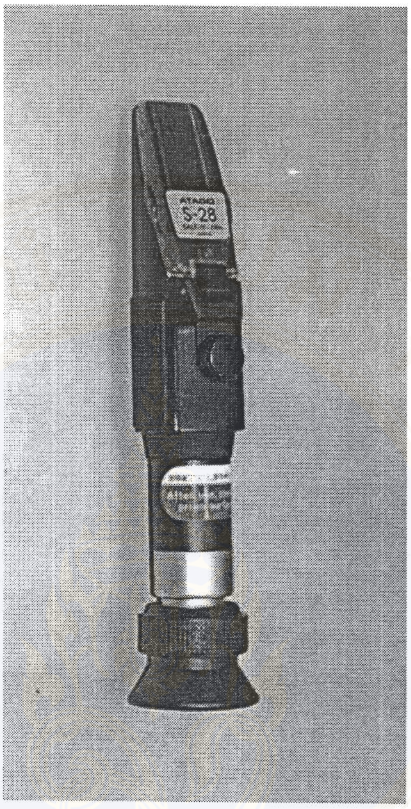

Figure C-2 Salinity Meter

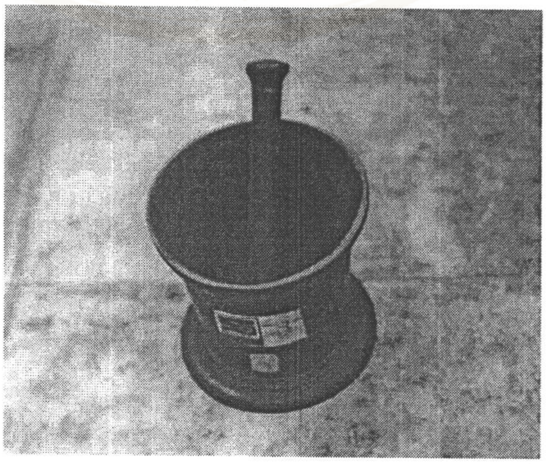

Figure C-3 Soiltest engineering test equipment

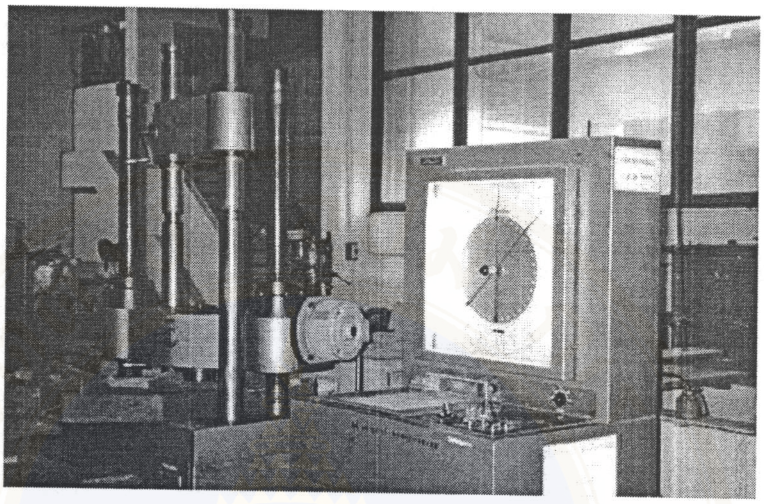

Figure C-4 Testing Machine

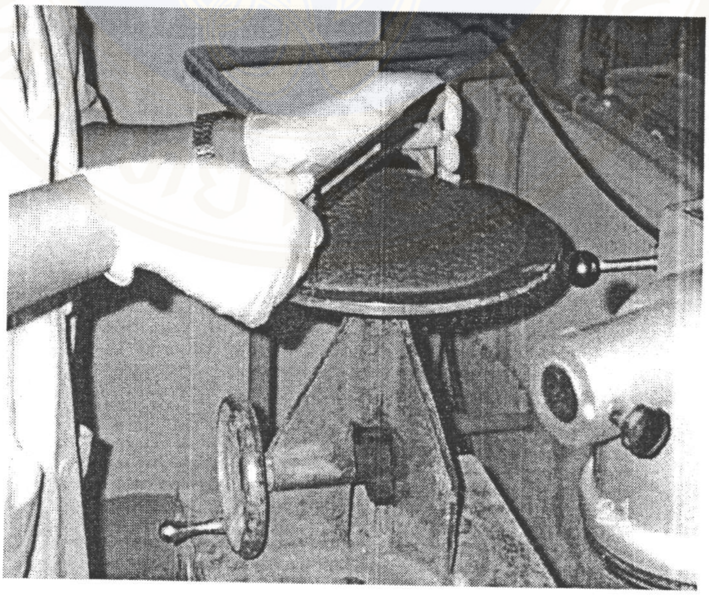

Figure C-5 Flow Determination

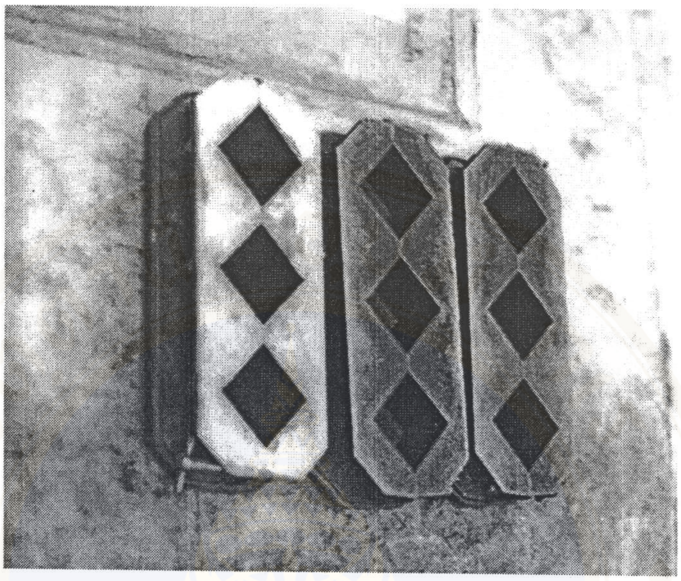

Figure C-6 2-inch or [50 mm] cube mold

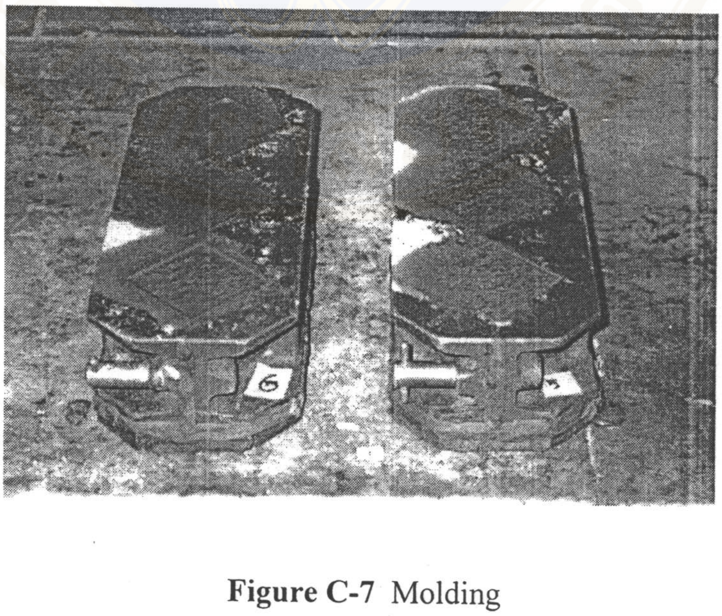

Figure C-7 Molding

Figure C-8 Mechanical Mixer

BIOGRAPHY

NAME	Miss Aungsiri Klinmalee
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INSTITUTIONS ATTENDED	Silpakorm University, 1993 –1996: Bachelor of Science (Environmental Science) Mahidol University, 1997 – 1999: Master of Science (Environmental Technology)
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