A STUDY OF HEAVY METALS IN BOTTOM ASH FROM MEDICAL WASTE INCINERATOR IN NAKHONRATCHASIMA MUNICIPALITY

Miss Patcharin Racho

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Master in Environmental Engineering
Suranaree University of Technology
Academic Year 2002
ISBN 974-533-616-9

การศึกษาปริมาณโลหะหนักในขี้เถ้าก้นเตาเผาขยะติดเชื้อโรงพยาบาลในเขตเทศบาลนคร นครราชสีมา

นางสาว พัชรินทร์ ราโช

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตร์มหาบัณฑิต
สาขาวิศวกรรมสิ่งแวดล้อม
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2545

ISBN 974-533-616-9

พัชรินทร์ ราโช: การศึกษาปริมาณโลหะหนักจากขี้เถ้าก้นเตาเผาขยะติดเชื้อโรงพยาบาลในเขตเทศบาลนคร นครราชสีมา
(A STUDY OF HEAVY METALS IN BOTTOM ASH FROM MEDICAL WASTE INCINERATOR IN NAKHON RATCHASIMA MUNICIPALITY)
อ. ที่ปรึกษา: Asst. Prof. Dr. Ranjna Jindal, 110 หน้า. ISBN 974-533-616-9

เตาเผาขยะเป็นระบบการกำจัดขยะติดเชื้อที่นิยมใช้อยู่ในปัจจุบันซึ่งสามารถลดปริมาตรขยะติดเชื้อและทำลายเชื้อโรคต่าง ๆ ได้เป็นอย่างดีแต่อย่างไรก็ตามการเผาไม่สามารถที่จะกำจัดส่วนที่เป็นสารอนินทรีย์ได้ ซึ่งได้แก่ โลหะหนักต่าง ๆ โดยโลหะหนักเหล่านี้สามารถที่จะรวมตัวเป็นสารประกอบอยู่ในขี้เถ้าก้นเตาเผาขยะติดเชื้อและอาจมีความเข้มข้นในระดับที่เป็นอันตรายได้ ในปัจจุบันการศึกษาพฤติกรรมและปริมาณโลหะหนักในขี้เถ้าก้นเตาเผาขยะติดเชื้อยังมีอยู่น้อยมาก ขี้เถ้าก้นเตาเผาขยะติดเชื้อส่วนใหญ่จะถูกนำไปฝังกลบ สารอินทรีย์ที่เกิดจากการเผาไหม้สามารถย่อยสลายได้แต่โลหะหนักซึ่งเป็นสารอนินทรีย์ไม่สามารถย่อยสลายได้ยังคงมีความเข้มข้นสูงอยู่ใต้พื้นที่ฝังกลบ เมื่อเกิดสภาวะที่มีความเข้มข้นของกรด-เบสสูงในพื้นที่ฝังกลบอาทิสภาวะฝนกรด โลหะหนักสามารถที่จะปนเปื้อนออกมาสู่สิ่งแวดล้อมโดยการปนเปื้อนน้ำชะล้างได้

ในการศึกษาครั้งนี้มีวัตถุประสงค์เพื่อศึกษาปริมาณโลหะหนักซึ่งได้แก่ ตะกั่ว เงิน เหล็ก สังกะสี ในเถ้าก้นเตาเผาขยะติดเชื้อโรงพยาบาลราชสีมาธนบุรี และความเข้มข้นของโลหะหนักในน้ำชะขี้เถ้าก้นเตาเผา โดยพิจารณาแนวโน้มของโลหะหนักในอนุภาคที่แตกต่างกัน 4 ขนาดได้แก่ ขนาดใหญ่กว่า 9.5 mm, 9.5-4.75 mm, 0.5-4.75 mm และขนาดเล็กกว่า 0.5 mm แล้วทำการเปรียบเทียบความเข้มข้นของโลหะหนักในน้ำชะล้างกับมาตรฐานความเข้มข้นของโลหะหนักในน้ำชะล้างของเสียอันตรายตามประกาศกระทรวงอุตสาหกรรมฉบับที่ 6 (พ.ศ. 2540) ผลการศึกษาความเข้มข้นของ ตะกั่ว เงิน เหล็ก และ สังกะสี ในขี้เถ้าก้นเตาเผาขยะติเชื้อพบว่ามีความเข้มข้นเฉลี่ยเท่ากับ 765.25, 327.91, 314,121.19 และ 18,710.69 mg/kg ตามลำดับ ความเข้มข้นของ ตะกั่ว เงิน เหล็ก และ สังกะสี ในน้ำชะล้างขี้เถ้าก้นเตาเผาขยะติดเชื้อพบว่ามีความเข้มข้นเฉลี่ยเท่ากับ 0.08, 0.07, 0.21 และ 0.26 mg/L ตามลำดับ ซึ่งความเข้มข้นเฉลี่ยของโลหะหนักทั้ง 4 ชนิดในชะล้างขี้เถ้าไม่เกินมาตรฐานที่กฎหมายกำหนด

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา……………………………..
ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา……………………..

PATCHARIN RACHO: A STUDY OF HEAVY METALS IN BOTTOM ASH FROM MEDICAL WASTE INCINERATOR IN NAKHONRATCHASIMA MUNICIPALITY THESIS ADVISOR: ASST. PROF. DR. RANJNA JINDAL, 110 PP. ISBN 974-533-616-9

HEAVY METALS/BOTTOM ASH/MEDICAL WASTE INCINERATOR/
EXTRACTION (EP) TOXICITY

The environmental impact of medical waste incinerators has become the subject of public debate. The main goal of incinerators is to develop a sustainable waste management by reducing volume of non-avoidable and non- recyclable medical waste to be disposed, and to decrease its post depositional reactivity due to its organic matter inventory. Priority pollutants are trace metals enriched in medical waste products. Since combustion will not destroy inorganic compounds present in healthcare waste, such as metals, it is possible that such compounds may end up in bottom ash at harmful concentrations. Oxyanion-forming metals such as lead, cadmium, aluminum, zinc, silver, iron and the other heavy metals deserve special attention due to their toxic behavior. While some general information is available from recently published work, the behavior of the metals in medical waste incinerators bottom ash is yet to be understood. Although the bottom ash can be utilized for recovery from the conventional incinerators based on the grate system, a major portion of these residues are still landfilled. A bottom ash landfill can be regarded as a heterogeneous fixed bed reactor, where fast and slow acid-base reactions occur and continue for long term, with yet unknown end point. Major cation and anion concentrations observed in aqueous extracts and leachates reflect the advance of those primarily inorganic reactions.

The objectives of this research were: to study the quantities of heavy metals in the residual bottom ash from incineration of medical waste in Ratchasima-Thonburi Hospital; to investigate the relationship between the particle size and the concentrations of heavy metals in bottom ash as well as in the leachate; and to evaluate the toxicity of leachate from bottom ash. The four metals selected were lead, silver, iron and zinc. Investigations were carried out for the four particle sizes, >9.5 mm, 9.5-4.75 mm, 4.75-0.5 mm, and less than 0.5 mm respectively. The toxicity of simulated leachate from bottom ash was investigated for the four selected metals and the concentrations were compared with standards for heavy metals in the leachate of hazardous waste following the sixth notification issued by Thailand's Ministry of Industry. The average concentrations of lead, silver, iron, and zinc in bottom ash during the sampling period (25th October 2001-15th February 2002) were found to be 765.25, 327.91, 314,121.19, and 18,710.69 mg/kg, respectively. The extraction of leachate (EP) test showed the average concentrations of lead, silver, iron, and zinc to be 0.08, 0.07, 0.21 and 0.26 mg/L, respectively. The concentrations of all heavy metals were below the limits set by the Thai Ministry of Industry. The results of this study can be used to evaluate the suitable ways of disposing the bottom ash from medical waste incinerators.

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา................................

ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา........................

Acknowledgements

The author would like to express her sincere gratitude towards her advisor and chairperson Asst. Prof. Dr. Ranjna Jindal for her valuable guidance and continuing support. She also express her thanks towards Asst. Prof. Dr. Chongchin Polprasert and Asst. Prof. Dr. Santi Sakdarat for their guidance and support, and for serving as members of her examination committee.

She appreciates the active support of her friends-Mr. Burachat Viriya, Mr. Nirun Kongritti, Mr.Kraichat Tantrakanapa and Ms.Warutai Deittanon. She is also grateful to all the faculty and staff members of the Environmental Engineering and Highway laboratory at SUT for their help and assistance throughout the period of this study.

Last but not the least, she would like to acknowledge the heartfelt gratitude she feels towards her family for their support and encouragement throughout her course of study at Suranaree University of Technology and reaffirms her faith in the all mighty.

Patcharin Racho

Table of Contents

Page

CHAPTER

Table of Contents (Cont.)

Page

List of Tables

Table **Page**

List of Tables (Cont.)

Table **Page**

List of Tables (Cont.)

Table **Page**

List of Figures

Figure **Page**

List of Figures (Cont.)

Figure **Page**

List of Abbreviations

Ag = Silver
Al = Aluminum
As = Arsenic
Ba = Barium
Be = Beryllium
Ca = Calcium
Cal = Calorie
CBA = Composite bottom ash
Cd = Cadmium
Cl = Chlorine
CLS = Composite lagoon sludge
Cu = Copper
DPC = Department of public cleansing
EP = Extract procedure
Fe = Iron
Hg = Mercury
J = Joule
K = Potassium
Mg = Magnesium
MSW = Municipal solid waste
MSWI = Municipal solid waste incinerator
N = Nitrogen
Ni = Nickel
P = Phosphorous
Pb = Lead
PAHs = Polycyclic aromatic hydrocarbons
PCBs = Polychorobiphenyls

List of Abbreviations (Cont.)

PVC = Polyvinyl chloride
S = Sulfur
TC = Total carbon
TCDD = 2,3,7,8-Tetrachlorodibenzo-p-dioxin
TCPL = Toxicity characteristics leachaing procedure
Ti = Titanium
TIC = Total inorganic carbon
TOC = Total organic carbon
USEPA = United Stated Environmental Protection Agency
Zn = Zinc

Chapter 1

Introduction

1.1 Introduction

In pursuing their aims of reducing health problems and eliminating potential risks to people's health, health care services inevitably create waste that may itself be hazardous to health. The waste produced in the course of health care activities carries a higher potential for infection and injury than any other type of waste. Wherever it is generated, safe and reliable methods for its handling are therefore essential. Inadequate and inappropriate handling of health care waste may have serious public health consequences and significant impact on the environment. Sound management of health care waste is thus a crucial component of environmental health protection. In both the short term and long term, the actions involved in implementing effective medical waste management programs require disposal facilities (Prüss et al., 1999).

In the course of daily activities, a hospital produces waste. Some of that waste is discharged to the sanitary sewer systems and some of it is released in gaseous form through laboratory hood vent pipes. However, most of it is solid waste. Technically, solid waste is any waste which is not discharged into the air, so the term can be applied to liquids. Solid waste comprises the largest percentage of hospital generated waste and includes such waste types as general office trash, food service waste and even the fastest growing waste type, recyclable waste. In the United States, solid wastes from hospitals include three types of waste, which fall under us federal or state regulation: radioactive, chemical and potentially infectious. These three types of waste comprise regulated medical waste. Simply put, they are medically generated wastes, which are governed by regulation. In the Medical Waste Tracking Act of 1988 of USA, the term 'regulated medical waste' was used loosely to apply to those items identified by the Environmental Protection Agency (EPA) as being potentially Infectious (Michael, 1995).

Medical waste treatment facilities are the facilities that change the biological character or composition of medical waste to substantially reduce or eliminate its potential for causing disease. Destruction facilities are the facilities that destroy medical waste by mutilating it, or tearing it apart to render it less infection and unrecognizable as medical waste. Once medical waste is properly treated and destroyed, it no longer requires to be tracked. These treatment and destruction facilities include incinerators, and treatment operations include the processes that ground, steam sterilize, or treat the waste with disinfectants, heat, or radiation (USEPA, 2001a).

The environmental impact of medical waste incinerators has become the subject of public debate. The main goal of incinerators is to develop a sustainable waste management by reducing volume of non-avoidable and non- recyclable medical waste to be disposed, and reduce its post depositional reactivity due to its organic matter inventory. While energy utilization is increasingly being discussed as merely a secondary effect, the extensive reduction and controllability of potential long term emissions are primary reasons for the increasing role of medical waste incineration integrated waste management systems. A next generation of thermal treatment plants without relying on grate systems is currently being developed. These new systems are designed to separate more efficiently and thus to produce more inert ash quantities for construction related applications. Even though the bottom ash can be utilized already with conventional incinerators based on the grate system, a major portion of these residues are still landfilled. A bottom ash landfill can be regarded as a heterogeneous fixed bed reactor, where fast and slow acid-base reactions occur and continue for long term, with yet unknown end point. Major cation and anion concentrations observed in aqueous extracts and leachates reflect the advance of those primarily inorganic reactions. Priority pollutants are trace metals enriched in medical waste products. Oxyanion-forming metals such as lead, cadmium, aluminum, zinc, silver, iron and the other heavy metals deserve special attention due to their toxic behavior (Michael et al., 1998). While some information on the behavior of the metals is available from recently published work, the behavior of the metals in medical waste incinerators bottom ash is yet to be understood.

1.2 Objectives

The main objectives of this study were:

1. To evaluate the quantities of heavy metals in the residual bottom ash generated in a medical waste incinerator and to study the relationship with the size of particles present.
2. To study the toxicity of heavy metals from leachate of bottom ash.

1.3 Scope and limitations of the study

1. The bottom ash generated from the medical waste incinerator of Ratchasima-Thonburi Hospital in Nakhon Ratchasima was studied.
2. The four heavy metals selected were zinc (Zn), lead (Pb), silver (Ag), and iron (Fe). The quantities of these metals in the bottom ash generated were determined
3. Relationships between the particle size and the concentrations of heavy metals in the bottom ash as well as in the leachate were evaluated.
4. The toxicity of leachate from bottom ash were investigated and compared with the standards for the heavy metals' concentration in the leachate of hazardous waste, following the sixth notification issued by Thailand's Ministry of Industry (1999).

Chapter 2

Literature Review

2.1 Medical waste

2.1.1 Definitions and Classification of medical waste

Medical waste includes all the waste generated by health care establishments, research facilities, and laboratories. In addition, it includes the waste from "minor" or "scattered" sources such as that produced in the course of health care undertaken in the homes (dialysis, insulin injections, etc.).

Between 75% and 90% of the waste produced by health care providers is non-risk or general health care waste, comparable to domestic waste. It comes mostly from the administrative and housekeeping functions of maintenance of health care premises. The remaining 10-25% of health care waste is regarded as hazardous and may create a variety of health risks (Prüss et al., 1999).

Classification of hazardous health care waste is summarized as follows:

2.1.1.1 Infectious waste

Infectious waste is suspected to contain pathogens (bacteria, viruses, parasites, or fungi) in sufficient concentration or quantity to cause diseases in susceptible hosts. This category include:

- Cultures and stocks of infectious agents from laboratory work
- Waste from surgery and autopsies on patients with infectious diseases (e.g. tissues, and material or equipment that have been in contact with blood or other body fluids)
- Waste from infected patients in isolation wards (e.g. excreta, dressings from infested or surgical wounds, clothes heavily soiled with human blood or other body fluids)
- Waste that has been in contact with infected patients undergoing haemodialysis (e.g. dialysis equipment such as tubing and filters, disposable towels, gowns, aprons, gloves, and laboratory coats)

- Research animals’ tissues and parts
- Any other instruments or materials that have been in contact with infected persons or animals

Cultures and stocks of highly infectious agents, waste from autopsies, animal bodies, and other waste items that have been inoculated, infected, or in contact with such agents are called highly infectious waste.

2.1.1.2 Pathological waste

Pathological waste consists of tissues, organs, body parts, human fetuses and animal carcasses, blood, and body fluids. Within this category, recognizable human or animal body parts are also called anatomical waste. This category should be considered as a subcategory of infectious waste, even though it may also include healthy body parts.

2.1.1.3 Sharps

Sharps are items that could cause cuts or puncture wounds, including needles, hypodermic needles, scalpels and other blades, knives, infusion sets, sews, broken glass, and nails. Whether or not they are infected, such items are usually considered as highly hazardous healthy care waste.

2.1.1.4 Pharmaceutical waste

Pharmaceutical waste includes expired, unused, spilt, and contaminated pharmaceutical products, drugs, vaccines, and sera that are no longer required and need to be disposed of appropriately. The category also includes discarded items used in the handling of pharmaceuticals, such as bottles or boxes with residues, gloves, masks, connecting tubing, and drug vials.

2.1.1.5 Genotoxic waste

Genotoxic waste is highly hazardous and may have mutagenic, teratogenic, or carcinogenic properties. It raises serious safety problems, both inside hospitals and after disposal, and should be given special attention. Genotoxic waste may include certain cytostatic drugs, vomit, urine, or faeces from patients treated with cytostatic drugs, chemicals, and radioactive materials. Cytostatic drugs, the principal substances in the category, have ability to kill or stop the growth of certain living cells and are used in chemotherapy of cancer. They play an important role in the therapy of various neoplastic conditions but are also finding wider application as immunosuppressive agents in organ transplantation and in treating various diseases with an immunological basis. Cytostatic drugs are most often used in specialized departments such as oncology and radiotherapy units, whose main role is cancer treatment. However, their use in other hospital departments is increasing and they may also be used outside the hospital setting.

Harmful cytostatic drugs can be categorized as follows:

- Alkylating agents: cause alkylation of DNA nucleotides, which leads to cross-linking and miscoding of the genetic stock
- Antimetabolites: inhibit the biosythesis of nucleic acids in the cell
- Mitotic inhibitor: prevent cell replication

Cytostatic wastes are generated from several sources and can include the follows:

- Contaminated materials from drug preparation and administration, such as syringes, needles, gauges, vials, and packaging
- Outdated drugs, excess (leftover) solutions, drugs returned from the wards
- Urine, faeces, and vomit from patients, which may contain potentially hazardous amounts of the administered cytostatic drugs or of their metabolites and which should be considered genotoxic for at least 48 hours and sometimes up to 1 week after drug administration

2.1.1.6 Chemical waste

Chemical waste consists of discarded solid, liquid, and gaseous chemicals, for example from diagnostic and experimental work and from cleaning, housekeeping, and disinfecting procedures. Chemical waste from health care may be hazardous or nonhazardous. In the context of protecting health care, it is considered to be hazardous if it has at least one of the following properties:

- toxic
- corrosive (e.g. acids of pH < 2 and based on pH > 12)
- flammable
- reactive (explosive, water-reactive, shock-sensitive)

- genotoxic (e.g. cytostatic drugs)

Nonhazardous chemical waste consists of chemicals with none of the above properties, such as sugars, amino acid, and certain organic and inorganic salts.

The types of hazardous chemicals most commonly used in maintenance of health case centres and hospitals and the most likely to be found in waste are discussed in the following paragraphs.

- Formaldehyde

  Formaldehyde is a significant source of chemical waste in hospitals. It is used to clean and disinfect equipment (e.g. haemodialysis or surgical equipment), to preserve specimens, to disinfect liquid infectious waste, and in pathology, autopsy, dialysis, embalming, and nursing units.
- Photographic chemicals

  Photographic fixing and developing solutions are used in X-ray departments. The fixer usually contains 5-10% hydroquinone, 1-5% potassium hydroxide, less than 1% silver. The developer contains approximately 45% glutaraldehyde. Acetic acid is used in both stop baths and fixer solutions.
- Solvents

  Wastes containing solvents are generated in various departments of a hospital, including pathology and histology laboratories and engineering departments. Solvents used in hospitals include halogenated compounds such as methylene chloride compounds, chloroform, trichloroethylene, and refrigerants, and non-harogented compounds such as xylene, methanol, acetone, isopropanol, toluene, ethyl acetate, and acetonitrile.
- Organic chemicals

  Waste organic chemicals generated in health care facilities include:
  - disinfecting and cleaning solutions such as phenol based chemicals used for scrubbing floors, and perchlorethylene used in workshops and laundries.
  - oils such as vacuum-pump oils, and used engine oil from vehicles

(particularly if there is a vehicle service station on the hospital premises).

- insecticides, rodenticides.

2.1.1.7 Waste with high content of heavy metals

Waste with high content of heavy metals represent a subcategory of hazardous chemical waste, and are usually highly toxic. Mercury wastes are typically generated by spillage from broken clinical equipment but their volume is decreasing with the substitution of solid state electronic sensing instruments (thermometers, blood-pressure gauges, etc.). Whenever possible, spilled drops of mercury should be recovered. Residues from dentistry have a high mercury content. Cadmium waste comes mainly from discarded batteries. Certain “reinforced wood panels” containing leads are still used in radiation proofing of X-ray and diagnostic departments. A number of drugs contain arsenic, but these are treated here as pharmaceutical waste.

2.1.1.8 Pressurized containers

Many types of gases are used in health care, and often stored in pressurized cylinders, cartridges, and aerosol cans. Many of these, once empty or of no further use (although they may still contain residues), are reusable. Certain types, notably aerosol cans not be disposed of. Whether inert or potentially harmful, gases in pressurized containers should always be handled with care; containers may explode if incinerated or accidentally punctured.

2.1.1.9 Radioactive waste

Ionizing radiation cannot be detected by any of the senses other than burns, which may occur in exposed areas usually with no immediate effects unless an individual receives a very high dose. The ionizing radiation of interest in medicine include the X-rays, α-and β-particles, and γ-rays emitted by radioactive substances. An important difference between these types of radiation is that X-ray from X-ray tubes are emitted only when generating equipment is switched on, whereas radiation from radionuclides can never switched off and can be avoided only by shielding the material. Radionuclides continuously undergo spontaneous disintegration (known as radioactive decay) in which energy is liberated, generally resulting in the formation of new nuclides. The process is accompanied by the emission of one more type of radiation, such as α- and β-particles and γ-rays. These cause ionization of intracellular material. Radioactive substances are therefore gennotoxic.

2.1.2 Sources of medical waste

The sources of health care waste can be classed as major or minor according to the quantities produced. The major sources are listed below (Prüss et al., 1999):

- Hospitals
  - university hospital
  - general hospital
  - district hospital
- Other health cares establishments
  - emergency medical care services
  - health care centres dispensaries
  - obstetric and maternity clinics
  - outpatient clinics
  - first-aid and sick bays
  - long term health care establishments and hospices
  - transfusion centres
  - military medical services
- Related laboratories and research centres
  - medical and biomedical laboratories
  - biotechnology laboratories and institutions
  - medical research centres
- Mortuary and autopsy centres
- Animal research and testing
- Blood banks and blood collection services
- Nursing home the elderly

Some minor and scattered sources may produce health care waste in categories similar to hospital waste, but their composition will be different. For example:

- they rarely produce radioactive orcytostatic waste
- human body parts are in general not included
- sharps consist mainly of hypodermic needles

Minor sources of health care waste are listed below:

- Small health care establishments
    - physicians' office
    - dental clinics
    - acupuncturists
    - chiropractors
- Specialized health care establishments and institutions with low waste generation
    - convalescent nursing homes
    - psychiatric hospitals
    - disabled persons' institutions
- Non health activities involving intravenous or subcutaneous interventions
    - cosmetic ear piercing and tattoo parlours
    - licit drug users
- Funeral services
- Ambulance services
- Home treatment

The composition of waste is often characteristic of the type of source. For example, the different units within a hospital would generate waste with the following characteristics:

- Medical wards: mainly infectious waste such as dressings, bandages, sticking plaster, gloves, disposable medical items, used hypodermic needles and intravenous sets, body fluids and excreta, contaminated packaging, and meal scraps.
- Operating theatres and surgical wards: mainly anatomical waste such as tissues, organs, fetuses, and body parts, other infectious waste, and sharps.
- Other health care units: mostly general waste with a small percentage of infectious waste.
- Laboratories: mainly pathological (small pieces of tissue, microbiological cultures, stocks of infectious agents, infected animal carcasses, blood and other body fluids), and sharps, plus some radioactive and chemical waste.

- Pharmaceutical and chemical stores: small quantities of pharmaceutical and chemical waste, mainly packaging (containing only residues if stores are well managed), and general waste.
- Support units: general waste only.

Health care waste from scattered source generally has the following characteristic composition:

- Health care provided by nurses: mainly infectious waste and many sharps.
- Physicians' offices: mainly infectious waste and some sharps.
- Dental clinics and dentists' offices: mainly infectious waste and some sharps wastes with high heavy metal content.
- Home health cares (e.g. dialysis, insulin injections): mainly infectious waste and sharps.

2.1.3 Generation rates and composition of medical waste

Some surveys have provided an indication of typical health care waste generation data in Europe and United Republic of Tanzania as summarized in Tables 2.1 and 2.2. Table 2.3 shows the average values of waste composition obtained from 10 large hospitals in Bombay, Calcutta, Delhi, and Nagpur during the period 1993-1996.

2.1.4 The medical waste management

The medical waste investigation program set up provisions for tracking medical waste from generator to the disposal site. One such program was designed by USEPA to ensure proper handling, tracking, and disposal of medical waste. The system required that a tracking form accompany the waste and signed copy be retained by the generator, transporter, transfer station, and the treatment, destruction, and disposal facility that handle the waste. When the final disposal facility accepted the waste, a copy of the signed tracking form was returned to the generator. Through this process, the generator was assured that the waste was actually received for disposal.

Table 2.1. Health care waste from small waste generators in Europe

Source type	Waste generation (kg/day)
General practitioners	
- Sharps	4
- Infectious waste	20
- Total waste	100
Phlebotomists	
- Infectious waste	175
Gynaecologists	
- Infectious waste	350
Nurses	
- Sharps	20
- Infectious waste	100
Dentists	
- Sharps	11
- Infectious waste	50
- Heavy metals	2.5
- Total waste	260
Biomedical laboratories (60 analyses per day) - Infectious waste	At least than 300
Kidney dialysis (3 per week) - Infectious waste	400

Source: Prüss et al. (1999).

Table 2.2. Health care waste generation in government health facilities of Dar es Salaam (United Republic of Tanzania)

Health care facility	Health care waste quantities in 1995/1996	
	Non-hazardous waste (kg/day per patient)	Hazardous waste (kg/day per patient)
District hospital (in and out patient)	0.06	0.08
Health centres (urban)	0.01	0.01
Dispensaries		
-rural	0.02	0.02
-urban	0.01	0.01

Source: Prüss et al. (1999).

The tracking program also included exception and discrepancy reporting to EPA and the state if the wastes were not being handled properly. To minimize contact with medical waste by workers, handlers and the public, the program also included specific requirements for segregation, packing, labeling, marking, and storing of medical wastes before they were shipped to another site for treatment, destruction, or disposal.

Table 2.3. Average composition of hospital waste in India

Material	Percentage (wet-weight basis) (%)
Paper	15
Plastics	10
Rags	15
Metals (sharps)	1
Infectious waste	1.5
Glass	4.0
General waste (food waste, sweepings from hospital premises)	53.5

Source: Prüss et al. (1999).

2.1.4.1 Waste segregation and packaging

The key to minimization and effective management of health care waste is segregation (separation) and identification of the waste. Appropriate handling, treatment, and disposal of waste by type reduce costs and dose much to protect public health. Segregation should always be the responsibility of waste producer, and should be maintained in storage areas and during transport. The same system of segregation should be forced throughout the country (Prüss et al., 1999).

The most appropriate way of identifying the categories of health care waste is by sorting the waste in to colour coding scheme as given in Table 2.4.

2.1.4.2 On-site collection, transportation, and storage of waste

1. Collection

Nursing and other clinical staff should ensure that waste bags are tightly closed and sealed when they are about three quarters full. Light gauge bags can be closed by tying the neck, but heavier gauge bags probably require a plastic sealing tag of the self locking type. Bags should not be closed by stapling. Sealed sharps containers should be placed in a labelled, yellow infectious health care waste bag before removal from the hospital ward or department.

Table 2.4. Recommended colour coding for health care waste

Type of waste	Colour of container and making	Type of container
1. Highly infectious waste	Yellow, marked "HIGHLY INFECTIOUS"	Strong, leak-proof plastic bag, or container capable of being autoclaved
2. Other infectious waste, pathogenic and anatomical waste	Yellow	Leak-proof plastic bag or container
3. Sharps	Yellow, marked "SHARPS'	Puncture proof container
4. Chemical and pharmaceutical waste	Brown	Plastic bag or container
5. Radioactive waste	-	Lead box, labeled with the radioactive symbol
6. General health care waste	Black	Plastic bag

Source: Prüss et al. (1999).

Waste should not be allowed to accumulate at the point of production. A routine programme for their collection should be established as part of the health care waste management plan.

Certain recommendations listed below, should be followed by the ancillary workers in-charge of waste collection:

- Waste should be collected daily (or as frequently as required) and transported to the designated central storage site.
- No bags should be removed unless they are labelled with their point of production (hospitals and ward or department) and contents.
- The bags or containers should be replaced immediately with new ones of same type.

A supply of fresh collection bags or containers should be readily available at all locations where waste is produced (Prüss et al., 1999).

2. Storage

A storage location for heath care waste should be designated inside the health care establishment or research facility. The waste, in bags or containers, should be stored in a separate area, room, or building of a size appropriate to the quantities of waste produced and the frequency of collection. Recommendations for the storage area and its equipment are listed below:

- The storage area should have an impermeable, hard-standing floor with good drainage; it should be easy to clean and disinfect.
- There should be a water supply for cleaning purposes.
- The storage area should afford easy access for staff in-charge of handling the waste.
- It should be possible to lock the store to prevent access by unauthorized persons.
- Easy access for waste collection vehicles is essential.
- There should be protection from the sun.
- The storage area should be inaccessible for animals, insects, and birds.
- There should be good lighting and at least passive ventilation.
- The storage area should not be situated in the proximity of fresh food stores or food preparation facilities.
- A supply of cleaning equipment, protective clothing, and waste bags or containers should be located conveniently close to the storage area.

Unless a refrigerated storage room is available, storage times for health care waste (i.e. the delay between production and treatment) should not exceed the following:

Temperate climate:	72 hours in winter
	48 hours in summer
Warm climate:	48 hours during the cool season
	24 hours during the hot season

Cytotoxic waste should be stored separately from other health care waste in a designated secure location.

Radioactive waste should be stored in containers behind lead shielding that prevent dispersion. Containers should be labeled with the type of radionuclide, the date, and the details of required storage condition (Prüss et al., 1999).

3. On-site transport

Health care waste should be transported within the hospital or other facility by means of wheeled trolleys, containers, or carts that are not used for any other purpose and meet the following specifications:

- easy to and unload
- no sharp edges that could damage waste bags or containers during loading and unloading
- easy to clean

The vehicles should be cleaned and disinfected daily with an appropriate disinfectant. All waste bag seals should be in place and intact at the end of transportation. Different types of vehicles used for the on-site transportation of health care waste in Thailand are shown in Figure 2.1 (Prüss et al., 1999).

2.1.4.3 Off site transportation of waste

1. Regulations and control system

The health care waste producer is responsible for safe packing and adequate labeling of waste to be transported off-site and for authorization of its destination. Packaging and labeling should comply with national regulations governing the transport of hazardous wastes, and with international agreements if wastes are to be shipped abroad for treatment. In case there are no such national regulations, responsible authorities may refer to recommendation on the transport of dangerous goods, published by the United Nations (Prüss et al., 1999).

The control strategy for health care waste should have the following components:

- A consignment note should accompany the waste from its place of production to the site of final disposal. On completion of the journey, the transporter should complete the part of consignment note especially reserved for him and return to the waste producer.
- The transporting organization should be registered with, or known to, the waste regulation authority.
- Handling and disposal facilities should hold a permit, issued by a waste regulation authority, allowing the facilities to handle and dispose of health care waste.

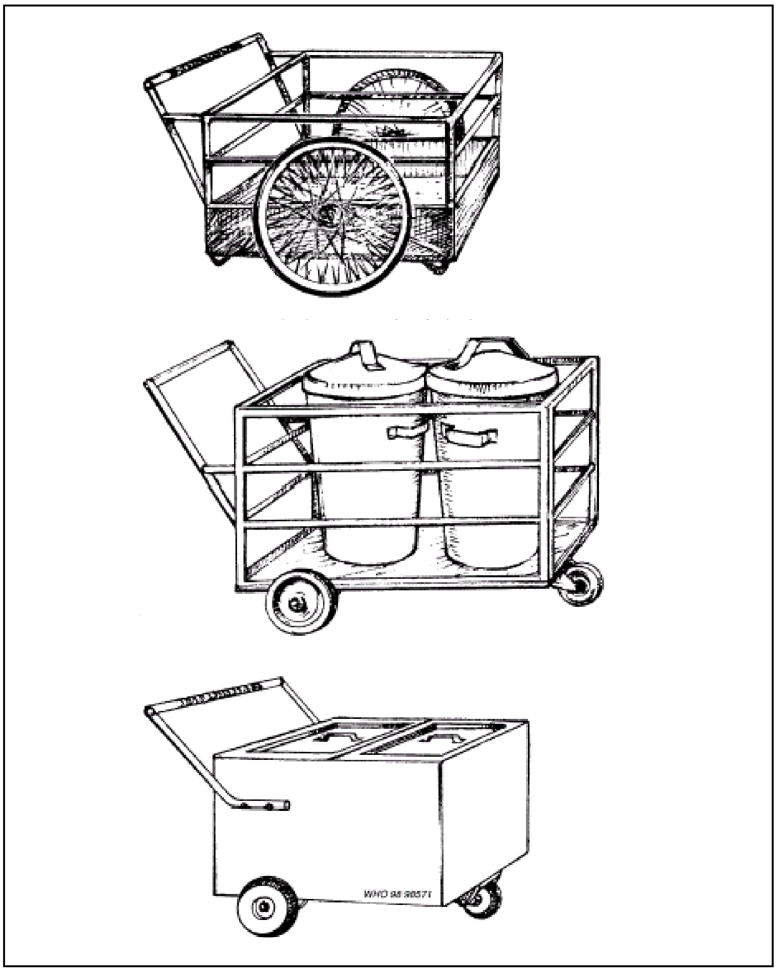


Figure 2.1. Wheeled vehicles used for transportation of health care waste in small hospitals in Thailand. (Ministry of public health, 1995).

2. Special packaging requirement for off-site transport

In general, the waste should be packaged according to the above recommendations, in sealed bags or containers, to prevent spilling during handling and transportation. The bags or containers should be appropriately robust for their content (puncture-proof for sharps, for example, or resistant to aggressive chemicals) and for normal conditions of handling and transportation, such as vibration or change in temperature, humidity, or atmospheric pressure.

3. Labeling

All waste bags or containers should be labeled with basic information on their content and on the waste producer. This information may be written directly on the bags or containers or on preprinted labels, securely attached.

For health care waste, the following additional information should be marked on the label:

- Waste category
- Date of collection
- Place in hospital where produced (e.g. ward)
- Waste destination

4. Transportation vehicles or containers

Waste bags may be placed directly into the transportation vehicles, but it is safer to place them in further containers (e.g. cardboard boxes or wheeled, rigid, lidded plastic or galvanized bins). This has advantage of reducing the handling of filled waste bags but results in higher disposal costs. These secondary containers should be placed close to the waste source.

Vehicles or containers used for the transportation of health care waste should not be used for the transportation of any other material. They should be kept locked at all times, except when loading and unloading. Articulated or demountable trailers (temperature-controlled if required) are particularly suitable, as they can easily be left at site of waste production. Other systems may be used, such as specially designed large containers or skips. Open-topped skips or containers should never be used for transporting health care waste.

Where the use of a dedicated vehicles cannot be justified, a bulk container that can be lifted on to a vehicle chassis may be considered. The container may be used for storage at the health care establishment and replaced with an empty one when collected. Refrigerated containers may be used if the storage time exceeds the recommendation or transportation times are long. The finish of these bulk containers should be smooth and impervious and permit easy cleansing or disinfection. A vehicle used for the transportation of health care waste in the United Kingdom is shown in Figure 2.2.

5. Routing

Health care waste should be transported by the quickest possible route, which should be planned before journey begins. After departure from the waste production point, every effort should be made to avoid further handling. If handling cannot be avoided, it should be pre-arranged and take place in adequately designed and authorized premises. Handling requirements can be specified in the contract established between the waste producer and the carrier.

Figure 2.2. Example of vehicle used for transportation of health care waste in the United Kingdom (London Waste Regulation Authority, 1994)

2.1.4.4 Treatment and disposal for medical waste

Incineration used to be the method of choice for most hazardous health care wastes and is still widely used. However, recently developed alternative treatment methods are becoming increasingly popular. The final choice of treatment system should be made carefully, on the basis of various factors, many of which depend on local conditions as described below (Prüss et al., 1999):

1. Chemical disinfection

Chemical disinfection, used routinely in health care to kill microorganisms on medical equipment and floors and walls, is now being extended to the treatment of health care waste. Chemicals are added to waste to kill or inactivate the pathogens it contains. This treatment usually results in disinfection rather than sterilization. Chemical disinfection is most suitable for treating liquid waste such as blood, urine, stools, or hospital sewage. However, solid and even highly hazardous health care wastes, including microbiological cultures, sharps, etc., may also be disinfected chemically.

2. Wet and dry thermal treatment

- Wet thermal and steam disnfection is based on exposure of shredded infectious waste to high temperature, high pressure steam, and is similar to the autoclave sterilization process. It inactivates most types of microorganisms if temperature and contact time are sufficient. For sporulated bacteria, a minimum temperature of 121°C is needed. About 99.99% inactivation of microorganisms may be expected, compared with the 99.9999% achievable with autoclave sterilization.

  The wet thermal process requires that waste be shredded before treatment; for sharps, milling or crushing is recommended to increase disinfection efficiency. The process is inappropriate for the treatment of anatomical waste and animal carcasses, and will not efficiently treat chemical or pharmaceutical waste.
- Screw feed technology

  Screw feed technology is the basis of a non-burn, dry thermal disinfection process in which waste is shredded and heated in a rotating auger. Continuously operated units, also called continuous feed augers, are commercially available and already in use at several hospitals in developed countries. The principal steps of the process are the following:
  - The waste is shredded to particles about 25 mm. in diameter.
  - The waste enters the auger, which is heated to a temperature of 110-140°C by oil circulating through its central shaft.
  - The waste rotates through the auger for about 20 minutes, after which the residues are compacted.

  The waste is reduced by 80% in volume and by 20-35% in weight. This process is suitable for treating infectious waste and sharps, but it should not be used to process pathological, cytotoxic, or radioactive waste. Exhaust air should be filtered, and condensed water generated during the process, should be treated before discharge.

3. Microwave irradiation

Most microorganisms are destroyed by the action of microwaves of a frequency of about 2450 MHz and a wavelength of 12.24 cm. The water contained within the wastes is rapidly heated by the microwaves and the infectious components are destroyed by heat conduction.

In a microwave treatment unit, a loading device transfers the wastes into a shredder, where it is reduced to small pieces. The waste is then humidified, transferred to the irradiation chamber, which is equipped with series of microwave generators, and irradiated for about 20 minutes. After irradiation, the waste is compacted inside a container and enters the municipal waste stream.

4. Land disposal

If a municipality or medical authority genuinely lacks the means to treat waste before disposal, the use of a landfill has to be regarded as an acceptable disposal route. Allowing health care waste to accumulate at hospitals or elsewhere constitutes a far higher risk of the transmission of infectious than careful disposal in a municipal landfill, even if the site is not designed to the standard used in higher income countries. The primary objections to landfill disposal of hazardous health care waste, especially untreated waste, may be cultural and religious or based on a perceived risk of the releases of pathogens to air and water or on the risk of access by scavengers.

2.2 Medical Waste Incinerators

Garbage and medical waste incinerators are large sources of dioxin identified by the USEPA. Polyvinyl chloride (PVC) plastic is major source of chlorine in these wastes. Besides being emitted into the air, dioxins end up in the bottom ash and the fly ash captured by pollution control equipment in incinerator. Other combustion sources of dioxins include cement klins, hazardous waste incinerators, metals smelters, wood burning, and vehicles running on leaded gassoline (Hollie, 2001).

2.2.1 Principles of incineration

Incineration is a high temperature dry oxidation process that reduces organic and combustible waste to inorganic, incombustible matter and results in a significant reduction of waste volume and weight. This process is usually selected to treat wastes that cannot be recycled, reused, or disposed of in a landfill site. The process flow is illustrated schematically in Figure 2.3.

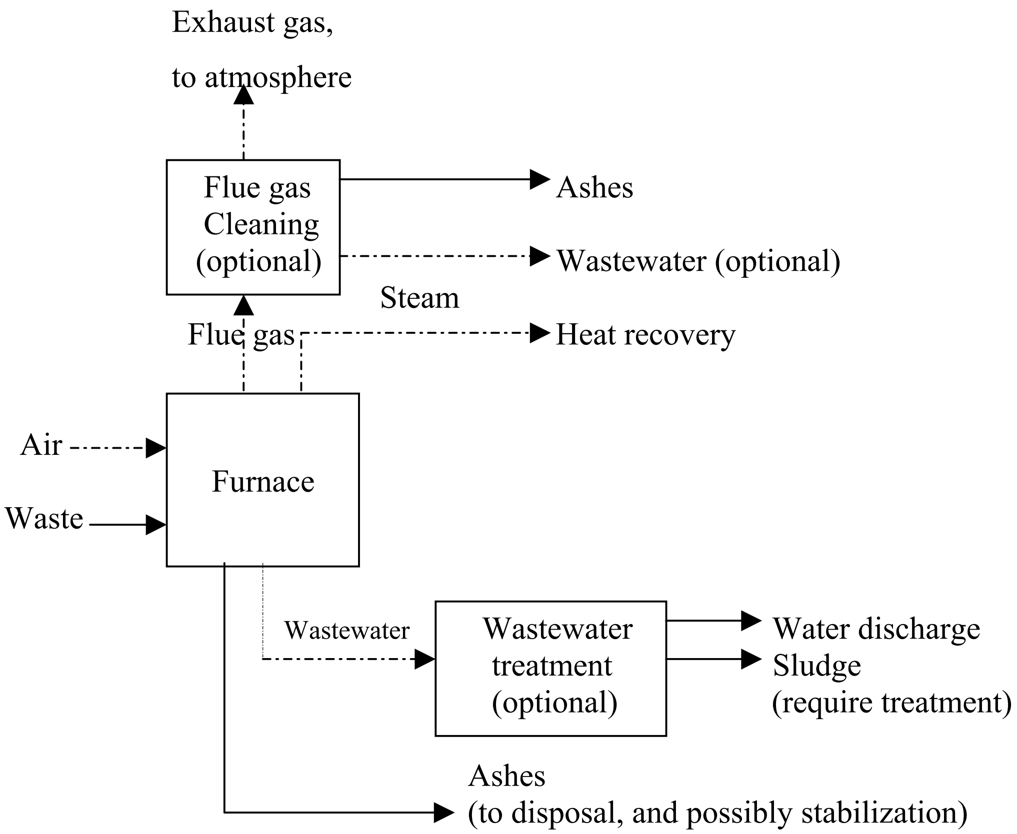


Figure 2.3. Simplified flow scheme of incinerator (Prüss et al., 1999)

Combustion of organic compounds produces mainly gaseous emissions, including steam, carbon dioxide, nitrogen oxide, and certain toxic substances (e.g. metals, halogenic acids), and the particulate matter, plus solid residues in the from of ashes. If the conditions of combustion are not properly controlled, toxic carbon monoxide will also be produced. The ash and wastewater produced by the process also have toxic compounds, which have to be treated to avoid adverse effects on health and the environment.

Most large, modern incinerators include energy recovery facilities. In cold climates, steam and/or hot water from incinerators can be used to feed urban district heating systems, and in warmer climates the steam from incinerator is used to generate electricity. The heat recovered from small hospital incinerators is used for preheating of waste to be burnt (Prüss et al., 1999).

Incineration of waste is affordable and feasible only if the heating value of waste reaches at least 2,000 kcal/kg (8,370 kJ/kg). Although, the value for infectious waste, for instance, exceeds 4,000 kcal/kg, the characteristics that make waste suitable for incineration are listed below:

- low heating value: above 2,000 kcal/kg (8,370 kJ/kg) for single chamber incinerator, and above 3,500 kcal/kg (14,640 kJ/kg) for pyrolytic double-chamber incinerator
- content of combustion matter above 60%
- content of non-combustion solids below 5%
- content of non-combustion fines below 20%
- moisture content below 30%

An input of appropriate fuel may overcome a slightly deficient heating value or a slightly excessive moisture content.

Incineration requires no pretreatment, provided that certain waste types are not included in the matter to be incinerated. Wastes that can not be incinerated are listed below:

- pressurized gas containers
- large amounts of reactive chemical wastes
- silver salts and photographic or radiographic waste
- halogenated plastic such as polyvinyl chloride (PVC)
- waste with high mercury or cadmium content, such as broken thermometers, used batteries and lead-lined wooden panels
- sealed ampoules or ampoules containing heavy metals

2.2.2 Types of medical waste incinerator

Incinerators can range from extremely sophisticated high temperature operating types to the very basic combustion units that operate at much lower temperatures. All types temperature incinerators, if operated properly, eliminate pathogens from waste and reduce the waste to ashes. However, certain types of health waste, e.g. pharmaceutical or chemical waste, require higher temperature for complete destruction. Higher operating temperatures and cleaning of exhaust gases limit the atmospheric pollutants and odors produced by incineration process (Prüss et al., 1999).

Incinerator equipment should be carefully chosen on the basic of the available resources and local situation, and of risk benefit consideration balance of public health benefits of pathogen elimination before waste disposal against the potential risks of air or groundwater pollution caused by inadequate destruction of certain waste.

Three basic kinds of incineration technology are of interest, which may be especially designed to burn infectious health care waste:

- double chamber pyrolytic incinerators, which may be especially designed to burn infectious health care waste
- single chamber furnaces with static grate, which should be used only if pyrolytic incinerators are not affordable
- rotary kilns operating at high temperature, capable of causing decomposition of genotoxic substances and heat resistant chemicals

Incinerators designed especially for treatment of medical waste should operate at temperature between 900 and 1,200°C. Lower cost, high temperature incinerators of simple design are currently being developed, and a system designed specifically for health care and pharmaceutical waste in low income countries is currently under test at De Montfort University in England.

Mobile incinerators for medical waste have been tested in Brazil. These units permit on site treatment in hospitals and clinics, thus avoiding the need for transporting the infectious waste through city streets. Test results for unit with capacity of 30 kg/hour were satisfactory in terms of function, performance, and air pollution (Bartone, 1998).

High temperature incineration of chemical and pharmaceutical waste in industrial cement or steel kilns is practiced in many countries and is a valuable option. No additional investments are required and industry benefits from a supply of a free combustible matter.

Assessment of waste parameters

Specific waste parameters should be assessed at the planing stage to determine the most suitable type and size of incinerator.

- Current extent of waste production and type of health care waste
- Estimated future waste production
- Production of incinerable waste per day (and per bed per day)
- All the physical parameters that determine the suitability of waste for incineration, such as low heating value and moisture content

2.2.2.1 Pyrolytic incinerators

The most reliable and commonly used treatment process for health care waste is pyrolytic incinerator, also called controlled air incineration or double chamber incineration. The main characteristics of pyrolytic incinerators, which may be especially designed for hospitals, are summarized below (Prüss et al., 1999):

Characteristics of pyrolytic incinerators

1. Adequate for the following waste categories:

- Infectious waste (including sharps) and pathological waste
  - efficient treatment, elimination of all pathogens
- Pharmaceutical and chemical residues
  - Cause disintegration of most residues; however, only small amounts (e.g. 5% of total waste load) of these wastes should be incinerated in this process.

The low heating value of the wastes should exceed 3,500 kcal/kg (14,650 kJ/kg)

2. Inadequate for the following wastes:

- Non risk health care similar to urban waste
  - Pyrolytic incineration would waste resource.
- Genotoxic waste
  - Treatment probably not efficient
- Radioactive waste
  - Treatment dose not affect radioactive properties and may disperse radiation.

3. Following wastes should not be incinerated:

- Pressurized containers
  - May explode during incineration and cause damage to the equipment.

- Waste with high heavy metal content
  - Incinerator will cause emission of toxic metals (e.g. lead, cadmium, and mercury) into the atmosphere.

4. Incineration temperature: 800-900°C
5. Incinerator capacity: Available capacities range from 200kg/day to 10 tones/day. Hospitals are usually equipped with incinerators with a capacity of less than 1 tone/day
6. Exhaust gas-cleaning equipment: Needed for larger facilities
7. Additional remarks: The equipment is expensive to operate and maintain. Well-trained personnel are required

The pyrolytic incinerator comprises a pyrolytic chamber and the post combustion chamber and functions as follows:

- In the pyrolytic chamber, the waste is thermally decomposed through an oxygen deficient, medium temperature combustion process (800-900°C), producing solid ashes and gases. The pyrolytic chamber includes a fuel burner, used to start the process. The waste is loaded in suitable waste bags or containers.
- The gases produced in this way are burned at high temperature (900-1200°C) by a fuel burner in the post combustion chamber, using an excess of air to minimize smoke and odors.

Design and size of a pyrolytic incinerator:

Optional combustion conditions are essential if there is to be an almost complete destruction of waste without the generation of significant amounts of harmful solids, liquids, or gaseous outputs (e.g. dioxins, furans). The burning temperature, waste residence time inside the furnace, gas turbulence, and size of airflow inputs are therefore critical. The incinerator should fulfill the following criteria:

- The temperature in the post combustion chamber should be at least 900°C, and gas residence time should be at least 2 seconds; air inflow with 100% excess oxygen and high turbulence should be ensured.

- The pyrolytic chamber should be of sufficient size to allow a residence time for the waste of 1 hour. It should contain baffles or dampers to increase the mixing of waste with the air inflow.
- The pyrolytic and post combustion chambers should be of steel with an internal lining of refractory bricks, resistant to corrosive waste or gases, and to thermal shocks.
- The feed opening should be large enough to allow the loading of packed waste. The size of ash removal opening should be appropriate for the expected percentage of incombustion in waste. There should be provision for accumulated ashes to cool down before disposal.
- The incinerator should be operated, monitored, and regulated from a central console, which should include a continuous display of operating parameters and conditions (temperature, airflow, fuel flow, etc.).

2.2.2.2 Rotary kilns incinerator

A rotary kiln, which comprises a rotating oven and post combustion chamber, may be specifically used to burn chemical waste, and is also suited for use as a regional health care waste incinerator. The main characteristics of a rotary kiln are summarized below:

Characteristics of rotary kilns

- Adequate for the following waste categories:
  - infectious waste (including sharps) and pathological waste
  - all chemical and pharmaceutical waste, including cytotoxic waste
- Inadequate for the following wastes:
  - non risk health care waste; incineration in rotary kilns would represent a waste of resource
  - radioactive waste; treatment dose affect radioactive properties and may disperse radiation.
- Waste that should not be incinerated:
  - pressurized containers; may explode during incineration and

cause damage to the equipment

  - waste with heavy metal content; incineration will cause emission of toxic metals (e.g. lead, cadmium, and mercury) into the atmosphere

- Incineration temperature: 1,200-1,600°C, which allows decomposition of very persistent chemicals such as PCBs (polychlorobiphenyls).
- Incinerator capacity: available capacities range from 0.5 to 3.0 tones/hour.
- Exhaust gas cleaning and ash treatment equipment: Likely to be needed, as the incineration of chemical waste produces exhaust gases and ashes that may be loaded with toxic chemicals.
- Additional remarks: Equipment and operation costs are high, as is the energy consumption. Wastes and incineration by-products are highly corrosive, and the refectory linings of the kiln often have to be repaired. Well-trained personnel are required.

2.2.2.3 Municipal incinerators

It is economically attractive to dispose of infectious health care waste in municipal incinerators if these are located reasonably close to hospitals. As the heating value of health care waste is significantly higher than that of domestic refuse, the introduction of relatively small quantities of health care waste will not affect the operation of municipal incinerator. Municipal incinerators are usually of a double chamber design, with gas combustion in second chamber and the temperature of, typically, 1,000-1,200°C.

A number of rules and recommendations apply to the disposal of health waste in municipal facilities:

- When health care waste is delivered to the incineration plant, the packaging should be checked to ensure that it is undamaged.
- Health care waste should not be packed in cylindrical containers, because these could roll on the grids where they are placed for combustion.

- Facilities should be available at the incineration site for the cleaning and disinfection of the transportation equipment, including vehicles.
- Deposit of health care waste in the normal reception bunker is not recommended: there are risks of waste bags being damaged during transfer to the furnace by the overhead crane. Health care waste should therefore be loaded directly into the furnace.
- Use of an automatic loading device for bags/containers of health care waste, rather than manual loading, would protect the safety of workers.
- Health care waste should not be stored for more than 24 hours at incineration plant. Longer storage would require cooling facilities to prevent the growth of certain pathogens and development of odorous.
- The combustion efficiency should be checked. It should be at least 97% during incineration of health care waste.
- Health care waste should be introduced into furnace only when the normal conditions of combustion have been established, never during start up or shutdown of combustion process.
- The process should be designed to prevent contamination of ash or wastewater by health care waste.

2.3 The bottom ash from medical waste incinerators

Incinerator ash is divided into two categories: Bottom ash and fly ash. Most of the ash is bottom ash that is the residues inside the burner after incineration. Fly ash settles on post burner equipment such as scrubbers.

2.3.1 The quantities of bottom ash from medical waste incinerator

The bottom ash generation depends on the quantities, density, and characteristics of solid waste incinerated. From the study of the typical solid waste composition in Phuket Province of Thailand, the ash is 22.17% by weight of total waste as shown in Table 2.5 (Ministry of public health, 1997).

Table 2.5. Physical and Chemical components of solid waste in Phuket Province, Thailand.

Material	Physical Component (%)			Characteristic	Chemical component (% by weight)		
	Min.	Max.	Ave.		Min.	Max.	Ave.
Food waste	12.16	27.61	20.75	Carbon	4.46	25.00	15.49
Paper	8.02	24.00	7.53	Hydrogen	0.54	3.00	1.86
Plastic	4.17	26.20	13.26	Oxygen	18.30	25.60	22.10
Rubber	0.31	2.38	0.74	Nitrogen	0.57	1.94	1.19
Leather	1.04	10.16	4.41	Sulfur	0.42	0.20	0.16
Textile	0.80	9.83	4.56	Chloride	0.70	1.48	0.99
Wood	7.50	21.74	13.67	Moisture content	33.30	67.16	49.42
Glass	2.86	10.96	4.85				
Metal	0.44	13.36	4.11	Valutile solids	8.03	45.00	27.87
Construction waste	1.06	9.16	3.23				
				Ash	17.73	28.03	22.71
Other	10.44	19.94	14.91	Heat capacity (kcal/kg)	4,303	5,130	4,791
Density (kg/m^3)	167.0	257.0	210.0	Heat capacity (kcal/kg)	1,251	2,826	2,022

Source: Ministry of public health (1997)

Based on a study conducted by Bungorn (1991), composition of medical waste in Bangkok hospitals was reported as shown in Table 2.6.

Table 2.6. The components of medical waste from hospitals in Bangkok, Thailand

Characteristic	Size of hospital (no. of beds)			
	< 149	150-500	500-1,000	>1,000
Moisture content (%)	44.6	43.0	44.8	41.0
Volatile Solids (% dry weight)	36.4	41.4	39.9	40.4
Ash (% dry weight)	17.7	16.6	15.2	18.5
Density (kg/m^3)	206.8	205.9	209.5	198.8

Source: Bungorn (1991)

2.3.2 The density of bottom ash

The quantities of bottom ash from the municipal incinerators in Canada and Massachusetts, USA have some difference in ash characteristics depending on the types of incinerator. A comparative view of incinerator ash density is shown in Table 2.7.

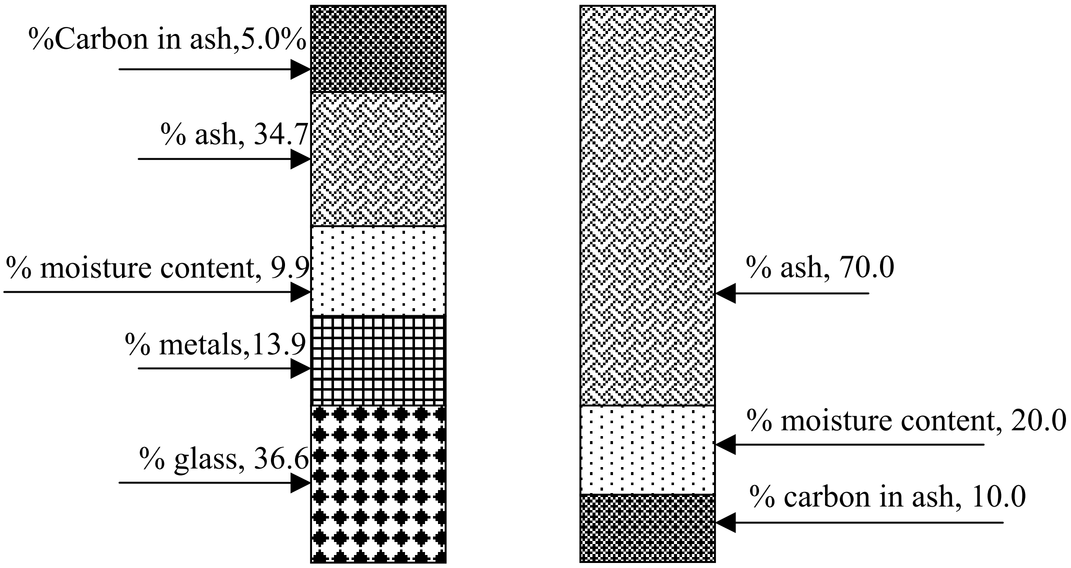
Table 2.7. The Density of bottom ash and fly ash.

Sources of ash	Density (kg/m^3)
Fly ash from 1st incinerator, Canada	0.37
Fly ash from 2nd incinerator, Canada	0.57
Bottom ash, Canada	1.04
Bottom ash, Massachusetts	0.73
Fly ash, Massachusetts	0.82

Source: Ontiveros et al. (1988)

2.3.3 The composition of bottom ash

From the sampling of bottom ash from some medical waste incinerators in New York City, following composition was found: carbon 5%, fine ash 34.7%, moisture content 9.9%, glass 36.6%, and metals 13.9%. But when they separated bulky waste such as metals and glass, the composition of ash changed to: carbon 10%, fine ash 70%, and moisture content 20.0% as shown in Figure 2.4.



a) Total bottom ash composition

b) Bottom ash composition after metal and glass separation

Figure 2.4. The comparison of total ash and ash with separated metal and glass components (Hasselriis and Consantine, 1992).

In a study of characterization of municipal incineration ash by Bagchi and Sopcich (1989), they carried out the sampling of fly ash from composite lagoon sludge (CLS) and bottom ash from composite bottom ash (CBA), then mixed the two. Subsequently, they analyzed the dry bulk density, specific gravity, and organic matter as shown in Table 2.8.

Table 2.8. Physical composition of municipal incinerator ash from Sheboygan, Wisconsin, USA

Physical Characteristics	CLS	CBS	Mixed ash
Density (kg/m^3)	427.00	781.00	955.00
Specific gravity	1.15	1.52	1.67
Organic matter (%)	3.00	7.9	6.60

Source: Bagchi and Sopcich (1989)

2.3.4 The chemical characteristics of bottom ash

Chemical components of bottom ash are related to the chemical components of solid waste which is incinerated in the starved air incinerator. The incinerator emits chlorine, nitrogen, heavy metals, and organic matter such as dioxins and furans etc. as shown in Table 2.9.

In a study of chemical composition of bottom ash from MSW incinerator in Horgen, Switzerland, by Belevi et al. (1992), two types of samples were collected, Ante sample and Post sample. The Ante sample was taken before quench tank and the post sample was taken after quench tank. The results of their study are shown in Table 2.10.

2.3.5 The emission of metals from incinerators

There are three emission pathways from an incineration system, namely, air emissions, wastewater discharge, and solid waste residue, or ash. All three of these discharges are sensitive to the presence of effective combustion within the furnace. With combustion, inorganics will not be effectively destroyed, and intolerable amounts of hazardous constituents could be transferred to the ash or the scrubber-water discharge (Calvin, 1993). There is a growing concern over the introduction of certain metals into the environment from incineration and other industrial discharges. Five of the metals which have been of particulars concern are lead, nickel, hexavalent chromium, mercury, and cadmium.

Table 2.9. The chemical composition of bottom ash and the emissions from the starved-air combustion incinerator

Component	Percentage	Lbs./ton	The emission	lbs./ton
Carbon	33.3	666	CO_2	1,693
Hydrogen	5.9	118	-	-
Oxygen	11.5	230	O_2	512
Chlorine	1.0	20	HCl	20
Nitrogen	3.0	6	N_2	5,820
Sulfur	2.0	4	SO_2	8
Water	23.5	470	H_2O	1,127
Ash	24.3	486	Fly ash	3
			Residues	486
			Pb	0.057
			Fe	0.007
			Cd	0.0066
			Mn	0.0004
			Co	0.00036
			As	0.00028
Total		2,000		9,099.07164

Source: Hasselriis (1992)

Table 2.11 lists the disposition of metals from the discharges of solid waste incinerators with a wet scrubber. Table 2.12 lists the fate of metals in an incinerator system firing solid waste and discharging through an electrostatic precipitator.

2.3.6 Effect of temperature on the quantities of heavy metal emissions from incineration facilities

Inorganic components of wastes fed to an incinerator cannot be destroyed, only oxidized. Most of the inorganic materials are chemically classified as metals, and enter the combustion process as the component of a waste. Generally, these metals will exit the combustion process as oxides of the metal that enters.

Table 2.10. Chemical composition of bottom ash from municipal incinerator

Chemical elements	Composition of bottom ash from incinerator in Switzerland (g/kg dry weigh)	Composition of bottom ash in the study of Belevi et al.(1992) (kg/kg dry weight)	
		Ante sample	Post sample
Silica (Si)	220-260	240	250
Calcium (Ca)	100-110	100	99
Iron (Fe)	55-110	67	73
Aluminum (Al)	50-65	59	50
Nickel (Ni)	23-42	39	36
Magnesium (Mg)	14-16	17	18
Potassium (K)	13-15	10	10
Titanium (Ti)	4-6	7	5
Total Carbon (TC)	15-19	15	24
Total Inorganic Carbon (TIC)	-	5	6
Total Organic Carbon (TOC)	-	10	18
Phosphorus (P)	2-5	4	3
Sulfur (S)	2-5	2	2
Nitrogen (N)	-	0.3	0.5
Chlorine (Cl)	1-4	4	3
Zinc (Zn)	1-4	2	2
Copper (Cu)	1-3	2	1
Lead (Pb)	0.9-1.4	4	3
Cadmium (Cd)	0.004-0.014	0.02	0.01
Mercury (Hg)	0.0001-0.0003	0.0002	0.0002

Source: Belevi et al. (1992)

If metal enters the process as a metal salt which has a boiling point lower than the incinerator temperature, it may vaporize and not oxidize and therefore be present in the flue gas. For example, lead chloride has a vaporization temperature of 950°C. Lead, which enters an incinerator as a chloride, may show up as lead in the flue gas unless it is condensed in the air pollution control equipment. Lead oxide, however, is not volatile and would stay in the bottom ash. Most metal compounds will remain in the incinerator bottom ash, but the volatility of certain metals such as arsenic, antimony, cadmium, and mercury can create problems in the flue gas. High metal content wastes are not good candidates for incineration but appropriate air pollution control equipment can usually remove metals to acceptable flue gas levels for discharges to the atmosphere (Michael et al., 1994). Melting points and boiling points of some metal oxides are shown in Table 2.13.

Table 2.11. Estimate of the fate of particulate emission from solid waste incinerator with wet scrubber.

Metal	In bottom ash (%)	In scrubber water (%)	Stack discharge (%)
Aluminum	57	42	1
Antimony	45	54	1
Arsenic	30	62	8
Barium	39	60	1
Beryllium	40	59	1
Cadmium	31	62	7
Chromium	31	59	10
Cobalt	45	52	3
Copper	47	51	2
Iron	53	46	1
Lead	16	82	2
Magnesium	33	66	1
Manganese	20	78	2
Mercury	0	10	90
Molybdenum	58	2	40
Nickel	30	66	4
Selenium	1	19	80
Titanium	45	54	1
Vanadium	18	79	3
Zinc	20	76	4

Source: Calvin (1993)

2.3.7 Investigations of ash leachate

Combustion produces ash that may generate heavy metals leachate from the landfills to contaminate groundwater as well as surface water. Temporary storage or permanent disposal of combustion residues over a permeable but chemically reactive barrier containing Fe may offer a preferable strategy to traditional bottom sealing with an impermeable liner and long term collection and treatment of leachate from the landfills. Cr is the most critical component in leachate from medical waste incinerator ash landfills. Immobilization of this component in reactive barrier makes the leachate much more environmentally compatible. The effectiveness of such reactive barrier relies on

i) chemical conditions favoring immobilization process.

ii) large surface area to serve as a source for reactants and as sites for sorption and precipitation of reaction products

iii) relatively low hydraulic conductivity to increase residence time thus increasing reaction potential.

Table 2.12. Estimate of the fate of particulate emission from solid waste incinerator with electrostatic precipitator

Metal	In bottom ash (%)	ESP Scrubber (%)	Stack discharge (%)
Aluminum	57	35	8
Antimony	45	28	27
Arsenic	30	47	23
Barium	39	60	1
Beryllium	40	58	2
Cadmium	31	47	22
Chromium	31	57	12
Cobalt	45	53	2
Copper	47	39	14
Hafnium	49	50	1
Iron	53	39	8
Lead	16	76	18
Magnesium	33	66	1
Manganese	20	78	2
Mercury	0	1	99
Molybdenum	58	17	25
Nickel	30	52	18
Potassium	52	47	1
Selenium	1	19	80
Sodium	44	55	1
Tantalum	37	62	1
Titanium	45	52	3
Vanadium	18	78	4
Zinc	20	60	20

Source: Calvin (1993)

However, hydraulic conductivity should be high enough for allowing all leachate to migrate through the barrier (Thomas et al., 2000). Table 2.14 shows the concentrations of heavy metals in the leachate from combined bottom ash and fly ash disposal site by laboratory leaching test.

In USA, most of leachability tests have been undertaken in laboratory using distilled water. However, leaching of the metals from the ash is greatly increased if acidic solutions, which attempt to simulate acid rain conditions, are used. Extraction procedure, in accordance with guidance of USEPA, may also be used to simulate the leaching in which a waste may undergo if disposed of in a sanitary landfill (Williams, 1994).

Table 2.13. Melting points and boiling points of some metal oxides

Metal oxide	Melting point (°C)	Boiling point (°C)
Arsenic	358	-
Arsenic trioxide	312	457
Barium	614	1,640
Barium oxide	1,918	2,000
Barium dioxide	450	800
Cadmium	321	765
Cadmium oxide	>1,500	1,559*
Chromium	1,302	2,672
Chromium oxide	300	-
Lead	328	1,740
Lead oxide	886	-
Lead dioxide	290	-
Selenium	217	685
Selenium dioxide	316	-
Selenium trioxide	118	180
Silver	962	2,212
Silver oxide	>100	-

* Sublimation temperature

Source: Weast (1984)

Table 2.14. Leachate from solid incinerator residues.

Pollutant	Concentration (mg/L)
Cl	6,500-20,000
SO_4	70-1,300
F	0
Pb	0.4-1.7
Cr	0.1-0.9
Cu	0.05-0.30
Zn	0.05-0.3
Cd	0.02-0.15
Ni	0.05-0.60

Source: Williams (1994)

If the extract from a representative sample of waste contains contamination in excess of that allowed in Table 2.15, it is classified as hazardous waste. From USEPA hazardous waste classification, extract procedure (EP) toxic waste is classified to hazard code "E". An EP toxic waste, which is not listed elsewhere as a hazardous waste, is given an USEPA hazardous waste number corresponding to the number of contaminant listed in Table 2.15.

2.3.8 Effects of bottom ash disposal on human health

Combusting medical waste in an incinerator creates noncombustible bottom ash in the primary chamber of the incinerator. This bottom ash is removed from the primary chamber either periodically (intermittent and batch municipal waste incinerators) or continuously (continuous municipal waste incinerators) (US.EPA, 1995). Bottom ash contains toxic heavy metals (chromium, cadmium, lead, arsenic, zinc, and other metals) as well as organic compounds (PCBs, dioxins, benzene, and other cancer causing organics) (Peter, 1988).

Table 2.15. Allowable contaminants

USEPA's 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

Source: Calvin (1993)

Although amounts of polycyclic aromatic hydrocarbons (PAHs) found in incinerator emissions are very small, many PAHs are toxic in tiny quantities; parts per billion or trillion, as opposed to parts per million for most other toxins studied. A review of reproductive animal studies on PCB effects concluded that a "No Observable Adverse Effect Level" could not be formulated since effects were present at the lowest levels studied; the background contamination of the control diets would interfere with testing of lower amounts. This is especially troubling since many PAHs are not excreted from the body; they build up in fat tissues; this is well established in humans, other mammals, fish, and insects.Virtually all humans are now carrying a load of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) at more than 3 parts per trillion; in the U.S.A. the range is from 1.4 to 20.2 ppt for non-occupationally exposed individuals. Human and animal studies show that, in case of PCBs, the unmetabolized body burden can be passed in mother's milk to the infant. Particularly troubling are two independent studies showing PCB-related development impairment in children at levels now encountered in the general population (Rowat, 1994).

Metals and Heavy Metals: Over thirty-five metals are reported from MSW incineration process; most are found in all of bottom ash, fly ash, and suspended particulates, and undergo enrichment in the fine ash. Several are reported as possible human carcinogens or toxins, including Cd, Cr, Ni, Pb, Hg, As, Ba, and Be. Al, Cu, Fe, Pb, Ti and Zn are found largely in slag. More volatile elements such as Cd, Pb, Sb, Se and Sn are vaporized and condense on fine particles, which are either trapped or escape to the atmosphere as suspended particulates. Volatile chlorides of elements including As, Cd, Ni, Pb, Sb, and Zn are also formed, which greatly increase their presence in fly ash and suspended particulates. Over 80% of inputted Hg, largely from Hg batteries, is estimated to be released in gas phase as halides. Other metals are also used in batteries and deserve attention. Small boilers employing hazardous waste as a fuel, including waste oil, are a serious concern since 50 to 60% of the inputted Pb is emitted from the stack (Rowat, 1994).

2.4 Past studies on generation, processing and handling of incinerator ash

There have been a number of studies around the world on MSW incineration in general, and the heavy metals in the incinerator bottom ash and fly ashes in particular.

Greenpeace International conducted a study on heavy metals contents in bottom ash of medical waste incinerator in southern Thailand in 1999 (Labunska et al., 2000). They visited the municipal and medical waste incinerator complex near Phuket, both in June and October 1999 in order to collect samples of bottom and fly ashes stored on site for chemical analysis. A single sample was also collected from the waste incinerator located on Samui Island.

Analysis conducted at the Greenpeace Research Laboratories revealed that:

1. Bottom ash and fly ash residues arising from the Phuket municipal solid waste incinerator contained high levels of toxic heavy metals, e.g. lead and cadmium (with lead present at over 0.1% by weight of the ash). Similar levels were recorded in ash dumped from test burns conducted early in 1998 as were found in ashes arising from the operation of plant between June and October 1999.
2. Levels of metals in bottom ash from medical waste incinerator on the same site were lower than in other materials sampled, although a much wider range of organic contaminants (typical products of incomplete combustion) were isolated and identified in this sample. These contaminants included some chlorinated residues and phthalate esters which could have arisen from the incomplete combustion of PVC components in the medical waste.

The result of this preliminary study demonstrated the hazardous nature of the solid wastes generated by incineration of medical and even municipal solid waste. Toxic heavy metals are present in MSW ash residues as a result of their continued use in wide range of commercial and consumer products. Incineration dose not destroy these metals, but simply disperses them via the incinerator stack and, as demonstrated in the current study, concentrates them into bottom ash and fly ash residues. Far from solving a waste problem, therefore, incineration is simply creating a new and more toxic one.

In a similar study, the quantities of heavy metals in the residual bottom ash from incineration of medical waste in Phuket, Thailand were investigated (Thanachit,1999). Furthermore, the toxicity of bottom ash leachate with respect to heavy metals was evaluated in three particle sizes. These results could be used to evaluate suitable ways for disposing of bottom ash from medical waste incineration. Samples from four medical waste incinerators in Phuket were taken over a period of two weeks. The bottom ash was partitioned into three sizes. A sample of each size was digested and extracted according to the extraction procedure in accordance with guidance of ministry of industry. The amount of heavy metals concentrations were observed and compared with standards. The average concentrations of barium, lead, chromium, silver, selenium, and cadmium in bottom ash were found to be 2,602.41, 1,130.00, 559.91, 245.27, 39.48, 13.18 mg/kg, respectively. It was observed that, the concentration of heavy metals increased as bottom ash particle size decreased. This trend was found for barium, lead, silver, selenium, cadmium, and chromium in multiple chamber incinerator ash except for chromium in local incinerator bottom ash. The remaining metals showed no observable trend. The extraction of leachate showed average concentrations of barium, lead, cadmium, chromium, cadmium, selenium, silver, mercury and arsenic at 14.30, 2.71, 2.23, 0.44, 0.23, 0.08 mg/kg, and 96 and 2.76 μg/kg, respectively. The concentrations of all heavy metals in the bottom ash leachate were below the limit values set in guidance from the Thailand's Ministry of Industry. The bottom ash from the two medical waste incinerators in Phuket were disposed in sanitary landfills. Whereas, bottom ash from the other two incinerators were disposed by dumping on land or in the holes next to the incinerators.

Greenpeace International also carried out investigation at the Trieco incinerator located in Doc Sud area of the Buenos Aires Province, Argentina (Brigden et al., 2000). This facility is licensed to incinerate both hazardous chemical waste and medical wastes. The permitted wastes include compounds of heavy metals and wide range of organic compounds. Ashes from incinerator are stored in barrels within the Trieco incinerator grounds. Many of these barrels are in very poor condition, and are not sealed to prevent the spread of ashes to the environment. Greenpeace visited the Trieco incinerator facility in July 2000 and collected samples of incinerator ashes and sediment to determine the potential impacts on the environment from the activities at this facility. The analysis of these samples for organic contaminants and heavy metals demonstrated the following:

- The ashes produced at the Trieco incinerator facility contained a wide range of toxic pollutants, especially concentrated levels of heavy metals.
- The improper storage of these ashes is resulting in the release of pollutants to the local environment. This was clearly demonstrated by the high levels of many heavy metals in sediment close to this facility.

- A sample of sediment collected from a water runoff channel coming from the Trieco facility contained a number of toxic heavy metals at significantly elevated levels, with certain metals at even higher concentrations than those found in the ashes themselves. This suggested that, either accumulation of metals leached from the ashes into the sediment, or was due to the selective carry over of the fine fractions of the ash containing concentrations of these metals higher than the ashes as a whole.
- In addition to the detrimental effect placed on the environmental by the released of incinerator ashes, it was highly likely that a wide range of pollutants were also being released to the environment via emissions to air from this facility.

In a recent study, Koralewska and Faulstich (2000)'s aimed to define and test the process conditions of an integrated wet chemical treatment of raw bottom ashes in a bottom ash discharger. This should lead to an improved quality of raw bottom ashes. Results indicated that easily soluble salts and fine particles were removed by washing procedure. In laboratory experiments, the concentrations of heavy metals in leachate after treatment could be lowered significantly by the addition of gaseous carbon dioxide. However, in some pilot-scale experiments the concentrations of carbon dioxide in process fluids were too low, and hence the expected stabilization of heavy metals was not achieved. The chemical reactions of carbon dioxide mostly happen in the washing solution. Stabilization could be reached only with a large amount of additive. After wet chemical treatment all raw bottom ashes exhibited a significant improvement of technical construction material characteristics. Based on this study it was concluded that, this procedure may be applied without incurring substantial investment costs by retrofitting existing incineration plants to allow on-site washing of raw bottom ashes. In addition the carbon dioxide from the cleaned flue gas can be used to accelerate the aging process.

In another study Boddum and Skaarup (2000) conducted experiments with the purpose of evaluating suitable methods of improving the quality of bottom ash from municipal solid waste incinerator. Full scale washing in the quench tank of an incinerator plant and pilot scale washing/separation at soil cleaning facility had been tested. Emphasis was laid on the emission of salts. The effect of washing was evaluated by a leaching test following the European Committee of Standardization. The effect of separating fines and organic material was evaluated by determination of total content in the produced fractions. Quench tank washing was found unfit to reduce the leaching of salt sufficiently. The effect of increased water supply in the quench tank was negligible. Washing on a pilot scale soil cleaning facility reduced the emission of sodium and chloride to meet the limit values. Sulphate proved to be difficult to remove. The limit value was not reached. Arsenic, cadmium, chromium, lead, and zinc were found to be enriched in the fine fraction <100 μm.

A feasibility study of MSW incinerator bottom ash for chromate removal by adsorption was evaluated by Chang and Ho (2002). MSW incinerator bottom ashes used were sampled from a large MSW incinerator in Taiwan. To realize proper pretreatment needed for sampled ash, both physical and chemical characteristics were tested. Since pH value might be one of the primary factors that affect the removal of chromate from solution, water and acid wash pretreatments were taken to remove the alkalinity existed in MSW ash. After that, batch chromate adsorption experiments were executed with water pretreated and acid pretreated ashes. And the mechanism of chromate removal by MSW bottom ash was also described by adsorption experiments with the main oxide composites of MSW bottom ash – silica, iron and aluminum oxides.

In another study (Chiang et al., 2002), investigated the heavy metals separation from MSW incinerator ash using an extraction and neutralization process were carried out. To cope with increasingly stringent waste disposal regulations and the constantly growing amount of MSW, the R.O.C (Republic of China) government plans to install more than 36 municipal solid waste incinerators (MSWI) before 2003. These facilities will be designed to process an estimated 75% of the island's MSW. However, the potential environmental risk from the release of heavy metals though flue gas and incinerator residues from the burning of MSW has become a primary concern of the island's population. This study investigated the efficiency of heavy metals separation recovery in electrostatic precipitator (ESP) ash from MSWI using a combined flue gas (carbon dioxide) neutralization and acid extraction approach. These experiments were conducted at 120 times with pH values varying from 3 to

7.51 and particle sizes varying from 40-200. The pH level is the prominent factor affecting the extraction of heavy metals from EPS ash. The results indicated that a decrease in the pH value enhanced the separation and recovery efficiency of heavy metals in the MSWI EPS ash. The separation efficiency of Cd, Zn and Cu increased significantly with a decreased pH value. Furthermore, high extractability of Cd and Zn at low pH values (pH 3-4) was evident. In cases with a pH value 3 and the smallest particle size (100-200), the Cd, Zn and Cu extraction rates were 89.04± 4.09%, 60.25±9.19% and 32.54±1.73%, respectively. It was unclear as to whether solid-phase solubility or surface adsorption controls the Pb concentrations. Accordingly, the tested pH values could not be clearly related to Pb extraction concentrations. Meanwhile, Pb and its compounds remained in a stable state (extraction rate was approximately 18.86±3.51%) under experimental conditions. The results showed that the metals extraction rate was not significantly influenced by variations in the tested particle size range. The Pb, Cd, Zn and Cu concentrations of the leachate in the treated ESP ash from Toxicity Characteristics Leaching Procedure (TCLP) test complied with the regulatory thresholds of the R.O.C. EPA. The above results pointed toward the feasibility of heavy metal recovery and fly ash non-toxicification using an acid extraction and neutralization process combination.

2.5 Bottom ash recovery and reuse

Incinerator ash utilization is particularly attractive since it couples resource conservation with attenuation of disposal problems. Although extensive studies have indicated that the ash can be beneficially utilized, utilization of MSW residues is not routinely practised or mandated in most countries. In some European countries, 50% or more of the ash is utilized, while less than 5% of the ash is being utilized in the U.S (Show et al., 2000).

Sisomphon et al. (1999) found that MSW ash had irregular grain surface and very high specific surface area. Other properties such as high loss ignition, highly variable characteristics, and low reactivity were also contributing problems to the use of MSW ash as cement replacement. A study of the properties of concrete containing MSW fly ash was carried out by Hamernik and Frantz (1991). They reported that different burning conditions affected the reactivity of MSW fly ash differently. In addition, MSW samples with different compositions had resulted in varying chemical and physical properties of the final MSW ash concrete.

Sue-Huai (2001) discovered that bottom ashes from municipal solid waste incinerator (MSWI) in Taiwan have characteristics of low compressibility and high shear strength. And that, they are similar to the gravel of good gradation for civil engineering construction. The study intended to evaluate the possibility of the geotechnical application of bottom ashes for the sub-base of road construction. The analysis showed that the characteristics of the ashes met the regulations of the construction materials of the Chinese National Standard. The field density test also showed that the result of the maximum compression degree was 97%, which met the standard that is greater than 95%. Nevertheless, the leaching of Pb may possibly exceed the toxicity characteristics leaching procedure (TCPL) regulation. Therefore, the substitute percentage for natural gravel should be considered, in order to prevent the pollution to the environment.

Municipal solid waste (MSW) generation in Thailand is of critical concern, especially for big cities. Bangkok, alone, produced approximately 8,500 tons of solid waste per day (DPC, 2002). The incineration of municipal solid waste, an effective method of high volume reduction, is presently receiving widespread attention as a final disposal method of MSW in Bangkok. However, the incineration process produces some amounts of ash which is normally disposed of by landfilling, that may still create further problem, i.e. leaching of harmful compounds to groundwater. On the other hand, if MSW ash has a potential use in cement manufacturing, we could not only reduce the amount of raw materials needed, but also solve the ash disposal problems simultaneously. In addition, carbon dioxide, a major greenhouse gas released from cement production can be greatly decreased if the bottom ash substitution in cement making is practiced.

Chapter 3
Methodology

3.1 Sampling site

The bottom ash samples were taken from the medical waste incinerator at Ratchasima-Thonburi Hospital. It is a 300 beds hospital in the Nakhon Ratchasima municipality, Thailand. The location of the hospital is shown in Figure 3.1 below.

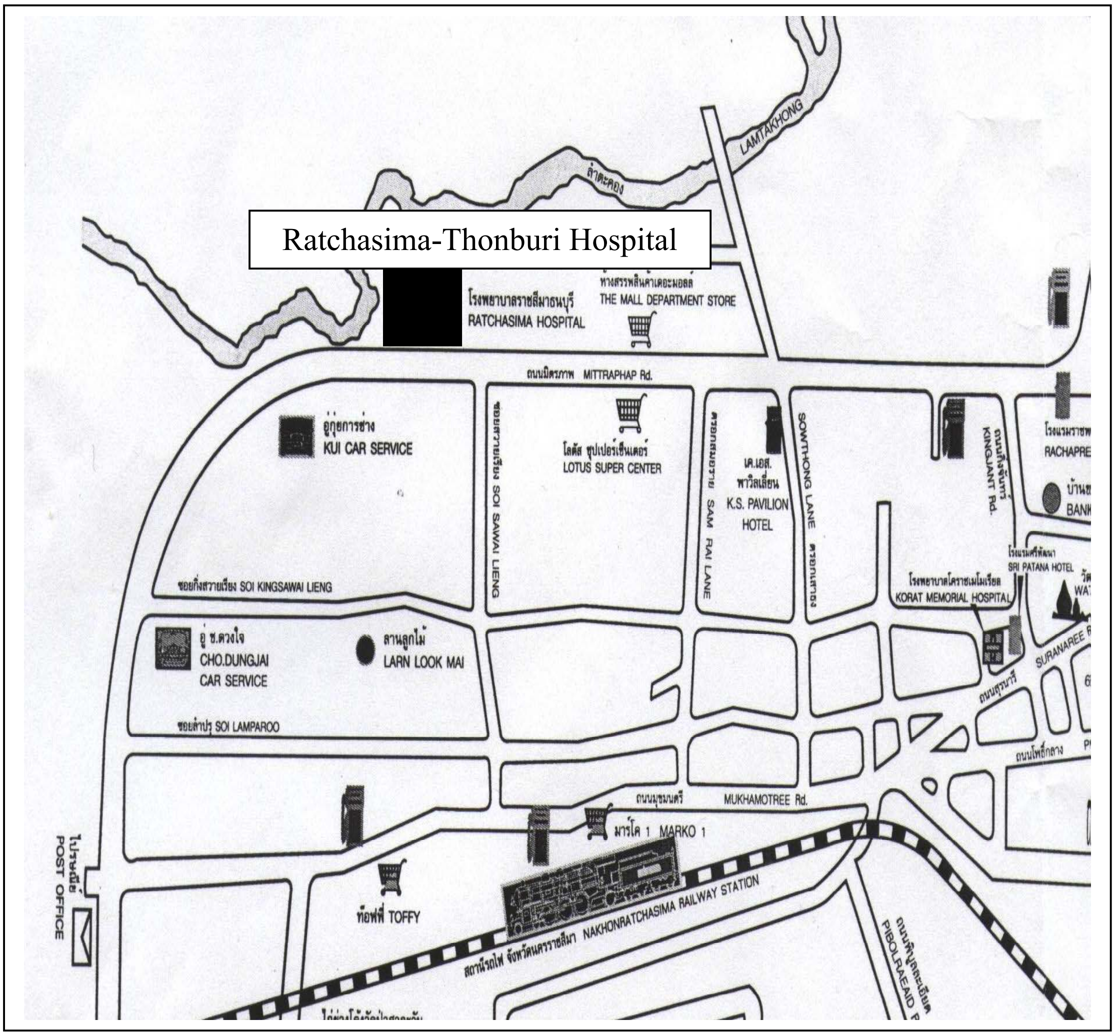


Figure 3.1. The site of Ratchasima-Thonburi Hospital in the Nakhon Ratchasima municipality, Thailand.

3.2 Generation rate evaluation

Medical waste generation depends on numerous factors such as established waste management, hospital specializations, proportion of patients treated on a day-care basis. Ratchasima-Thonburi Hospital has performed its own surveys of medical waste inventory and the estimated amount is 0.09 kg/day per patient on an average.

3.3 Ratchasima-Thonburi medical waste incinerator

Ratchasima-Thonburi Hospital uses medical waste incinerator from ENTECH's company; which has the details as shown below:

Model : BV 200
Serial No. : 1120
Designed average
Burning rate : 60 kg/hr
Main combustion chamber volume : 1.5 m^3
Method of operation : batch
Temperature of combustion chamber : 550-950°C

The front view of Rachasima-Thonburi Hospital medical waste incinerator is shown in Figure 3.2.

Figure 3.2. The front view of Ratchasima-Thonburi Hospital medical waste incinerator

3.4 Sampling

The ash samples were taken from the waste incinerator at Ratchasima-Thonburi Hospital in Nakhon Ratchasima, during October 2001 to February 2002. During this period, the 32 samples were obtained for heavy metals investigations. Samples of total bottom ash produced on any day were collected and transported to Suranaree University of Technology's laboratory in polyethylene containers one day after incineration. Table 3.1 shows the sampling schedule for this study. The various steps of the research methodology are shown in Figure 3.2.

Table 3.1. The sampling schedule

Sampling Day	Date & Time of Incineration	Date & Time of Sampling	Total ash (kg)
1	25-Oct-01 8.07 hr. - 13.00 hr.	26-Oct-01 11.00 am.	33.0
2	02-Nov-01 8.15 hr. - 13.50 hr.	03-Nov-01 10.00 am.	26.4
3	16-Nov-01 8.30 hr. - 13.50 hr.	17-Nov-01 09.30 am.	29.1
4	18-Nov-01 7.15 hr. – 12.50 hr.	19-Nov-01 1.30 pm.	30.3
5	20-Nov-01 8.35 hr. – 13.00 hr.	21-Nov-01 10.00 am.	30.1
6	23-Nov-01 8.20 hr. – 13.30 hr.	24-Nov-01 10.00 am.	25.3
7	29-Nov-01 9.50 hr. – 13.40 hr.	30-Nov-01 11.30 am	25.5
8	03-Dec-01 8.40 hr. – 12.30 hr.	04-Dec-01 11.00 am.	22.0
9	06-Dec-01 9.30 hr. – 12.45 hr.	07-Dec-01 10.30am.	21.0
10	09-Dec-01 8.00 hr. – 11.45 hr.	10-Dec-01 9.45am.	29.5
11	12-Dec-01 9.00 hr. – 12.30 hr.	13-Dec-01 10.00am.	23.7
12	14-Dec-01 9.20 hr. – 13.00 hr.	15-Dec-01 10.20am.	25.6
13	17-Dec-01 8.40 hr. – 12.30 hr.	18-Dec-01 10.30am.	23.2
14	20-Dec-01 9.30 hr. –12.30 hr.	21-Dec-01 11.20am.	16.4

Table 3.1. The sampling schedule (Cont.)

Sampling Day	Date & Time of Incineration	Date & Time of Sampling	Total ash (kg)
15	24-Dec-01 9.00 hr.- 12.00 hr.	25-Dec-01 11.00am.	16.0
16	27-Dec-01 8.30 hr. – 12.30 hr.	28-Dec-01 10.30am.	25.5
17	30-Dec-01 9.00 hr. – 12.50 hr.	31-Dec-01 10.00am.	22.3
18	03-Jan-02 8.20 hr. – 13.30 hr.	04-Jan-02 10.0am.	29.6
19	06-Jan-02 8.30 hr. – 12.10 hr.	07-Jan-02 11.00am.	29.3
20	09-Jan-02 9.30 hr. – 13.40 hr.	10-Jan-02 11.10am	15.6
21	12-Jan-02 9.00 hr. –13.00 hr.	13-Jan-02 10.00am.	15.1
22	15-Jan-02 8.20 hr. – 13.40 hr.	16-Jan-02 10.00am.	35.0
23	18-Jan-02 8.40 hr. – 12.30 hr.	19-Jan-02 11.00am.	30.2
24	20-Jan-02 9.00 hr. – 13.00 hr.	21-Jan-02 10.30am.	32.5
25	23-Jan-02 9.30 hr. – 13.40 hr.	24-Jan-02 11.00am.	29.5
26	26-Jan-02 8.50 hr. – 12.50 hr.	27-Jan-02 10.30am.	33.0
27	29-Jan-02 9.30 hr. – 13.00 hr.	30-Jan-02 10.00am.	36.0
28	01-Feb-02 8.00 hr. – 11.45 hr.	02-Feb-02 10.30am.	29.0
29	05-Feb-02 9.00 hr. – 12.30 hr.	06-Feb-02 8.30am.	35.0
30	08-Feb-02 8.00 hr. – 11.30 hr.	09-Feb-02 10.00am.	27.8
31	12-Feb-02 8.30 hr. –11.45 hr.	13-Feb-02 10.00am.	25.6
32	15-Feb-02 8.10 hr. – 12.20 hr.	16-Feb-02 10.00am.	40.0

3.5 Sample preparation for analysis

3.5.1 Sieve analysis was carried out to separate the various particle sizes from the ash as indicated below:

1) bigger than 3/8 mesh screen size, particle size range of > 9.5 mm
2) less than 3/8 mesh screen size, particles size range of 4.75-9.5 mm
3) less than 4 mesh screen size, particles size range of 0.5-4.75 mm
4) less than 30 mesh screen size, particles size range of <0.5 mm

From sieve analysis, four categories of samples of different particle sizes were obtained. The proportion of each particle size was calculated in percent by weight.

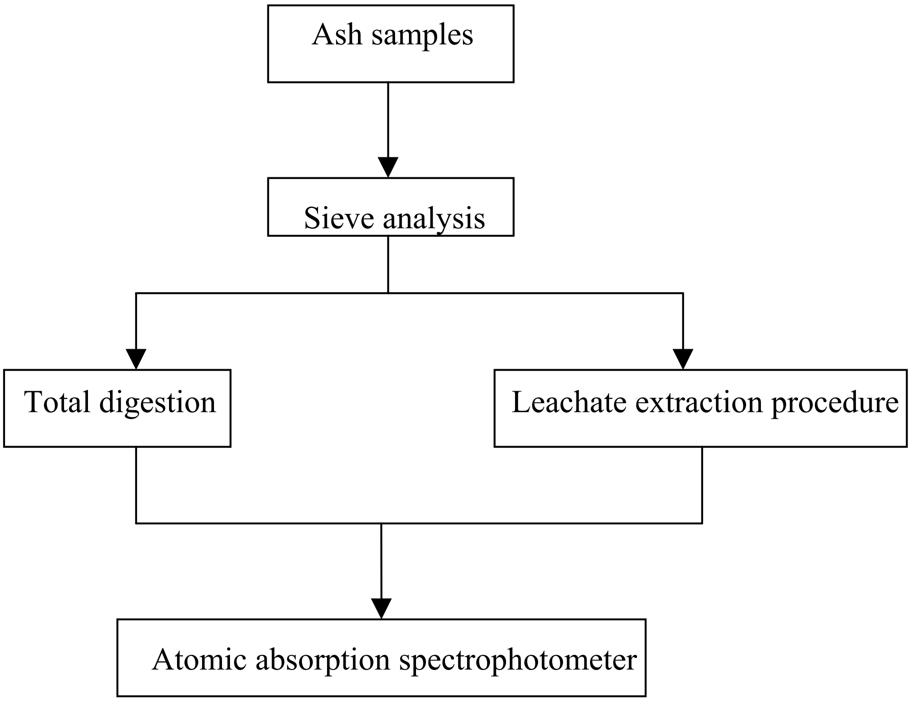


Figure 3.3. Research methodology flow chart

3.5.2 After size separation, all samples were subjected to an appropriate dissolution prior to analysis.

3.6 Heavy metal's analysis

Heavy metals in bottom ash may be readily determined by atomic absorption spectrophotometer. Detection limits, sensitivity, and optimum range of the metals will vary with the matrices and models of atomic absorption spectrophotomers. The data shown in Table 3.2 provides some indication of the detection limits obtainable by direct aspiration and by furnace techniques. Direct aspiration determinations are normally completed as single element analyses and are relatively free of inter element spectral interferences. Either a nitrous-oxide/acetylene or air/acetylene flame is used as an energy source for dissociation of the aspirated sample into the free atomic state, making analyze atoms available for absorption of light. In the analysis of some elements, the temperature or type of flame used is critical. If the proper flame and analytical conditions are not used, chemical and ionization interferences can occur. Furnace technique replaces the flame with an electrically heated graphite furnace. The furnace allows for gradual heating of the sample aliquot in several stages. Thus, the processes of dissolution, drying, decomposition of organic and inorganic molecules and salts, and formation of atoms, which may occur in a flame in a few milliseconds, may be allowed to occur over a much longer time period and at controlled temperatures in the furnace (USEPA, 2001b). Direct aspiration, flame method was used in this study.

For evaluating heavy metals in the samples of bottom ash and simulated bottom ash leachate, following procedures were carried out (USEPA, 2001b):

3.6.1 Acid digestion

This digestion procedure is used for the preparation of aqueous samples. Aqueous samples should be prepared according to steps given in the USEPA guidance for solids waste-SW-846. The applicability of a sample preparation technique to a new matrix type must be checked by analyzing spiked or relevant standard reference materials. The steps for acid digestion are as follows:

1. Weigh 4.0 g of samples, add 100 mL distilled water in beaker.
2. For metals that are to be analyzed, add 2 mL of concentrated HNO_3 and 5 mL of concentrated HCl. The sample is covered with a ribbed watch glass or other suitable covers and heated on steam bath, hot plate or other heating source at 90 to 95 °C until the volume has been reduced to 15-20 mL.
3. Remove the beaker and allow to cool. Wash down the beaker walls and watch glass with water and, when necessary, filter or centrifuge the

sample to remove silicates and other insoluble material that could clog the nebulizer. Filtration should be done only if there is concern that insoluble materials may clog the nebulizer; this additional step is liable to cause sample contamination unless the filter and filtering apparatus are thoroughly cleaned and prerinsed with dilute HNO_3.

4. Adjust the final volume to 100 mL with reagent water.

Table 3.2. Atomic absorption concentration ranges

Metal	Direct Aspiration		Furnace Procedure Detection Limit (µg/L)
	Detection Limit (mg/L)	Sensitivity (mg/L)	
Aluminum	0.1	1	-
Antimony	0.2	0.5	3
Arsenic	0.002	-	1
Barium	0.1	0.4	2
Beryllium	0.005	0.025	0.2
Cadmium	0.005	0.025	0.1
Calcium	0.01	0.08	-
Chromium	0.05	0.25	1
Cobalt	0.05	0.2	1
Copper	0.02	0.1	1
Iron	0.03	0.12	1
Lead	0.1	0.5	1
Lithium	0.002	0.04	-
Magnesium	0.001	0.007	-
Manganese	0.01	0.05	0.2
Mercury	0.0002	-	-
Molybdenum	0.1	0.4	1
Nickel	0.04	0.15	-
Osmium	0.03	1	-
Potassium	0.01	0.04	-
Selenium	0.002	-	2
Silver	0.01	0.06	0.2
Sodium	0.002	0.015	-
Strontium	0.03	0.15	-
Thallium	0.1	0.5	1
Thin	0.8	4	-
Vanadium	0.2	0.8	4
Zinc	0.005	0.02	0.05

Source: USEPA (2001b)

3.6.2 Extraction Procedure (EP) toxicity test method

This method is an interim method to determine whether a waste exhibits the characteristics of extraction procedure toxicity. The procedure may also be used to simulate the leaching which a waste may undergo if disposed of in a sanitary landfill. The steps of extraction procedure toxicity to simulate the leaching are as follows:

1. The solid material that do not have free liquids shall be evaluated for particle size. Solid material should have a surface area per g of material ≥ 3.1 cm^2 or passes through a 9.5 mm (0.375 in.) standard sieve.
2. Weigh the samples and place the appropriate amount of material into the extractor and add 16 times its weight with water.
3. After the solid material and water are placed in the extractor, the operator shall begin agitation and measure the pH of the solution in the extractor. If the pH is > 5.0, the pH of solution should be decreased to 5.0±0.2 by slowly adding 0.5 N acetic acid. If the pH is ≤ 5.0, no acetic acid should be added. The pH of the solution should be monitored, as described below. During the course of the extraction, if the pH rises above 5.2, 0.5 N acetic acid should be added to bring the pH down to 5.0±0.2. However, in no event shall the aggregate amount of acid added to the solution exceed 4 mL of acid per g of ash sample. The mixture should be agitated for 24 hours and maintained at 20-40°C during this time. If, at the end of the 24 hours extraction period, the pH of the solution is not below 5.2 and the maximum amount of acid (4 mL per g of solids) has not been added, the pH should be adjusted to 5.0±0.2 and the extraction is continued for an additional 4 hours, during which the pH should be adjusted at 1 hour intervals.
4. At the end of the extraction period, water should be added to the extractor in an amount determined by the following equation:

$$V = (20)(W)-(16)(W)-A$$

Where:

V = mL water to be added

W = Weight in g of solid charged to extractor

A = mL of 0.5 N acetic acid added during extraction

5. The material in extractor should be separated into its component liquid and solid phases in the following manner:
    - Allow slurries to stand to permit the solid phase to settle (waste that are slow to settle may be centrifuged prior to filtration) and set up the filter apparatus
    - Wet the filter with a small portion of the liquid phase from the waste or from extraction mixture. Transfer the remaining material to the filter holder and apply vacuum or gentle pressure (10-15 psi) until all liquid passes through the filter. Stop filtration when air or pressurizing gas moves though the membrane. If this point is not reached under vacuum or gentle pressure, slowly increase the pressure in 10 psi increments to 75 psi. Halt filtration when liquid flow stops.

Chapter 4

Results and Discussion

4.1 General

Bottom ash samples from the medical waste incinerator were taken from Ratchasima-Thonburi hospital to analyze the physical and chemical characteristics. Physical characteristics were determined for particle size distribution and moisture content. Chemical characteristics included quantities of four heavy metals (lead, silver, iron and zinc) in bottom ash and simulated leachate of bottom ash.

4.2 Physical characteristics of bottom ash

Physical tests were performed on individual bottom ash samples from each sampling day to determine the moisture content and particle sizes distribution.

4.2.1 Moisture content of bottom ash

The moisture content of bottom ash samples was expressed as a percentage of wet weight of material, and is shown in Figure 4.1 and Table 1A (in appendix A). For the 32 bottom ash samples collected during the experimental period, between 25th October 2001 to 16th February 2002, moisture content ranged from 1.02 to 2.01% and average was 1.54%. Such fluctuation was caused by the varying composition of the waste, the handling and weather conditions.

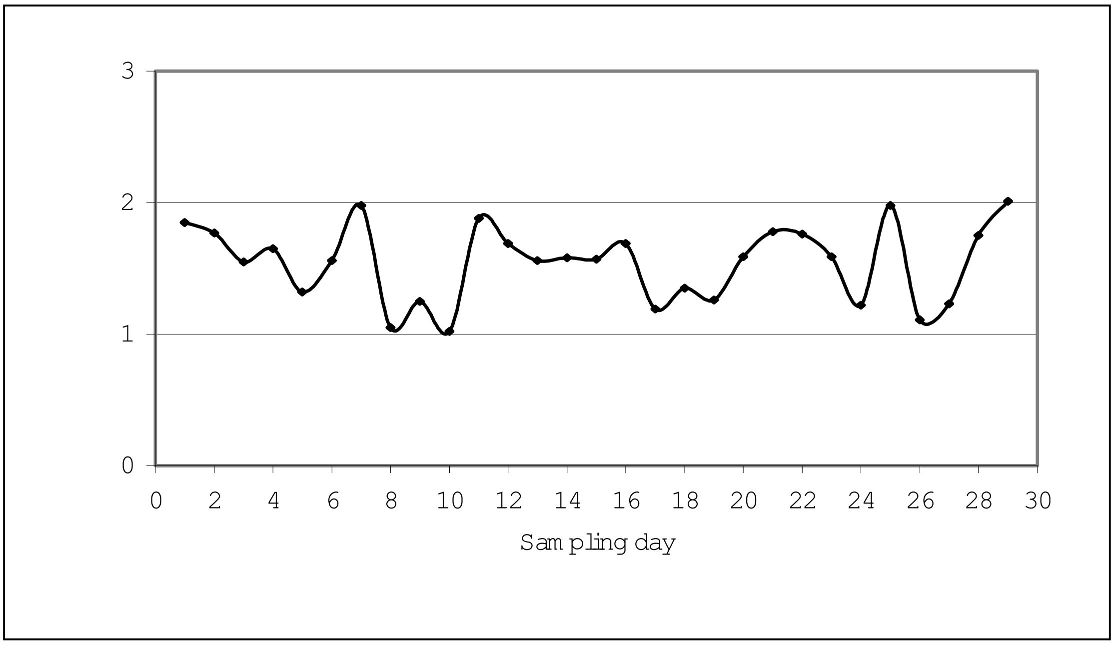


Figure 4.1 Moisture contents in bottom ash from Ratchasima-Thonburi Hospital incinerator during experimental period

4.2.2 Particle size distribution

The size and size distribution of components in incinerator bottom ash are important consideration in materials recovery, especially with mechanical means such as trommel screens. Sieve analyses were carried out to separate the various particle sizes from the ash indicated below:

1. retained on 3/8 mesh screen size ⇒ particle size range: >9.5 mm
2. retained on 4 mesh screen size ⇒ particle size range: 4.75-9.5 mm
3. retained on 30 mesh screen size ⇒ particle size range: 0.5-4.75 mm
4. pass through 30 mesh screen size ⇒ particle size range: <0.5mm

Figures 4.2-4.5 show the physical components of bottom ash with respect to particle size. The data on size distribution of the individual components in bottom ash are presented in Table 1A (appendix A) and Figure 4.6. As shown in Figure 4.2, the largest fraction of bottom ash (58.39% by weight) was in >9.5 mm particle size range. The second largest fraction (18.50% by weight) was in 0.5-4.75 mm particle size range. And remaining two fractions were 10.92% and 10.65% for 4.75-9.5 mm and <0.5 mm particle sizes, respectively.

Figure 4.2. Bottom ash components with particles size range of > 9.5 mm

Figure 4.3. Bottom ash components with particle size of 4.75-9.5 mm

Figure 4.4. Bottom ash components with particle size of 0.5-4.75 mm

Figure 4.5. Bottom ash components with particle size of <0.5 mm

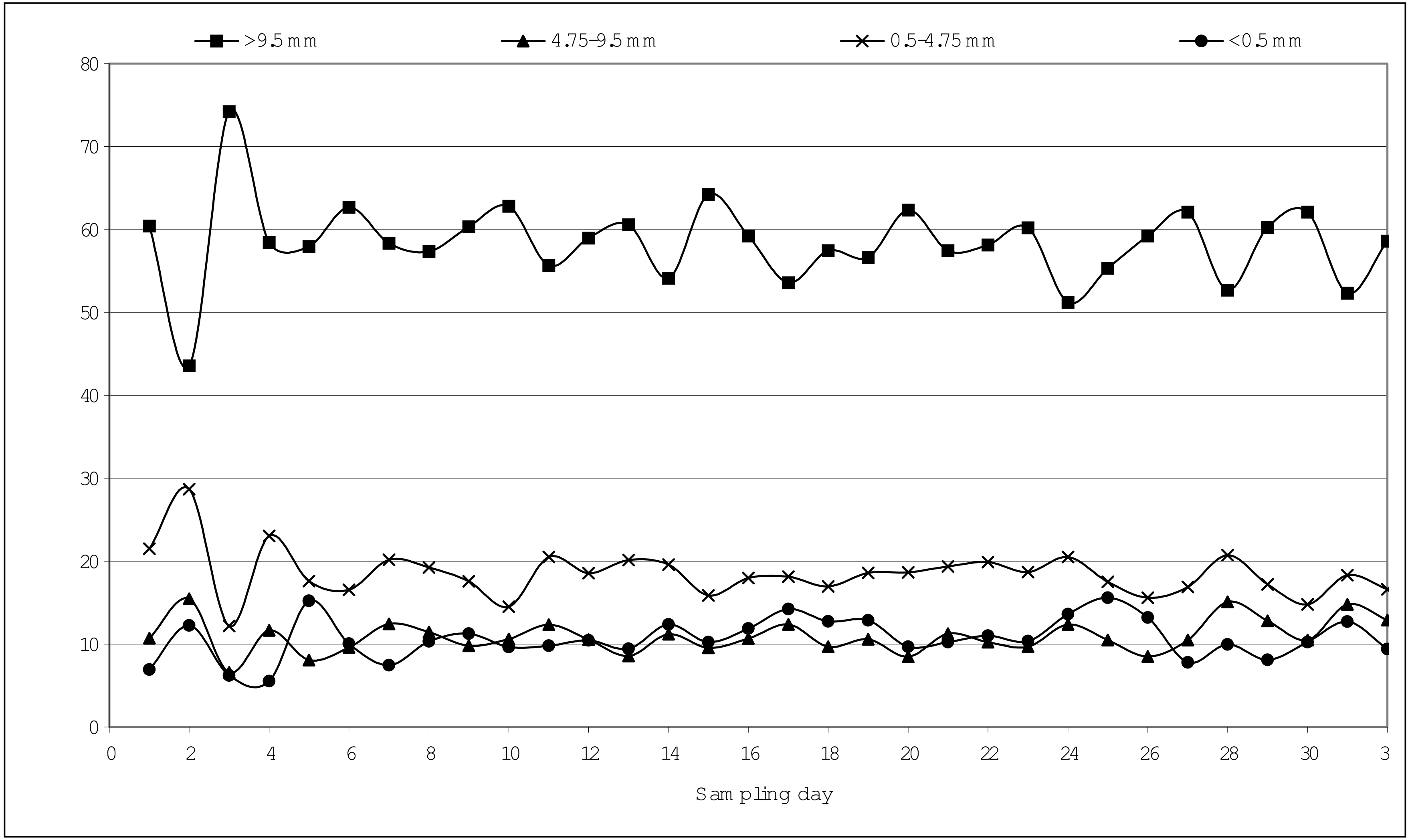


Figure 4.6. Particle size distribution in bottom ash during experimental period

4.3 Results of heavy metals analysis in bottom ash

After sieve analysis, the bottom ash samples were investigated for heavy metals' concentration (lead, silver, iron, zinc) for four particle sizes as shown in Tables 4.1-4.8 and Figures 4.7-4.10. Details of the analysis are given below.

4.3.1 Lead

The concentration of lead in bottom ash was found to be in the range of 214.93-1,789.93 mg/kg. From the data shown in Table 4.1 and Figure 4.7, it can be seen that lead concentration increased as particle size decreased. The highest concentration of lead was found to be in <0.5 mm particle size range. The lowest concentration was found to be in >9.5 mm particle size range. Because lead has lower melting point (328°C) than incineration temperature (550-950°C), it might have melted during incineration process and adsorbed on surface area of bottom ash. The small particle size increases available surface area exposed to adsorption process. Hence, as the adsorbed lead might be concentrated at or near the surface of particles and it was largely present in the smallest particle size (<0.5 mm).

4.3.2 Silver

The concentration of silver in bottom ash was found to be in the range of 155.99-573.19 mg/kg. From the data shown in Table 4.2 and Figure 4.8, it can seen that the highest concentration was found to be in 0.5-4.75 mm particle size range. The lowest concentration was found to be in >9.5 mm particle size range.

4.3.3 Iron

The concentration of iron in bottom ash was found to be in the range of 193,462.14-581,002.34 mg/kg. From the data in Table 4.3 and Figure 4.9, it can be seen that the highest concentration was found to be in 4.75-9.5 mm size range. The lowest concentration was found to be in >9.5 mm size range.

4.3.4 Zinc

The concentration of zinc in bottom ash was found to be in the range of 9,922.15-34,114.62 mg/kg. From Table 4.4 and Figure 4.10, it can be seen that zinc concentration increased as particle size decreased. The highest concentration of zinc was found to be in <0.5 mm particle size range. The lowest concentration was found to be in >9.5 mm particle size range.

Table 4.1 Lead concentrations in the bottom ash with respect to particle size

Sampling Day	Date of Incineration	Pb				
		>9.5mm (mg/kg)	4.75-9.5 mm (mg/kg)	0.5-4.75 mm (mg/kg)	< 0.5mm (mg/kg)	Total (mg/kg)
1	03-Dec-01	43.31	58.52	130.85	324.01	556.69
2	06-Dec-01	19.52	108.86	225.45	279.25	633.06
3	09-Dec-01	6.58	80.42	100.42	243.88	431.29
4	12-Dec-01	19.76	131.86	144.58	253.30	549.49
5	14-Dec-01	1.76	171.67	195.48	311.16	680.06
6	17-Dec-01	17.55	97.50	140.58	257.80	513.42
7	20-Dec-01	5.65	240.57	360.79	428.05	1,035.04
8	24-Dec-01	113.76	134.56	233.15	368.32	849.78
9	27-Dec-01	98.85	154.50	272.85	391.25	917.44
10	30-Dec-01	7.55	119.84	287.75	413.61	828.75
11	3-Jan-02	93.95	18.77	97.90	173.88	384.49
12	6-Jan-02	14.65	53.67	81.01	542.01	691.34
13	9-Jan-02	72.82	28.65	58.95	149.01	309.42
14	12-Jan-02	31.72	64.86	88.65	171.90	357.13
15	15-Jan-02	212.71	31.03	421.75	448.57	1,114.06
16	18-Jan-02	36.33	61.10	45.37	72.12	214.93
17	20-Jan-02	6.53	8.10	106.05	317.02	437.68
18	23-Jan-02	75.31	91.37	169.30	266.54	602.52
19	26-Jan-02	332.26	199.35	211.95	377.70	1,121.25
20	29-Jan-02	72.13	114.61	119.81	296.27	602.83
21	1-Feb-02	233.15	271.38	526.28	759.13	1,789.93
22	5-Feb-02	119.45	299.01	369.15	1,000.10	1,787.71
23	8-Feb-02	147.12	257.81	499.17	878.65	1,782.75
24	12-Feb-02	51.75	21.55	107.05	318.80	499.14
25	15-Feb-02	52.84	65.68	116.94	205.52	440.99

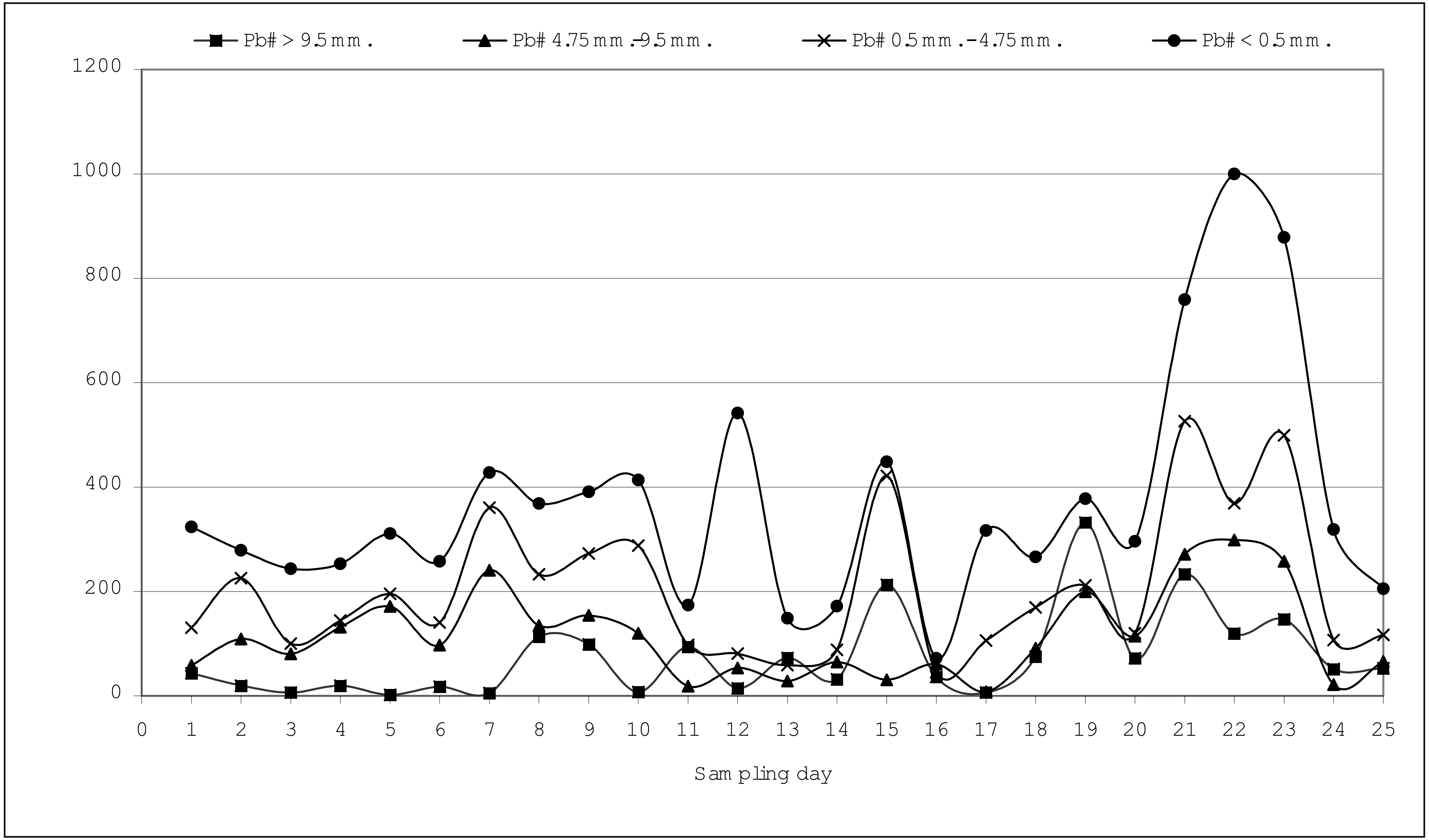


Figure 4.7. Relationship between lead concentration in bottom ash with respect to particle size

Table 4.2 Silver concentrations in the bottom ash with respect to particle size

Sampling day	Date of Incineration	Ag				
		>9.5mm (mg/kg)	4.75-9.5 mm (mg/kg)	0.5-4.75 mm (mg/kg)	< 0.5mm (mg/kg)	Total (mg/kg)
1	03-Dec-01	7.21	41.82	186.26	71.10	306.39
2	06-Dec-01	6.70	42.04	116.90	58.64	224.28
3	09-Dec-01	13.25	62.85	249.03	118.40	443.52
4	12-Dec-01	2.33	36.99	93.46	44.62	177.40
5	14-Dec-01	1.46	31.03	230.26	96.81	359.55
6	17-Dec-01	2.90	32.90	87.22	32.98	155.99
7	20-Dec-01	4.90	26.02	125.90	47.52	204.35
8	24-Dec-01	54.70	26.90	114.03	53.21	248.84
9	27-Dec-01	6.13	51.56	167.47	63.97	289.12
10	30-Dec-01	7.72	31.28	194.12	90.42	323.54
11	3-Jan-02	46.50	15.10	100.06	93.03	254.68
12	6-Jan-02	10.91	43.97	66.54	54.04	175.46
13	9-Jan-02	4.13	64.25	220.31	130.93	419.61
14	12-Jan-02	2.90	57.57	171.70	80.82	312.98
15	15-Jan-02	20.66	54.51	112.06	81.12	268.35
16	18-Jan-02	3.89	74.31	347.96	147.02	573.19
17	20-Jan-02	13.60	18.23	173.07	88.80	293.70
18	23-Jan-02	35.05	112.70	132.90	65.05	345.70
19	26-Jan-02	25.86	74.56	190.70	128.82	419.94
20	29-Jan-02	9.40	75.62	231.20	184.83	501.05
21	1-Feb-02	4.62	47.04	154.33	55.46	261.45
22	5-Feb-02	14.39	21.30	239.40	130.42	405.50
23	8-Feb-02	11.26	84.32	191.26	113.09	399.93
24	12-Feb-02	4.03	8.40	251.85	125.04	389.31
25	15-Feb-02	14.21	91.24	167.33	170.98	443.76

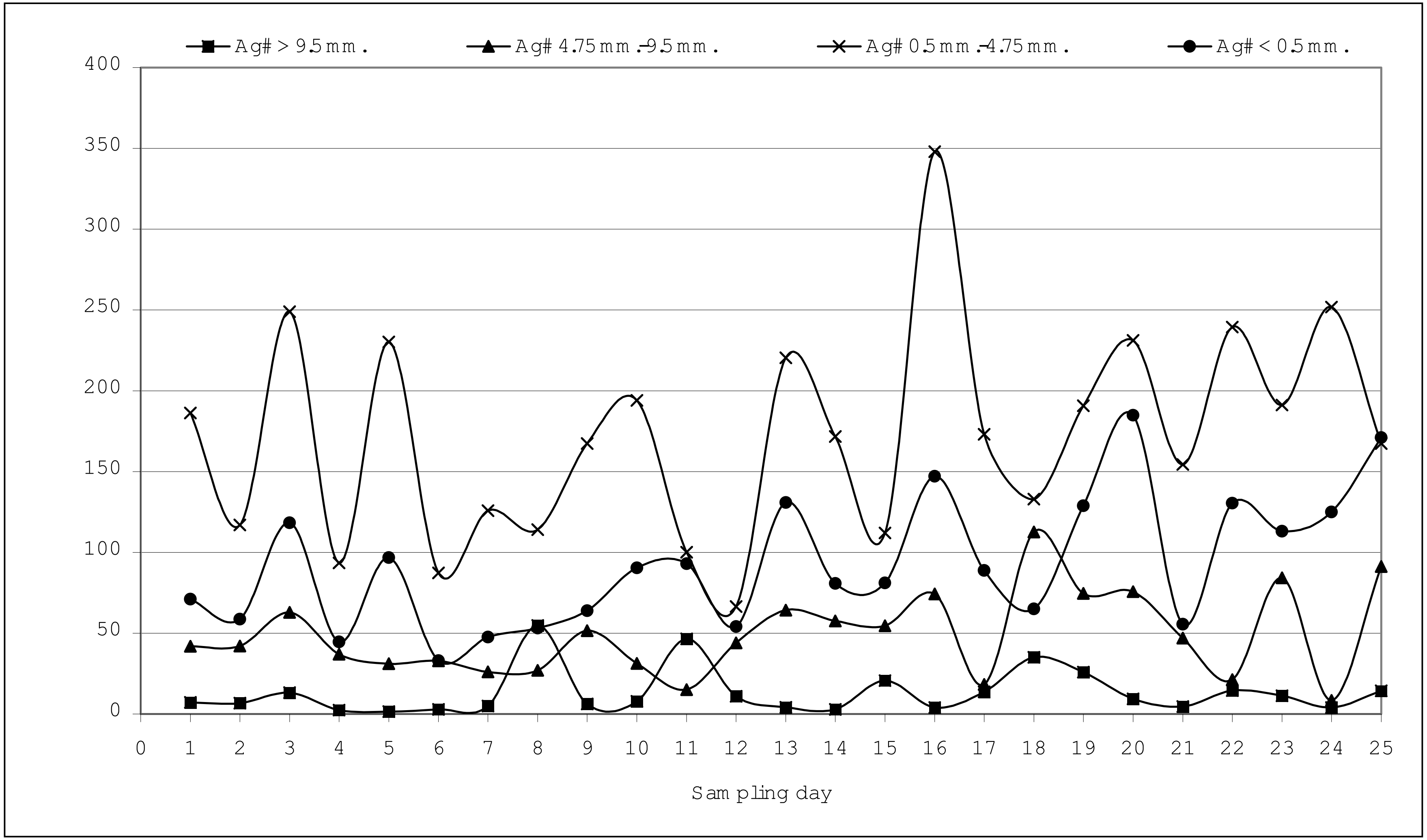


Figure 4.8. Relationship between silver concentration in bottom ash with respect to particle size

Table 4.3 Iron concentrations in the bottom ash with respect to particle size

Sampling Day	Date of Incineration	Fe				
		>9.5mm (mg/kg)	4.75-9.5 mm (mg/kg)	0.5-4.75 mm (mg/kg)	< 0.5mm (mg/kg)	Total (mg/kg)
1	03-Dec-01	4,453.51	143,426.00	73,558.99	12,159.34	233,597.84
2	06-Dec-01	3,325.56	149,450.81	44,313.06	12,377.30	209,466.72
3	09-Dec-01	10,060.15	309,647.26	149,195.54	10,143.65	479,046.59
4	12-Dec-01	8,511.60	145,380.43	30,657.20	10,854.68	195,403.91
5	14-Dec-01	5,043.22	139,893.66	98,094.01	12,126.35	255,157.25
6	17-Dec-01	9,503.60	278,758.49	33,099.22	10,168.24	331,529.56
7	20-Dec-01	6,311.68	143,776.31	81,805.30	13,818.01	245,711.30
8	24-Dec-01	10,573.95	215,032.46	88,592.72	11,892.14	326,091.27
9	27-Dec-01	9,529.91	114,394.62	86,923.31	11,755.38	222,603.22
10	30-Dec-01	11,201.00	110,545.00	90,963.14	15,078.60	227,787.74
11	3-Jan-02	10,375.52	246,157.70	50,423.99	20,129.55	327,086.75
12	6-Jan-02	11,510.70	141,802.99	125,254.71	37,287.16	315,855.56
13	9-Jan-02	5,418.40	159,474.75	76,727.15	19,792.48	261,412.79
14	12-Jan-02	4,101.46	123,799.73	45,247.23	20,343.72	193,492.14
15	15-Jan-02	6,199.21	241,675.79	55,501.84	28,516.13	331,892.97
16	18-Jan-02	9,192.27	144,171.92	60,174.87	49,658.66	263,197.72
17	20-Jan-02	6,497.65	152,823.48	121,009.23	55,293.69	335,624.04
18	23-Jan-02	10,481.00	396,386.70	129,208.00	44,926.63	581,002.34
19	26-Jan-02	8,693.02	115,805.42	89,895.31	53,281.12	267,674.88
20	29-Jan-02	15,428.87	219,007.51	186,455.72	60,932.16	481,824.26
21	1-Feb-02	13,443.30	182,979.95	94,972.36	34,730.41	326,126.02
22	5-Feb-02	5,987.52	184,556.40	101,872.63	47,006.81	339,423.36
23	8-Feb-02	12,115.90	260,611.94	86,376.51	35,880.83	394,985.19
24	12-Feb-02	14,009.83	225,044.56	132,734.10	38,805.36	410,593.85
25	15-Feb-02	7,154.64	176,231.30	99,113.51	13,942.81	296,442.27

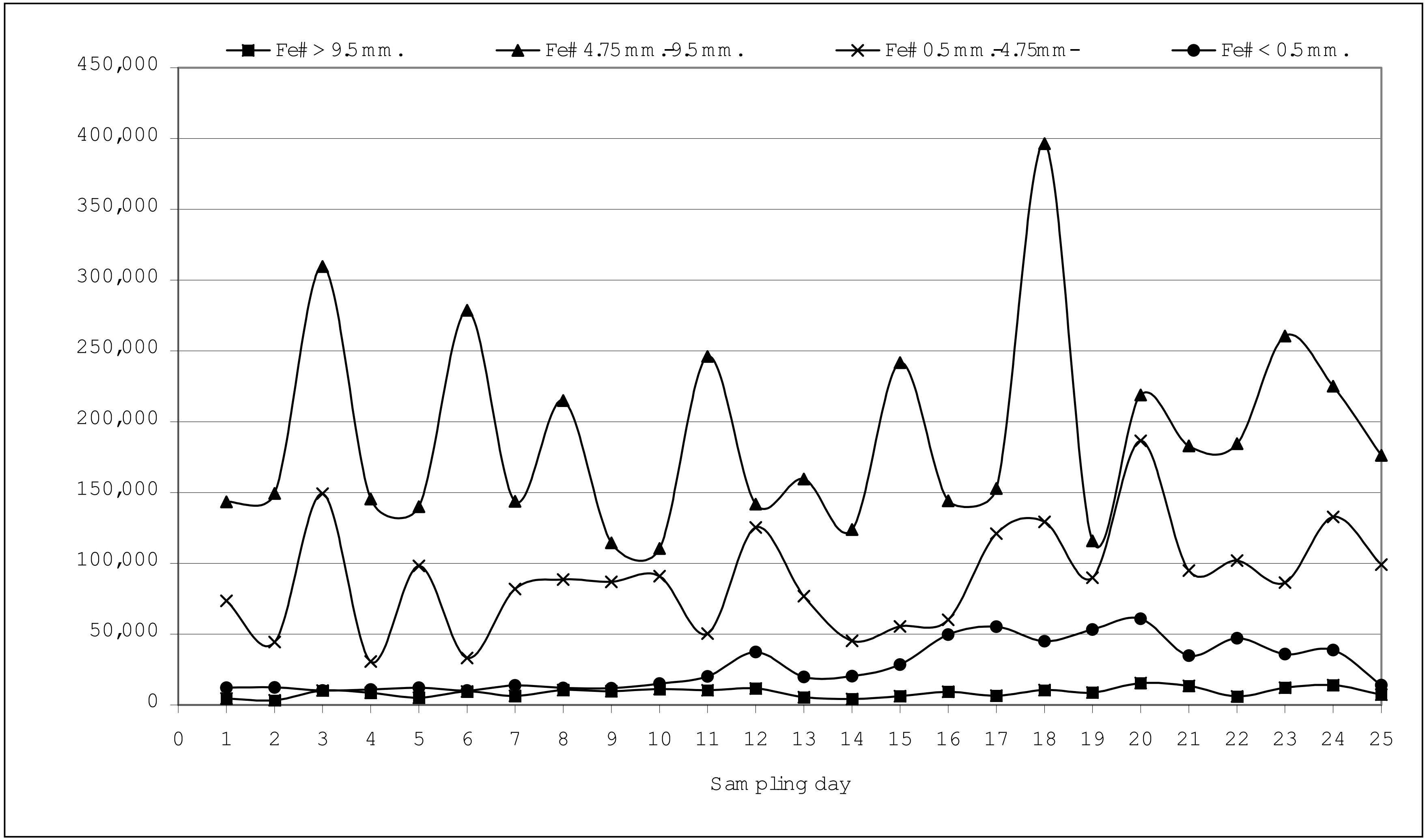


Figure 4.9. Relationship between iron concentration in bottom ash with respect to particle size

Table 4.4 Zinc concentrations in bottom ash with respect to particle size

Sampling day	Date of Incineration	Zn				
		>9.5mm (mg/kg)	4.75-9.5 mm (mg/kg)	0.5-4.75 mm (mg/kg)	< 0.5mm (mg/kg)	Total (mg/kg)
1	03-Dec-01	716.10	6,803.01	5,618.40	5,471.24	18,608.75
2	06-Dec-01	156.63	4,010.41	4,645.97	5,460.20	14,273.21
3	09-Dec-01	49.61	1,695.60	3,369.32	4,807.61	9,922.15
4	12-Dec-01	611.72	2,614.62	3,309.90	4,770.14	11,306.37
5	14-Dec-01	157.62	3,092.46	5,384.92	6,163.47	14,798.47
6	17-Dec-01	75.13	2,735.85	4,344.67	5,015.46	12,171.11
7	20-Dec-01	1,093.62	8,699.56	11,236.60	13,114.83	34,144.62
8	24-Dec-01	1,025.23	6,669.21	9,218.46	10,555.37	27,468.26
9	27-Dec-01	817.62	2,151.83	5,121.73	9,991.63	18,082.81
10	30-Dec-01	107.32	3,620.67	6,091.46	10,671.26	20,490.70
11	3-Jan-02	1,497.12	2,863.80	8,203.14	7,893.66	20,457.73
12	6-Jan-02	925.56	4,451.32	5,743.76	10,207.90	21,328.53
13	9-Jan-02	622.50	746.70	7,447.38	9,676.30	18,492.87
14	12-Jan-02	603.71	2,736.52	6,422.56	8,468.33	18,231.12
15	15-Jan-02	870.51	3,113.30	6,749.22	9,267.92	20,000.95
16	18-Jan-02	441.69	6,116.04	2,987.46	11,711.60	21,256.78
17	20-Jan-02	2,605.91	1,513.00	4,174.03	14,271.22	22,564.16
18	23-Jan-02	2,563.62	1,149.97	4,645.76	6,429.27	14,788.62
19	26-Jan-02	1,974.72	3,505.96	5,297.86	6,581.56	17,360.10
20	29-Jan-02	2,199.70	3,814.44	4,534.60	7,005.01	17,553.74
21	1-Feb-02	1,558.31	3,429.96	6,795.36	13,607.43	25,391.05
22	5-Feb-02	1,843.75	1,838.61	4,727.72	7,503.55	15,913.62
23	8-Feb-02	1,637.34	2,558.10	4,841.97	9,454.23	18,491.63
24	12-Feb-02	298.02	1,379.37	5,466.74	7,158.98	14,303.11
25	15-Feb-02	3,441.70	4,152.24	5,664.94	7,107.86	20,366.74

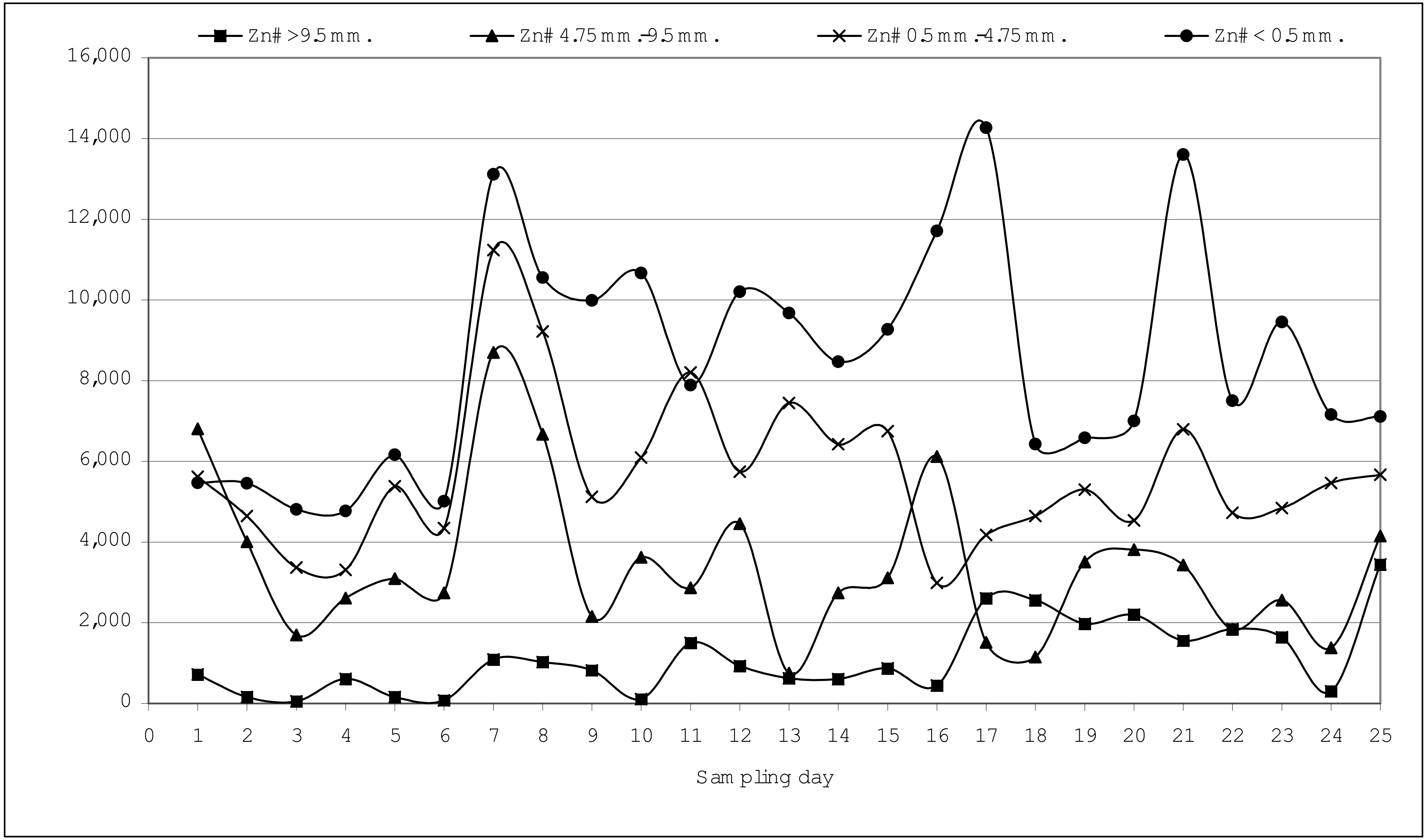


Figure 4.10. Relationship between zinc concentration in bottom ash with respect to particle size

Tables 4.5-4.8 show the total amount of four heavy metals with respect to the particle size of bottom ash produced on the sampling day. From these results, it was observed that the highest fraction metal was iron (31.41%). It could be due to the fact that the main component of medical equipment such as needles, hypodermic needles, scalpel, blades and others, is iron. Moreover, the highest melting point of iron (1,493° C) means the larger amount of its residues. Factions of other metals were 1.87%, 0.08%, and 0.03% for zinc, lead and silver, respectively. From statistical analysis (ANOVA), it was found that the silver and zinc concentrations in bottom ash with respect to particle size were significantly different for four size ranges. For lead, the concentration in the >9.5 mm and 4.75-9.5 mm particle size rages were not significantly different, while for iron, the concentrations in <0.5 mm and >9.5 mm were not significantly different.

Table 4.5 Total amount of lead with respect to four particle sizes in the bottom ash produced on the sampling days

Sampling Day	Date of Incineration	Pb					
		>9.5 mm (kg)	4.75-9.5 mm (kg)	0.5-4.75 mm (kg)	<0.5 mm (kg)	Total (kg)	% in bottom ash
1	03-Dec-01	0.0065	0.0088	0.0196	0.0486	0.0835	0.06
2	06-Dec-01	0.0031	0.0174	0.0361	0.0447	0.1013	0.06
3	09-Dec-01	0.0013	0.0165	0.0206	0.0500	0.0884	0.04
4	12-Dec-01	0.0033	0.0218	0.0239	0.0418	0.0907	0.05
5	14-Dec-01	0.0003	0.0321	0.0366	0.0582	0.1272	0.07
6	17-Dec-01	0.0031	0.0174	0.0250	0.0459	0.0914	0.05
7	20-Dec-01	0.0008	0.0349	0.0523	0.0621	0.1501	0.10
8	24-Dec-01	0.0181	0.0214	0.0371	0.0586	0.1351	0.08
9	27-Dec-01	0.0180	0.0281	0.0497	0.0712	0.1670	0.09
10	30-Dec-01	0.0013	0.0210	0.0504	0.0724	0.1450	0.08
11	3-Jan-02	0.0184	0.0037	0.0192	0.0341	0.0754	0.04
12	6-Jan-02	0.0028	0.0104	0.0156	0.1046	0.1334	0.07
13	9-Jan-02	0.0122	0.0048	0.0099	0.0250	0.0520	0.03
14	12-Jan-02	0.0051	0.0104	0.0143	0.0277	0.0575	0.04
15	15-Jan-02	0.0428	0.0062	0.0848	0.0902	0.2239	0.11
16	18-Jan-02	0.0071	0.0120	0.0089	0.0141	0.0421	0.02
17	20-Jan-02	0.0013	0.0016	0.0209	0.0625	0.0862	0.04
18	23-Jan-02	0.0139	0.0169	0.0313	0.0493	0.1115	0.06
19	26-Jan-02	0.0694	0.0417	0.0443	0.0789	0.2343	0.11
20	29-Jan-02	0.0166	0.0264	0.0276	0.0681	0.1387	0.06
21	1-Feb-02	0.0396	0.0461	0.0895	0.1291	0.3043	0.18
22	5-Feb-02	0.0251	0.0628	0.0775	0.2100	0.3754	0.18
23	8-Feb-02	0.0291	0.0510	0.0988	0.1740	0.3530	0.18
24	12-Feb-02	0.0088	0.0037	0.0182	0.0542	0.0849	0.05
25	15-Feb-02	0.0132	0.0164	0.0292	0.0514	0.1102	0.04
	Mean	**0.0145**	**0.0213**	**0.0376**	**0.0691**	**0.1425**	**0.08**
	SD	**0.0165**	**0.0159**	**0.0255**	**0.0448**	**0.0896**	**0.05**

Table 4.6 Total amount of silver with respect to four particle sizes in the bottom ash produced on the sampling days

Sampling day	Date of Incineration	Ag					
		>9.5 mm (kg)	4.75-9.5 mm (kg)	0.5-4.75 mm (kg)	<0.5 mm (kg)	Total (kg)	% in bottom ash
1	03-Dec-01	0.0011	0.0063	0.0279	0.0107	0.0460	0.03
2	06-Dec-01	0.0011	0.0067	0.0187	0.0094	0.0359	0.02
3	09-Dec-01	0.0027	0.0129	0.0511	0.0243	0.0909	0.04
4	12-Dec-01	0.0004	0.0061	0.0154	0.0074	0.0293	0.02
5	14-Dec-01	0.0003	0.0058	0.0431	0.0181	0.0672	0.04
6	17-Dec-01	0.0005	0.0059	0.0155	0.0059	0.0278	0.02
7	20-Dec-01	0.0007	0.0038	0.0183	0.0069	0.0296	0.02
8	24-Dec-01	0.0087	0.0043	0.0181	0.0085	0.0396	0.02
9	27-Dec-01	0.0011	0.0094	0.0305	0.0116	0.0526	0.03
10	30-Dec-01	0.0014	0.0055	0.0340	0.0158	0.0566	0.03
11	3-Jan-02	0.0091	0.0030	0.0196	0.0182	0.0499	0.03
12	6-Jan-02	0.0021	0.0085	0.0128	0.0104	0.0339	0.02
13	9-Jan-02	0.0007	0.0108	0.0370	0.0220	0.0705	0.04
14	12-Jan-02	0.0005	0.0093	0.0276	0.0130	0.0504	0.03
15	15-Jan-02	0.0042	0.0110	0.0225	0.0163	0.0539	0.03
16	18-Jan-02	0.0008	0.0146	0.0682	0.0288	0.1123	0.06
17	20-Jan-02	0.0027	0.0036	0.0341	0.0175	0.0579	0.03
18	23-Jan-02	0.0065	0.0208	0.0246	0.0120	0.0640	0.03
19	26-Jan-02	0.0054	0.0156	0.0399	0.0269	0.0878	0.04
20	29-Jan-02	0.0022	0.0174	0.0532	0.0425	0.1152	0.05
21	1-Feb-02	0.0008	0.0080	0.0262	0.0094	0.0444	0.03
22	5-Feb-02	0.0030	0.0045	0.0503	0.0274	0.0852	0.04
23	8-Feb-02	0.0022	0.0167	0.0379	0.0224	0.0792	0.04
24	12-Feb-02	0.0007	0.0014	0.0428	0.0213	0.0662	0.04
25	15-Feb-02	0.0036	0.0228	0.0418	0.0427	0.1109	0.04
	Mean	**0.0025**	**0.0094**	**0.0324**	**0.0180**	**0.0623**	**0.03**
	SD	**0.0025**	**0.0058**	**0.0141**	**0.0101**	**0.0262**	**0.01**

Table 4.7 Total amount of iron with respect to four particle sizes in the bottom ash produced on the sampling days

Sampling day	Date of Incineration	Fe					
		>9.5 mm (kg)	4.75-9.5 mm (kg)	0.5-4.75 mm (kg)	<0.5 mm (kg)	Total (kg)	% in bottom ash
1	03-Dec-01	0.6680	21.5139	11.0338	1.8239	35.0397	23.36
2	06-Dec-01	0.5321	23.9121	7.0901	1.9804	33.5147	20.95
3	09-Dec-01	2.0623	63.4777	30.5851	2.0794	98.2046	47.90
4	12-Dec-01	1.4044	23.9878	5.0584	1.7910	32.2416	19.54
5	14-Dec-01	0.9431	26.1601	18.3436	2.2676	47.7144	25.52
6	17-Dec-01	1.6916	49.6190	5.8917	1.8099	59.0123	33.15
7	20-Dec-01	0.9152	20.8476	11.8618	2.0036	35.6281	24.57
8	24-Dec-01	1.6813	34.1902	14.0862	1.8909	51.8485	32.61
9	27-Dec-01	1.7344	20.8198	15.8200	2.1395	40.5138	22.26
10	30-Dec-01	1.9602	19.3454	15.9185	2.6388	39.8629	22.78
11	3-Jan-02	2.0336	48.2469	9.8831	3.9454	64.1090	32.71
12	6-Jan-02	2.2216	27.3680	24.1742	7.1964	60.9601	31.59
13	9-Jan-02	0.9103	26.7918	12.8902	3.3251	43.9173	26.14
14	12-Jan-02	0.6603	19.9318	7.2848	3.2753	31.1522	19.35
15	15-Jan-02	1.2460	48.5768	11.1559	5.7317	66.7105	33.19
16	18-Jan-02	1.8017	28.2577	11.7943	9.7331	51.5868	26.32
17	20-Jan-02	1.2800	30.1062	23.8388	10.8929	66.1179	33.56
18	23-Jan-02	1.9390	73.3315	23.9035	8.3114	107.4854	58.10
19	26-Jan-02	1.8168	24.2033	18.7881	11.1358	55.9440	26.77
20	29-Jan-02	3.5486	50.3717	42.8848	14.0144	110.8196	48.18
21	1-Feb-02	2.2854	31.1066	16.1453	5.9042	55.4414	32.61
22	5-Feb-02	1.2574	38.7568	21.3933	9.8714	71.2789	33.94
23	8-Feb-02	2.3989	51.6012	17.1025	7.1044	78.2071	39.50
24	12-Feb-02	2.3817	38.2576	22.5648	6.5969	69.8010	41.06
25	15-Feb-02	1.7887	44.0578	24.7784	3.4857	74.1106	29.64
	Mean	**1.6465**	**35.3936**	**16.9708**	**5.2380**	**59.2489**	**31.41**
	SD	**0.6863**	**14.6824**	**8.6057**	**3.6500**	**22.3873**	**9.63**

Table 4.8 Total amount of zinc with respect to four particle sizes in the bottom ash produced on the sampling days

Sampling day	Date of Incineration	Zn					
		>9.5 mm (kg)	4.75-9.5 mm (kg)	0.5-4.75 mm (kg)	<0.5 mm (kg)	Total (kg)	% in bottom ash
1	03-Dec-01	0.1074	1.0205	0.8428	0.8207	2.7913	1.86
2	06-Dec-01	0.0251	0.6417	0.7434	0.8736	2.2837	1.43
3	09-Dec-01	0.0102	0.3476	0.6907	0.9856	2.0340	0.99
4	12-Dec-01	0.1009	0.4314	0.5461	0.7871	1.8656	1.13
5	14-Dec-01	0.0295	0.5783	1.0070	1.1526	2.7673	1.48
6	17-Dec-01	0.0134	0.4870	0.7734	0.8928	2.1665	1.22
7	20-Dec-01	0.1586	1.2614	1.6293	1.9017	4.9510	3.41
8	24-Dec-01	0.1630	1.0604	1.4657	1.6783	4.3675	2.75
9	27-Dec-01	0.1488	0.3916	0.9322	1.8185	3.2911	1.81
10	30-Dec-01	0.0188	0.6336	1.0660	1.8675	3.5859	2.05
11	3-Jan-02	0.2934	0.5613	1.6078	1.5472	4.0097	2.05
12	6-Jan-02	0.1786	0.8591	1.1085	1.9701	4.1164	2.13
13	9-Jan-02	0.1046	0.1254	1.2512	1.6256	3.1068	1.85
14	12-Jan-02	0.0972	0.4406	1.0340	1.3634	2.9352	1.82
15	15-Jan-02	0.1750	0.6258	1.3566	1.8629	4.0202	2.00
16	18-Jan-02	0.0866	1.1987	0.5855	2.2955	4.1663	2.13
17	20-Jan-02	0.5134	0.2981	0.8223	2.8114	4.4451	2.26
18	23-Jan-02	0.4743	0.2127	0.8595	1.1894	2.7359	1.48
19	26-Jan-02	0.4127	0.7327	1.1073	1.3755	3.6283	1.74
20	29-Jan-02	0.5059	0.8773	1.0430	1.6112	4.0374	1.76
21	1-Feb-02	0.2649	0.5831	1.1552	2.3133	4.3165	2.54
22	5-Feb-02	0.3872	0.3861	0.9928	1.5757	3.3419	1.59
23	8-Feb-02	0.3242	0.5065	0.9587	1.8719	3.6613	1.85
24	12-Feb-02	0.0507	0.2345	0.9293	1.2170	2.4315	1.43
25	15-Feb-02	0.8604	1.0381	1.4162	1.7770	5.0917	2.04
	Mean	**0.2202**	**0.6213**	**1.0370**	**1.5674**	**3.4459**	**1.87**
	SD	**0.2087**	**0.3136**	**0.2919**	**0.5107**	**0.9119**	**0.52**

4.4 Results of the EP toxicity test

EP toxicity tests were conducted on the simulated bottom ash leachate samples in laboratory following the USEPA guidance for solid waste SW-486. Heavy metals' concentrations were determined in these samples with respect to particle sizes. The results of above investigations are discussed below.

4.4.1 Lead

The concentration of lead in the samples from EP toxicity tests were found to be in range of 1.88 to 7.25 mg/L, with the mean at 4.26 mg/L. The typical data of lead concentrations in simulated leachate shown in Table 4.9. The relationship of lead concentrations with respect to the particle size is shown in Figure 4.11. From this figure it could be seen that lead concentrations increased as particle size decreased and were the lowest in >9.5 mm of particle size (average 0.40 mg/L). The highest concentration was found to be in <0.5 mm of particle size (average 1.97 mg/L).

4.4.2 Silver

The concentration of silver in the samples from EP toxicity tests were in range of 0.60 to 11.72 mg/L, with the mean at 3.65 mg/L. The typical data of silver concentrations in simulated leachate are shown in Table 4.10. The relationship of silver concentrations and particle sizes are shown in Figure 4.8. From this figure it could be seen that silver concentrations increased as particle size decreased. The lowest concentration was found to be in >9.5 mm of particle size (average 0.24 mg/L). The highest concentration was found in <0.5 mm particle size range (average 1.43 mg/L).

4.4.3 Iron

The concentration of iron in the samples from EP toxicity tests were found to be in the range of 3.16 to 19.07 mg/L, with the mean at 10.65 mg/L. The typical data of iron concentrations in simulated leachate are shown in Table 4.11. The relationship of iron concentrations with respect to the particle size are shown in Figure 4.11. From this figure it could be seen that iron concentration increased as particle size decreased. The lowest concentration was found to be in >9.5 mm particle size range (average 1.10 mg/L). The highest concentration was found to be in <0.5 mm particle size range (average 4.28 mg/L).

Table 4.9 Lead concentrations in simulated bottom ash leachate with respect to the particle size

Sampling Day	Date of Incineration	Pb				
		>9.5 mm (mg/L)	4.75-9.5 mm (mg/L)	0.5-4.75 mm (mg/L)	<0.5 mm (mg/L)	Total mg/L
1	03-Dec-01	0.62	0.81	1.00	1.92	4.34
2	06-Dec-01	0.25	0.68	1.66	2.06	4.65
3	09-Dec-01	0.36	0.86	1.76	2.79	5.77
4	12-Dec-01	0.23	0.60	1.00	1.82	3.66
5	14-Dec-01	0.31	0.52	0.74	1.79	3.36
6	17-Dec-01	0.08	0.62	0.87	1.55	3.11
7	20-Dec-01	0.43	0.67	0.99	1.65	3.74
8	24-Dec-01	0.05	0.46	2.09	4.58	7.18
9	27-Dec-01	0.09	0.40	1.27	3.70	5.46
10	30-Dec-01	0.38	0.45	1.16	2.57	4.56
11	3-Jan-02	0.49	0.69	1.08	1.61	3.87
12	6-Jan-02	0.72	1.70	2.26	2.58	7.25
13	9-Jan-02	0.25	1.73	1.95	2.26	6.20
14	12-Jan-02	0.08	0.92	0.98	1.16	3.14
15	15-Jan-02	1.10	0.70	1.09	1.71	4.60
16	18-Jan-02	0.23	0.76	0.93	1.48	3.41
17	20-Jan-02	0.23	0.32	1.23	2.23	4.00
18	23-Jan-02	0.46	0.84	1.34	0.45	3.09
19	26-Jan-02	0.46	0.11	0.40	0.91	1.88
20	29-Jan-02	0.90	0.09	0.19	0.94	2.12
21	1-Feb-02	0.70	0.61	1.73	1.79	4.83
22	5-Feb-02	1.06	0.95	1.10	1.27	4.38
23	8-Feb-02	0.06	0.74	1.29	2.97	5.05
24	12-Feb-02	0.44	1.01	0.59	2.35	4.38
25	15-Feb-02	0.08	0.59	0.72	1.00	2.39
	Mean	**0.40**	**0.71**	**1.18**	**1.97**	**4.26**
	SD	**0.30**	**0.38**	**0.51**	**0.91**	**1.39**

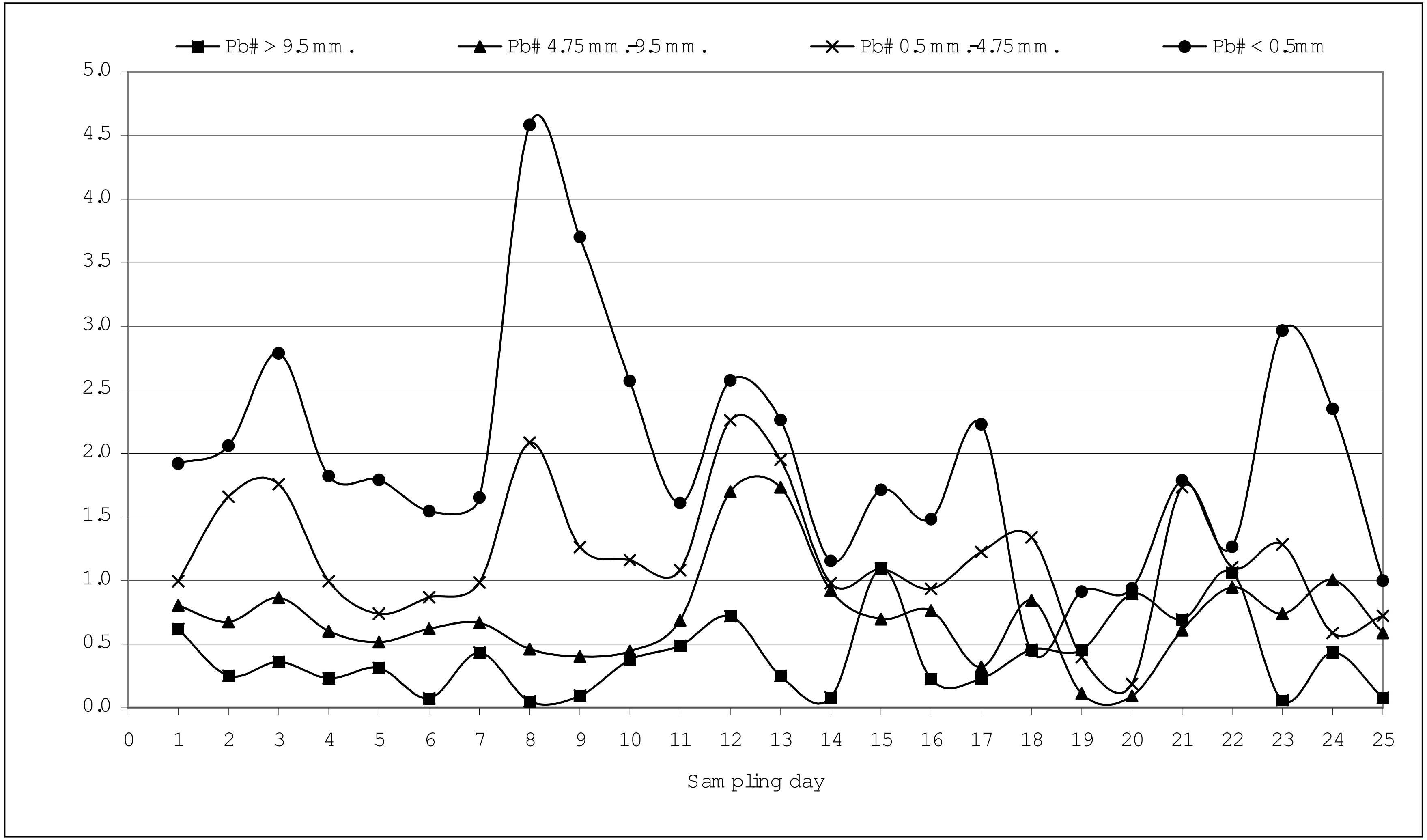


Figure 4.11. Relationship between lead concentration in bottom ash leachate with respect to particle size

Table 4.10 Silver concentrations in the simulated bottom ash leachate with respect to particle size

Sampling day	Date of Incineration	Ag				
		>9.5 mm (mg/L)	4.75-9.5 mm (mg/L)	0.5-4.75 mm (mg/L)	<0.5 mm (mg/L)	Total mg/L
1	03-Dec-01	0.62	3.52	3.52	4.06	11.72
2	06-Dec-01	0.39	0.77	1.08	1.79	4.02
3	09-Dec-01	0.47	0.66	2.61	2.66	6.40
4	12-Dec-01	0.56	1.00	2.67	2.76	6.98
5	14-Dec-01	0.59	0.55	1.55	1.67	4.36
6	17-Dec-01	0.39	0.84	1.53	1.55	4.31
7	20-Dec-01	0.15	0.46	2.56	2.61	5.77
8	24-Dec-01	0.47	0.04	0.44	0.60	1.54
9	27-Dec-01	0.23	0.10	0.48	0.33	1.13
10	30-Dec-01	0.15	0.09	0.13	0.23	0.60
11	3-Jan-02	0.08	0.99	1.16	1.31	3.54
12	6-Jan-02	0.10	0.69	0.74	0.86	2.39
13	9-Jan-02	0.24	0.24	1.17	1.18	2.84
14	12-Jan-02	0.12	0.14	0.92	0.64	1.82
15	15-Jan-02	0.05	0.55	0.93	0.69	2.22
16	18-Jan-02	0.29	0.86	1.48	1.28	3.91
17	20-Jan-02	0.04	0.28	1.29	1.40	3.01
18	23-Jan-02	0.04	0.39	1.86	1.46	3.76
19	26-Jan-02	0.26	0.07	1.06	0.99	2.37
20	29-Jan-02	0.09	0.04	1.14	1.05	2.32
21	1-Feb-02	0.01	0.05	1.22	1.13	2.41
22	5-Feb-02	0.28	0.13	1.13	1.12	2.65
23	8-Feb-02	0.25	1.12	2.44	2.20	6.00
24	12-Feb-02	0.06	0.48	1.11	1.01	2.66
25	15-Feb-02	0.05	0.32	1.12	1.10	2.59
	Mean	**0.24**	**0.57**	**1.41**	**1.43**	**3.65**
	SD	**0.19**	**0.70**	**0.80**	**0.87**	**2.34**

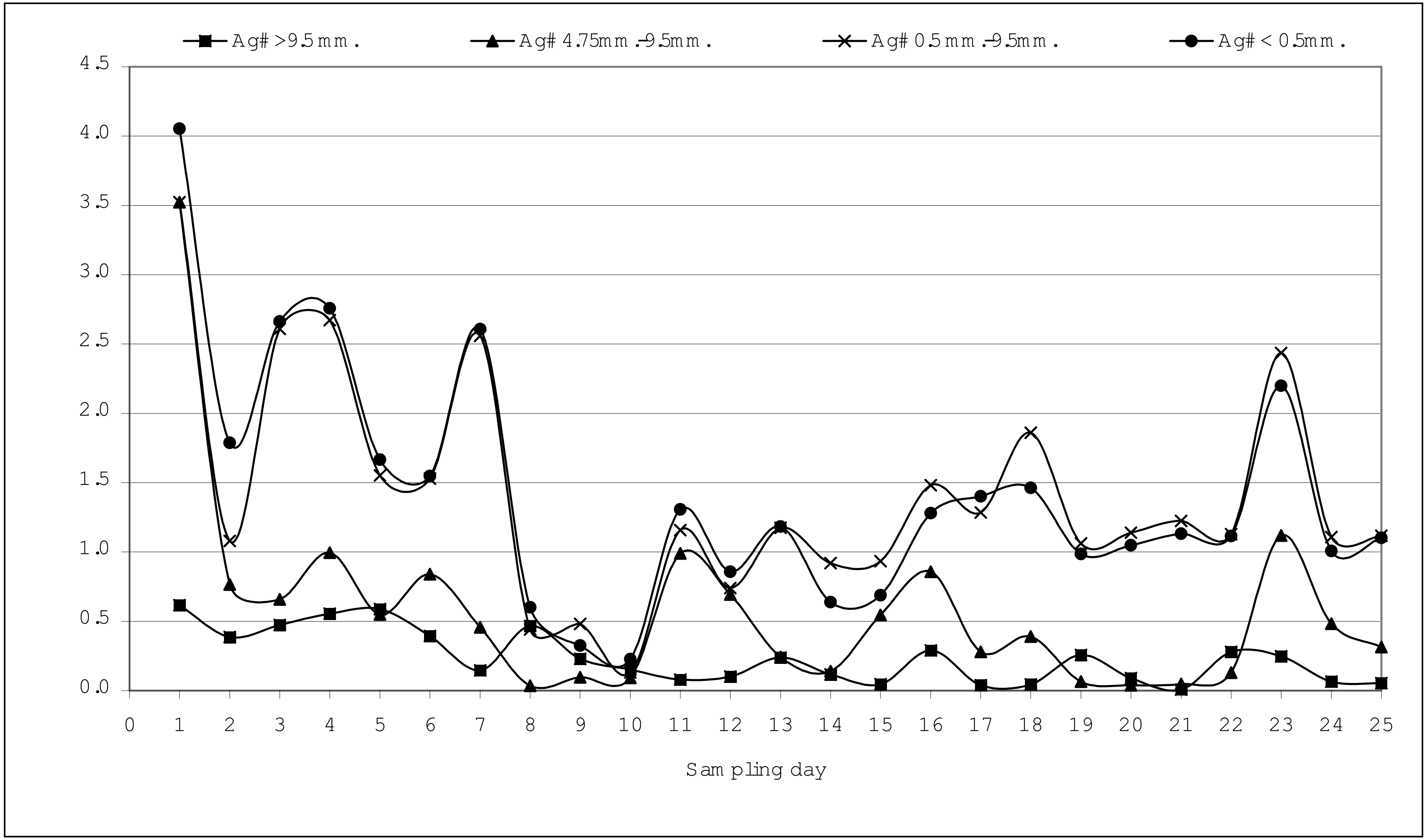


Figure 4.12. Relationship between silver concentration in bottom ash leachate with respect to particle size

Table 4.11 Iron concentrations in the simulated bottom ash leachate with respect to the particle size

Sampling day	Date of incineration	Fe				
		>9.5 mm (mg/L)	4.75-9.5 mm (mg/L)	0.5-4.75 mm (mg/L)	<0.5 mm (mg/L)	Total mg/L
1	03-Dec-01	1.30	1.14	4.62	5.46	12.52
2	06-Dec-01	0.64	1.72	3.71	3.09	9.16
3	09-Dec-01	0.71	1.04	5.10	6.31	13.15
4	12-Dec-01	3.36	3.60	5.58	6.54	19.07
5	14-Dec-01	1.31	0.89	2.03	2.07	6.29
6	17-Dec-01	0.48	0.94	3.91	3.94	9.28
7	20-Dec-01	1.11	1.01	2.11	2.11	6.34
8	24-Dec-01	5.53	1.04	3.13	3.99	13.69
9	27-Dec-01	1.17	1.16	4.10	4.05	10.48
10	30-Dec-01	0.41	1.06	3.07	4.05	8.59
11	3-Jan-02	0.43	1.49	1.54	2.71	6.16
12	6-Jan-02	0.93	1.39	5.47	8.42	16.20
13	9-Jan-02	0.58	2.11	1.80	2.45	6.94
14	12-Jan-02	0.38	0.32	1.02	1.44	3.16
15	15-Jan-02	0.58	0.79	2.48	5.55	9.40
16	18-Jan-02	0.61	1.48	4.69	6.73	13.50
17	20-Jan-02	0.30	3.58	5.51	3.79	13.18
18	23-Jan-02	0.37	1.82	4.54	4.94	11.67
19	26-Jan-02	0.38	0.45	2.49	2.52	5.84
20	29-Jan-02	0.42	1.32	2.48	2.58	6.79
21	1-Feb-02	0.64	1.95	2.79	2.12	7.49
22	5-Feb-02	2.41	4.16	7.13	8.46	22.16
23	8-Feb-02	0.47	2.61	5.58	5.75	14.41
24	12-Feb-02	1.90	2.67	4.69	4.12	13.37
25	15-Feb-02	1.00	1.50	1.18	3.74	7.42
	Mean	**1.10**	**1.65**	**3.63**	**4.28**	**10.65**
	SD	**1.17**	**0.99**	**1.63**	**1.96**	**4.50**

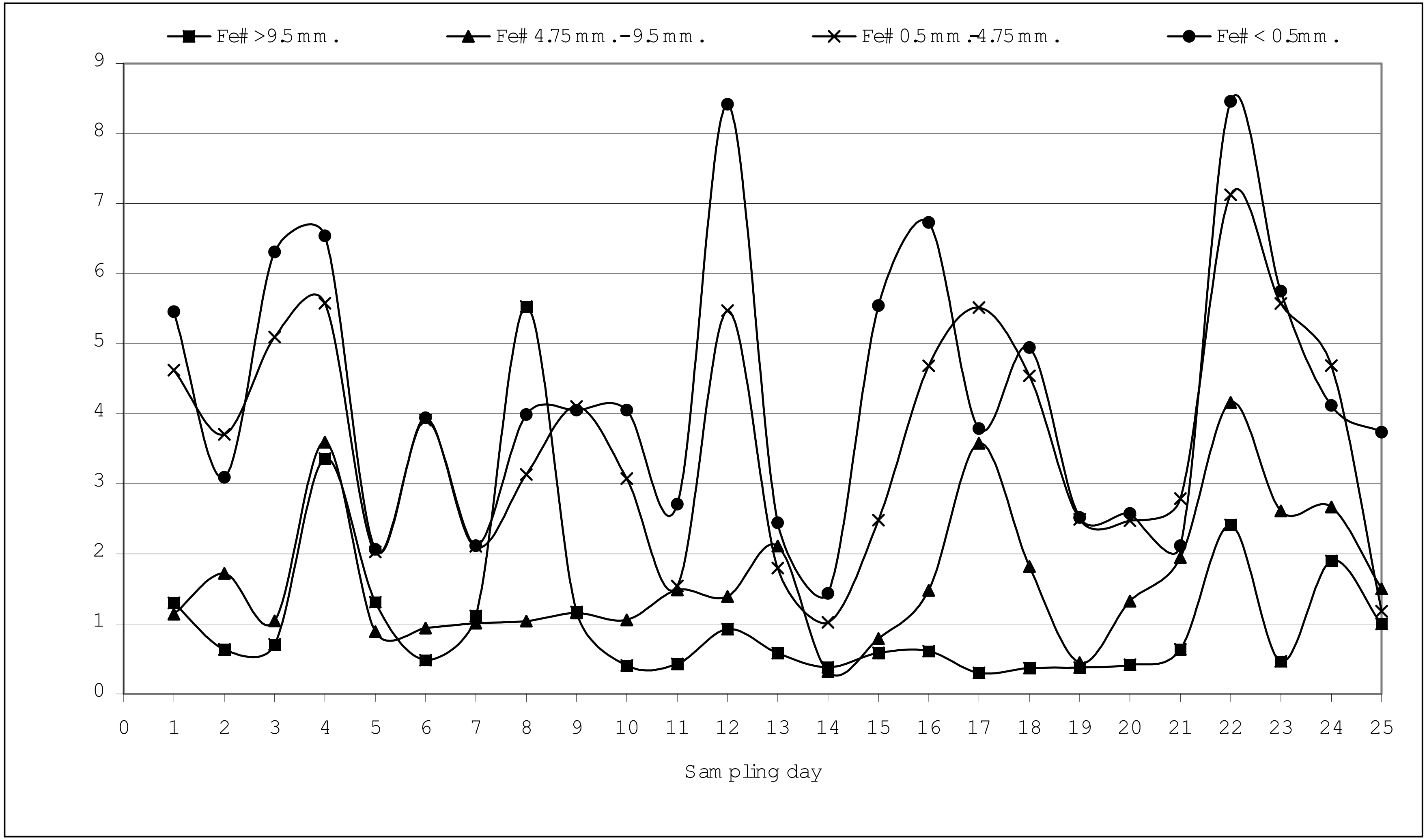


Figure 4.13. Relationship between iron concentration in bottom ash leachate with respect to particle size

4.4.4 Zinc

The concentration of zinc in the samples from EP toxicity tests were in the range of 8.66 to 21.35 mg/L, with the mean concentration at 13.27 mg/L. The typical data of zinc concentrations in simulated leachate are shown in Table 4.12. The relationship of zinc concentrations with respect to the particle size were shown in Figure 4.14. From this figure it could be seen zinc concentrations increased as particle size decreased. The lowest concentration was in >9.5 mm of particle size (average 1.32 mg/L). The highest concentration was found to be <0.5 mm of particle size (average 4.67 mg/L).

Heavy metals concentrations in simulated leachate were very low when compared to heavy metals in bottom ash. Because the leachability tests were undertaken under laboratory conditions using distilled water; however, leaching of the heavy metals from bottom ash can greatly increase if acidic solutions were used, which attempt to simulate acid rain conditions. Water in contact with bottom ash produced alkaline solutions rather than acidic ones. This made the heavy metals concentrations in bottom ash leachate much less than in bottom ash (Williams, 1994). The leachability of metals adsorbed on bottom ash particles is enhanced, since the heavy metals largely occur in the smallest size fraction and concentrated at or near the surface of the particle. The small particle size increases available surface area exposed to leaching.

The average concentrations of the four heavy metals, (as summarized in Table 4.13) were lower than the standards set by the sixth notification issued by Thailand's Ministry of Industry, and the EP toxicity limits. It can be seen that bottom ash from the medical waste incinerator at Ratchasima-Thonburi hospital was not hazardous. However, it had high Pb and Ag in general. Also from the data in Tables 4.9 to 4.12, it could be observed that and on certain days, Pb and Ag concentrations were higher than the standards. Hence, it was indicated that such a bottom ash should be classified to be hazardous at times, and is likely to have highly mobile constituents, which, if improperly managed, could impact groundwater. From statistical analysis (ANOVA), it was found that the concentrations in the simulated bottom ash leachate with respect to particle size were significantly different for all particle sizes in case of zinc. However, for lead, silver and iron, the concentrations in >9.5 mm and 4.75-9.5

Table 4.12. Zinc concentrations in simulated bottom ash leachate with respect to the particle size

Sampling day	Date of Incineration	Zn				
		>9.5 mm (mg/L)	4.75-9.5 mm (mg/L)	0.5-4.75 mm (mg/L)	<0.5 mm (mg/L)	Total mg/L
1	03-Dec-01	1.63	2.43	2.82	2.36	9.23
2	06-Dec-01	1.76	2.56	2.10	2.25	8.66
3	09-Dec-01	1.00	2.08	2.88	2.75	8.71
4	12-Dec-01	1.57	2.14	3.19	3.34	10.25
5	14-Dec-01	2.15	2.11	3.40	3.80	11.46
6	17-Dec-01	1.41	2.32	2.62	2.94	9.29
7	20-Dec-01	1.36	2.27	2.99	2.65	9.26
8	24-Dec-01	0.83	2.46	3.39	3.46	10.13
9	27-Dec-01	1.25	2.10	3.27	3.40	10.02
10	30-Dec-01	1.67	2.57	3.45	3.66	11.35
11	3-Jan-02	0.55	5.16	5.41	5.99	17.11
12	6-Jan-02	0.81	4.06	5.16	5.08	15.11
13	9-Jan-02	1.53	3.06	5.72	5.60	15.91
14	12-Jan-02	0.54	4.48	5.82	10.51	21.35
15	15-Jan-02	1.42	2.50	4.59	4.46	12.97
16	18-Jan-02	1.85	1.21	4.89	5.88	13.83
17	20-Jan-02	1.13	3.60	4.75	5.69	15.17
18	23-Jan-02	1.03	3.78	4.85	5.77	15.43
19	26-Jan-02	1.34	4.47	5.07	5.66	16.54
20	29-Jan-02	1.48	6.22	5.08	5.54	18.32
21	1-Feb-02	1.26	4.50	5.19	5.68	16.63
22	5-Feb-02	1.18	4.48	4.11	5.15	14.92
23	8-Feb-02	1.12	2.11	4.13	5.88	13.25
24	12-Feb-02	1.11	2.50	3.66	3.14	10.41
25	15-Feb-02	1.92	2.98	5.54	6.02	16.46
	Mean	**1.32**	**3.13**	**4.16**	**4.67**	**13.27**
	SD	**0.40**	**1.21**	**1.10**	**1.80**	**3.50**

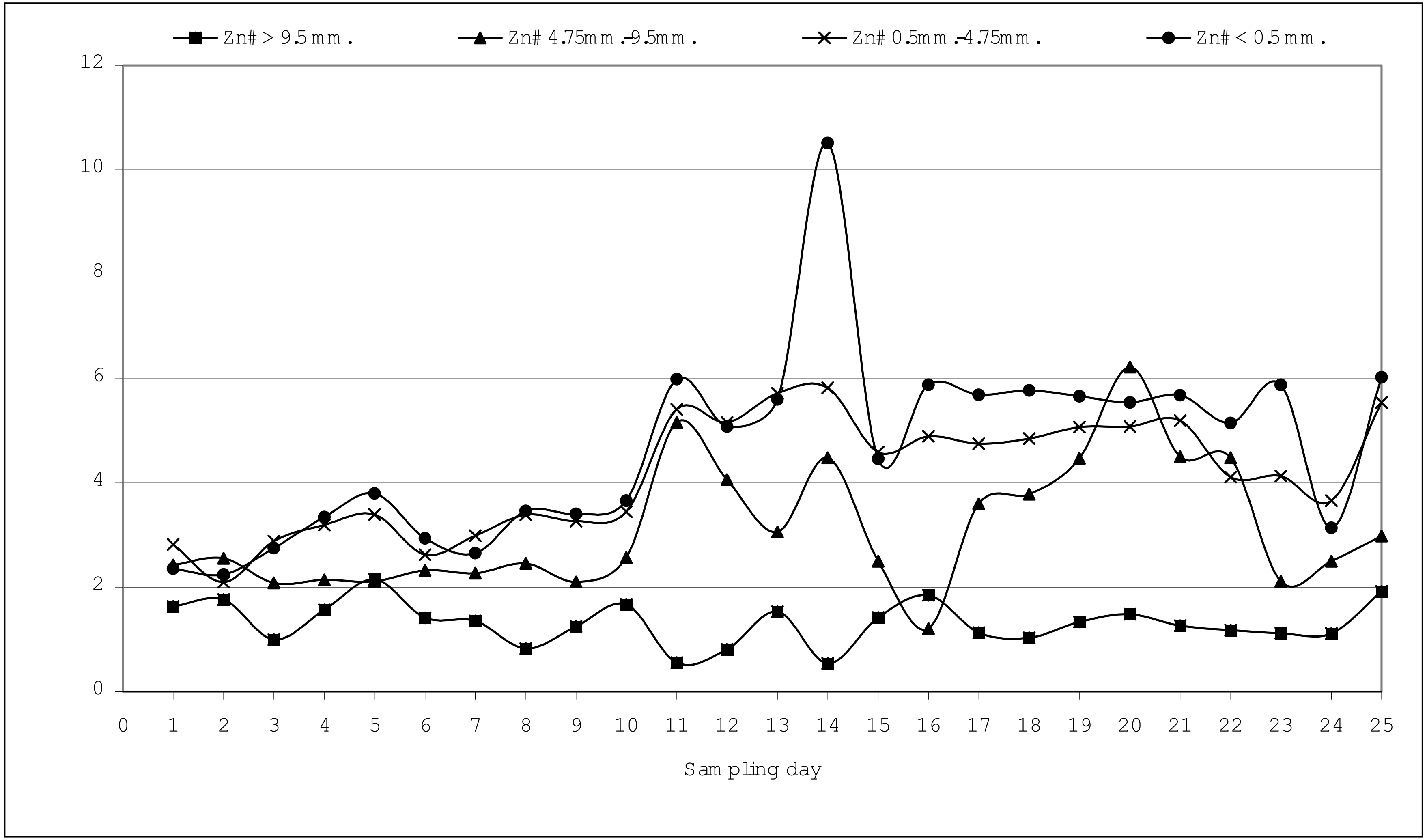


Figure 4.14. Relationship between zinc concentration in bottom ash leachate with respect to particle size

mm particle sizes were not significantly different but were significantly different for 0.5-4.75 mm and <0.5 mm particle sizes.

Table 4.13 Results of EP toxicity tests performed on Ratchasima-Thonburi Hospital incinerator bottom ash compared to the EP toxicity limits and the standards set by the sixth notification issued by Thailand's Ministry of Industry (1999).

Metals	Concentration (mg/L)	EP toxicity limit (mg/L)	Sixth notification issued by Thailand's Ministry of Industry (mg/L)
Lead	4.26	5.0	5.0
Silver	3.65	5.0	5.0
Iron	10.65	-	-
Zinc	13.27	-	-

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The results of this study demonstrate the hazardous nature of bottom ash generated by incineration of medical waste due to the presence of heavy metals. Incineration dose not destroy these metals but simply disperses them via the incinerator stack and, as demonstrated in the current study, concentrates them into bottom ash. Far from solving a waste problem, incineration is simply creating a new and more toxic one.

Based on the results this study, following conclusions could be drown:

1. Sieve analysis showed that the largest fraction of bottom ash (58.39% by weight) was in >9.5 mm particle size range. The second largest fraction (18.50% by weight) was in 0.5-4.75 mm particle size range. And remaining two particle sizes (4.75-9.5 mm and <0.5 mm) were 10.92% and 10.65%, respectively.
2. Bottom ash residues arising from the Ratchasima-Thonburi Hospital incinerator contained high levels of the toxic heavy metals.
3. Lead and zinc largely occurred in smallest particle size (<0.5 mm) fraction. For silver, 0.5-4.75 mm particle size range had the highest concentration; while for iron the highest concentration was found to be in 4.75-9.5 mm particle size range.
4. Highest fraction metal was iron (31.41% of total bottom ash generated). It could be due to the fact that the main component of medical equipment such as needles, hypodermic needles, scalpel, blades and others is iron. Moreover, the highest melting point of iron (1,493°C) means the larger amount of its residues. Fractions of other metals were 1.87%, 0.08%, and 0.03% for zinc, lead and silver, respectively.

5. The leachability of metals in the simulated bottom ash increased as particle size decreased. Concentrations of the four heavy metals in the simulated leachate largely occurred in smallest particle size fraction. Because, the small particle size increases the available surface area exposed to leaching fluid.
6. Heavy metals concentrations in simulated leachate were very low when compared to heavy metals in bottom ash. Because the leachability tests were undertaken under laboratory conditions using distilled water; however, leaching of the heavy metals from bottom ash can greatly increase if acidic solutions were used which attempt to simulate acid rain conditions. Water in contact with bottom ash produced alkaline solutions rather than acidic ones. This made the heavy metals concentrations in bottom ash leachate much less than in bottom ash.
7. The average concentrations of the four heavy metals were lower than the standards set by the sixth notification issued by Thailand's Ministry of Industry, and the EP toxicity limits. Hence, it can be seen that bottom ash from the medical waste incinerator at Ratchasima-Thonburi hospital was not hazardous on most sampling day.
8. However, it had high Pb and Ag in general. Also from the data in Tables 4.9 to 4.12, it could be observed that and on certain days, Pb and Ag concentrations were higher than the standards. Hence, it was indicated that such a bottom ash should be classified to be hazardous at times, and is likely to have highly mobile constituents, which, if improperly managed, could impact groundwater.
9. EP toxicity test results will help in choosing parameters for an appropriate groundwater monitoring program.

5.2 Recommendations

Following recommendations are made for the future research on heavy metals in medical waste incinerators bottom ash:

1. A detailed chemical waste characterization must be undertaken to determine whether a medical waste incinerator bottom ash should be classified as hazardous and what leachable constituents are present.
2. In order to protect ground water, medical waste incinerator bottom ash should be disposed by properly designed-engineered treatment methods.
3. More investigated should be carried out on the bottom ashes produced from waste incinerators in various hospitals in Thailand with regards to their hazardous nature due to the presence of heavy metals.
4. Potential of reuse of incinerator ashes in civil engineering applications should be evaluated. However, it is necessary to address the engineering, environmental and economic concerns before large scale use of the ash considered.

References

Bagchi, A. and Sopcich, D. (1989). Characterization of municipal solid waste incineration ash. **J. Envi. Engineer.** 115(2): 447-451.

Bartone, C. (1998). Municipal solid waste management. **Managing Pollutant Problems-The Brown Environmental Agenda** (Report No. 16635). Washington DC: World Bank.

Belevi, H., Stapfi, D. M. and Baccini, P. (1992). Chemical behavior of municipal solid waste incinerator bottom ash in monofill. **J. Waste Management & Research.** 10(3): 153-167.

Boddum, J. K. and Skaarup J. (2000). Use of incinerator ash. In R. K. Dhir, T. D. Dyer, and K. A. Paine (eds.). **Pilot and Full Scale Washing of Incinerator Bottom Ash** (1st ed. pp. 111-123). London: Thomas Telford.

Brigden, K., Labunska, I., Striger, R., Johnson, P., Santillo, D. and Ashton, J. (2000). **Identification of Organic Pollutants and Heavy Metal Contaminants in Samples Collected from The Trieo Hazardous and Medical Waste Incinerator, Buenos Aires Province, Argentina.** Greenpeace Research Laboratories, University of Exeter. UK.

Bungorn, K. (1991). **An Appropriate Alternative of Hospital Solid Waste Disposal in Bangkok Metropolitan.** M.S. thesis, Mahidol University. Bangkok.

Calvin, R.B. (1993). **Hazardous Waste Incineration** (2nd ed.). New York: MaGraw-Hill.

Chang, J. and Ho, K. (2002). Feasibility of MSW Incinerator Bottom Ash for Chromate Removal by Adsorption. In **Enviro 2002 Convention & Exhibition and IWA 3rd World Water Congress.** Melbourne, Australia.

Chiang, K., Chi, J. and Chien, M., (2002). Heavy Metals Separation from MSW Incinerator Ash Using an Extraction and Nuetralization Process. In **Enviro 2002 Convention & Exhibition and IWA 3rd World Water Congress.** Melbourne, Australia.

Department of Public Cleansing. (2002). **Report on Municipal Solid Waste Generation in Bangkok Municipality Area** [Online]. Available: http://www.bma.go.th/bmaeng/body_project22.html.

Dyer, T. D., Dhir, R. K. and Collier, T. C. (2000). Use of incinerator ash. In Dhir, R. K., Dyer, T. D. and Paine, K. A. (eds.). **Precast Concrete Products Produced Incinerator Bottom Ash** (1st ed. pp. 341-353). London: Thomas Telford.

Hamernik, J. D. and Frantz G. C. (1991). Strength of concrete containing municipal solid waste fly ash. **J. ACI Material.** 88(5): 508-517.

Hasselriis, F. and Constantine, L. (1992). Characterization of Today's Medical Waste. In Green, A. E. S. (ed). **Medical Waste Incineration and Pollution Prevention** (pp 37-51). New York: Van Nostrand Reihold.

Hasselriis, F. (1992). Ash disposal. In Green, A. E. S. (ed.). **Medical Waste Incineration and Pollution Prevention** (pp142-154). New York: Van Nostrand Reihold.

Hollie, S. (2001). **Pollution Prevention for Nurse: Minimizing the Averse Environmental Impact of Health Care Delivery** [Online]. Available: http://www.nihe.org/p24nurse.html.

Koralewska, R. and Faulstich, M. (2000). Use of incinerator ash. In R. K. Dhir, T. D. Dyer, and K. A. Paine (eds.). **Process Integrated Cabonation of Bottom Ash**(1st ed. pp. 195-203). London: Thomas Telford.

Labunska, I., Stehenson, A., Erry, B., Santillo, D., Stringer, R. and Johston, P. (2000). **Heavy Metals and Other Contaminants in Bottom Ash and Fly Ash Generated by Incinerators at Phuket and Samui Island, Thailand.** Greenpeace Research Laboratories, University of Exeter. UK.

London Waste Regulation Authority. (1994). **The London Waste Regulation Authority's Clinical Waste Guidelines** (2nd ed.). London.

Michael, K., Burkhard, S. D., Thomas L. and Annette, J., C. (1998). Speciation of Cr in leachates of MSWI bottom ash landfill. **J. Environ. Sci. Technol.** 32 (10): 1398-1403.

Michael, L. G. (1995). **Infectious Waste Management: A practical Guide.** London: Lewis publishers.

Ministry of Public Health. (1995). **Handbook of Hazardous Health Care Management in 10-beds and 30-beds community hospitals.** Bangkok.

Ministry of Public Health. (1997). **Report on Solid Waste Impaction to the Environment.** Phuket: Thailand.

Ontiveros, J. L., Kosson, D. S. and Ablert, R. C. (1988).Leaching Characteristics and composition of Residual ashes from Various Municipal Incinerators. In Wu (ed). **International Conference on PhysicoChemical and Biological Detoxification of Hazardous Wastes** (pp 515-526). New Jersy: Technomic Publishing.

Prüss, A., Giroult, E. and Rushbrook, P. (1999). **Safe Management of Wastes from Health Care Activities.** Geneva: World Health Organization.

Peter, M. (1988). **New Study Shows Incinerator Ash More Dangerous Than We Realized** [On-line]. Available: http://www.rachel.org/bulletin/bulletin.cfm?Issue_ID=1053.

Rowat, S. C. (1994). **Incinerator Toxic Emission: A Brief Summary of Human Health Effects with A Note On Regulation Control** [On-line]. Available: http://www.rowatworks.com/Science/IncineeratorToxic/.

Show, K., Y., Tay, J., H. and Cheong, H., K., (2000). Use of incinerator ash. In R. K. Dhir, T. D. Dyer and K. A. Paine (eds.). **Reuse of Incinerator Ash-Current and Future Trends**(1st ed. pp. 468-478). London: Thomas Telford.

Sisomphon, K., Honguinikul, S., Nimityongkul, P., Tangtermsirikul, S. and Rachdawong, P. (1999). Uses of municipal of solid waste ash as construction material. **Proceeding of the 5th National Convention on Civil Engineering.** Bangkok: Thailand.

Sue-Huai, G. (2001). **A Feasibility Study of Incinerator Bottom Ash Regeneration as A Substitute Material for The Sub-Base of Road Construction** [Online]. Available: http://www.awma.org/ACE2001/techprogram/0-tech-left-abstract.asp?abstract_no=1038.

Thailand's Ministry of Industry. (2002). **Standard for Heavy Metals' Concentration in Leachate of Hazardous Waste (6th Notification Issued)** [Online]. Available: http://www.diw.go.th.

Thanachit, S. (1999). **A Study of Heavy Metals in Bottom Ash from Medical Waste Incinerators in Phuket**. M.S. thesis (ISBN 974-663-177-2), Mahidol University. Bangkok.

Thomas, A., Stipp, S. L. S. and Thomas, H. C. (2000). Immobilization of chromate from coal fly ash leachate using an attenuating barrier containing zero valent iron. **J. Environ. Sci. Technol.** 34(19): 4163-4168.

United States Environmental Protection Agency. (1995). Standards of performance for new stationary sources and emission guidelines for existing sources: medical waste incinerator; proposed rule. **Federal Register**. 60(30): 10677-10682.

United States Environmental Protection Agency. (2001a). **Medical Waste Regulation** [On-line]. Available: http://www.epa.gov/epaoswer/general/oriental/rom52.pdf.

United States Environmental Protection Agency. (2001b). **Test Methods for Evaluation Solid Waste, Physical/Chemical methods** [Online]. Available: http://www.epa.gov/sw-846/main.htm

Weast, R. C. (ed.). (1984). **CRC Handbook of Chemistry and Physics** (65th ed). Boca Raton: CRC Press.

Williams, P. T. (1994). Pollutants from incineration: An overview. In Hester, R.E. and Harrison, R.M. (eds.). **Waste Incineration and Environment** (pp. 27-52). London: The Royal Society of Chemistry.

Appendix A

Physical characteristics of bottom ash from medical waste incinerator in Ratchasima-Thonburi Hospital

Table A.1. Physical characteristics of bottom ash from medical waste incinerator in Ratchasima-Thonburi Hospital

Sampling day	Date & Time of incineration	Date & Time of sampling	Medical waste	Total ash	Moisture content	Size of particles				Loss
			(kg)	(kg)	(%)	>9.5 mm (%)	9.5-4.75 mm (%)	4.75-0.5 mm (%)	<0.5 mm (%)	(%)
1	25-Oct-01 08.07am.-13.00pm.	26-Oct-01 11.00 am.	140.00	33.0	4.86	60.42	10.70	21.51	6.92	0.45
2	02-Nov-01 8.15am.-13.50pm.	03-Nov-01 10.00 am.	190.00	26.4	1.85	43.57	15.46	28.69	12.24	0.04
3	16-Nov-01 8.30am.-12.20am.	17-Nov-01 09.30 am.	170.00	29.1	0.41	74.23	6.59	12.19	6.21	0.78
4	18-Nov-01 7.15am.-12.50am.	19-Nov-01 1.30 pm.	130.00	30.3	4.12	58.45	11.65	23.06	5.53	1.31
5	20-Nov-01 8.35am.-13.00pm.	21-Nov-01 10.00 am.	200.00	30.1	1.77	57.95	8.08	17.59	15.21	1.17
6	23-Nov-01 8.20am.-13.30pm.	24-Nov-01 10.00 am.	185.00	25.3	1.55	62.69	9.58	16.56	10.05	1.12
7	29-Nov-01 9.50am.-13-40pm.	30-Nov-01 11.30 am	190.00	25.5	1.65	58.34	12.44	20.17	7.45	1.60
8	03-Dec-01 8.40am.-12.30pm.	04-Dec-01 11.00 am.	150.00	22.0	1.32	57.36	11.44	19.24	10.32	1.64
9	06-Dec-01 9.30am.-12.45pm.	07-Dec-01 10.30am.	160.00	21.0	1.56	60.32	9.81	17.56	11.25	1.06
10	09-Dec-01 8.00am.-11.45am.	10-Dec-01 9.45am.	205.00	29.5	1.98	62.80	10.60	14.50	9.64	2.46

Table A.1. Physical characteristics of bottom ash from medical waste incinerator in Ratchasima-Thonburi Hospital

Sampling day	Date & Time of incineration	Date & Time of sampling	Medical waste (kg)	Total ash (kg)	Moisture content (%)	Size of particles				Loss (%)
						>9.5 mm (%)	9.5-4.75 mm (%)	4.75-0.5 mm (%)	<0.5 mm (%)	
11	12-Dec-01 9.00am.-12.30pm.	13-Dec-01 10.00am.	165.00	23.7	1.05	55.64	12.35	20.50	9.80	1.71
12	14-Dec-01 9.20am.-13.00pm.	15-Dec-01 10.20am.	187.00	25.6	1.25	58.95	10.54	18.56	10.45	1.50
13	17-Dec-01 8.40am.-12.30pm.	18-Dec-01 10.30am.	178.00	23.2	1.02	60.56	8.56	20.14	9.44	1.30
14	20-Dec-01 9.30am.-12.30pm.	21-Dec-01 11.20am.	145.00	16.4	1.88	54.12	11.21	19.58	12.36	2.69
15	24-Dec-01 9.00am.-12.00pm.	25-Dec-01 11.00am.	159.00	16.0	1.69	64.21	9.57	15.87	10.23	0.12
16	27-Dec-01 8.30am.-12.30am.	28-Dec-01 10.30am.	182.00	25.5	1.56	59.21	10.68	17.96	11.87	0.28
17	30-Dec-01 9.00am.-12.50pm.	31-Dec-01 10.00am.	175.00	22.3	1.58	53.58	12.36	18.14	14.23	1.69
18	03-Jan-02 8.20am.-13.30pm.	04-Jan-02 10.0am.	196.00	29.6	1.57	57.45	9.67	16.96	12.74	3.18
19	06-Jan-02 8.30am.-12.10pm.	07-Jan-02 11.00am.	193.00	29.3	1.69	56.65	10.58	18.59	12.87	1.31
20	09-Jan-02 9.30am.-13.40pm.	10-Jan-02 11.10am	168.00	15.6	1.19	62.35	8.47	18.64	9.69	0.85

Table A.1. Physical characteristics of bottom ash from medical waste incinerator in Ratchasima-Thonburi Hospital

Sampling day	Date & Time of incineration	Date & Time of sampling	Medical waste (kg)	Total ash (kg)	Moisture content (%)	Size of particles				Loss (%)
						>9.5 mm (%)	9.5-4.75 mm (%)	4.75-0.5 mm (%)	<0.5 mm (%)	
21	12-Jan-02 9.00am.-13.00pm.	13-Jan-02 10.00am.	161.00	15.1	1.35	57.44	11.26	19.37	10.23	1.70
22	15-Jan-02 8.20am.-13.40pm.	16-Jan-02 10.00am.	201.00	35.0	1.26	58.13	10.23	19.89	11.01	0.74
23	18-Jan-02 8.40am.-12.30pm.	19-Jan-02 11.00am.	196.00	30.2	1.59	60.20	9.68	18.69	10.36	1.07
24	20-Jan-02 9.00am.-13.00pm.	21-Jan-02 10.30am.	197.00	32.5	1.78	51.20	12.36	20.51	13.6	2.29
25	23-Jan-02 9.30am.-13.40pm.	24-Jan-02 11.00am.	185.00	29.5	1.76	55.30	10.50	17.50	15.6	1.10
26	26-Jan-02 8.50am.-12.50pm.	27-Jan-02 10.30am.	209.00	33.0	1.59	59.20	8.50	15.60	13.2	3.50
27	29-Jan-02 9.30am.-13.00pm.	30-Jan-02 10.00am.	230.00	36.0	1.22	62.10	10.50	16.90	7.8	2.70
28	01-Feb-02 8.00am.-11.45am.	02-Feb-02 10.30am.	170.00	29.0	1.98	52.67	15.10	20.72	9.96	1.55
29	05-Feb-02 9.00am.-12.30pm.	06-Feb-02 8.30am.	210.00	35.0	1.11	60.23	12.80	17.20	8.1	1.67
30	08-Feb-02 8.00am.-11.30am.	09-Feb-02 10.00am.	198.00	27.8	1.23	62.10	10.50	14.80	10.25	2.35

Table A.1. Physical characteristics of bottom ash from medical waste incinerator in Ratchasima-Thonburi Hospital

Sampling day	**Date & Time of incineration**	**Date & Time of sampling**	**Medical waste** (kg)	**Total ash** (kg)	**Moisture content** (%)	**Size of particles**				**Loss** (%)
						>9.5 mm (%)	9.5-4.75 mm (%)	4.75-0.5 mm (%)	<0.5 mm (%)	
31	12-Feb-02 8.30am.-11.45am.	13-Feb-02 10.00am.	170.00	25.6	1.75	52.30	14.80	18.30	12.7	1.90
32	15-Feb-02 8.10am.-12.20pm.	16-Feb-02 10.00am.	250.00	40.0	2.01	58.60	12.90	16.60	9.4	2.50
		Mean	182.66	27.13	1.69	58.39	10.92	18.50	10.65	1.54
		SD	25.47	6.14	0.81	5.06	2.00	2.89	2.45	0.85

Appendix B

The sixth notification issued by Thailand’s Ministry of Industry

Table B.1. The sixth notification issued by Thailand's Ministry of Industry for leachate substances by leachate extraction procedure

leachate substances	Concentration mg/L
Arsenic (Total)	5.0
Barium	100.0
Benzene	0.5
Cadmium (Total)	1.0
Carbon tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100.0
Chloroform	6.0
Chromium (Total)	5.0
Ortho-Cresol	200.0
Meta-Cresol	200.0
Para-Cresol	200.0
Cresol (Total)	200.0
2-4 D	10.0
1,4-Dichlorobenzene	7.5
1,2-Dichlorobenzene	0.5
1,1-Dichloroethylene	0.7
Endrin	0.02
Heptachlor and its epoxide	0.008
Hexachlorobenzene	0.13
Hexachlorobutadiene	0.5
Hexachloroethane	3.0
Lead (Total)	5.0
Lindane	0.4
Mercury (Total)	0.2
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitrobenzene	2.0
2,4-Nitoluene	0.13
Pentachlorophenol	100.0
Pyridine	5.0
Selenium	1.0
Silver	5.0
Tetrachloroethylene	0.7
Toxaphene	0.5
Trichloroethylene	0.5
2,4,5-Trichlorophenol	400.0
2,4,6-Trichlorophenol	2.0
2,4,5-TP (Silvex)	1.0
Vinyl chloride	0.2

Remark: Date of print on 13 November 1999 in Government Gazette

Appendix C

Statistical analysis of heavy metals' concentration in bottom ash and simulated bottom ash leachate (ANOVA method)

Table C.1. Statistic analysis of lead concentration in bottom ash

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	1260193.497	3	420064.499	20.512	.000
Within Groups	1945534.499	95	20479.311		
Total	3205727.996	98			

LSD

(I) Bottom ash particle size	(J)Bottom ash particle size	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-38.5883	40.8959	.348	-119.7770	42.6004
	0.5-4.75 mm	-127.6280	40.8959	.002	-208.8167	-46.4393
	<0.5 mm	-293.0938	40.8959	.000	-374.2825	-211.9051
4.75-9.5 mm	>9.5 mm	38.5883	40.8959	.348	-42.6004	119.7770
	0.5-4.75 mm	-89.0397	40.4765	.030	-169.3958	-8.6837
	<0.5 mm	-254.5054	40.4765	.000	-334.8614	-174.1495
0.5-4.75 mm	>9.5 mm	127.6280	40.8959	.002	46.4393	208.8167
	4.75-9.5 mm	89.0397	40.4765	.030	8.6837	169.3956
	<0.5 mm	-165.4658	40.4765	.000	-245.8217	-85.1098
<0.5 mm	>9.5 mm	293.0938	40.8959	.000	211.9051	374.2825
	4.75-9.5 mm	254.5054	40.4765	.000	174.1495	334.8614
	0.5-4.75 mm	165.4658	40.4765	.000	85.1098	245.8217

Table C.2. Statistic analysis of silver concentration in bottom ash

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	348369.195	3	116123.065	67.793	.000
Within Groups	162726.357	95	1712.909		
Total	511095.552	98			

LSD

(I) Bottom ash particle size	(J)Bottom ash particle size	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-35.6644	11.8274	.003	-59.1448	-12.1840
	0.5-4.75 mm	-159.2170	11.8274	.000	-182.6974	-135.7366
	<0.5 mm	-79.6904	11.8274	.003	-103.1707	-56.2100
4.75-9.5 mm	>9.5 mm	35.6644	11.8274	.003	12.1840	59.1148
	0.5-4.75 mm	-123.5526	11.7061	.000	-146.7922	-100.3131
	<0.5 mm	-44.0260	11.7061	.000	-67.2655	-20.7864
0.5-4.75 mm	>9.5 mm	159.2170	11.8274	.000	135.7366	182.6974
	4.75-9.5 mm	123.5526	11.7061	.000	100.3131	146.7922
	<0.5 mm	79.5266	11.7061	.000	56.2871	102.7662
<0.5 mm	>9.5 mm	79.6904	11.8274	.000	56.2100	103.1707
	4.75-9.5 mm	44.0260	11.7061	.000	20.7864	67.2655
	0.5-4.75 mm	-79.5266	11.7061	.000	-102.7662	-56.2871

Table C.3. Statistic analysis of iron concentration in bottom ash

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	488996148273	3	162998716091	97.748	.000
Within Groups	158417015614	95	1667547532.784		
Total	647413163888	98			

LSD

(I) Bottom ash particle size	(J)Bottom ash particle size	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-179888.83	11669.75	.000	-203056.21	-156721.44
	0.5-4.75 mm	-80342.20	11669.75	.000	-103509.59	-5714.82
	<0.5 mm	-18191.47	11669.75	.120	-41458.85	4875.92
4.75-9.5 mm	>9.5 mm	179888.83	11669.75	.000	156721.44	203056.21
	0.5-4.75 mm	99546.62	11550.06	.000	76616.86	1224776.38
	<0.5 mm	161597.36	11550.06	.000	138667.60	184527.12
0.5-4.75 mm	>9.5 mm	80342.20	11669.75	.000	57174.82	103509.59
	4.75-9.5 mm	-99546.62	11550.06	.000	-122476.38	-76616.86
	<0.5 mm	62050.74	11550.06	.000	39120.98	84980.50
<0.5 mm	>9.5 mm	18291.47	11669.75	.120	-4875.92	41458.85
	4.75-9.5 mm	-161597.36	11550.06	.000	-184527.12	-138667.60
	0.5-4.75 mm	-62050.74	11550.06	.000	-84980.50	-39120.98

Table C.4. Statistic analysis of zinc concentration in bottom ash

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	730562304.312	3	243520768.104	60.883	.000
Within Groups	379983886.443	95	3999830.384		
Total	1110546190.756	98			

LSD

(I) Bottom ash particle size	(J)Bottom ash particle size	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-2286.0566	571.5355	.000	-3420.6980	-1151.4152
	0.5-4.75 mm	-4549.3116	571.5355	.000	-5683.9530	-3414.6702
	<0.5 mm	-7362.1955	571.5355	.000	-8496.8369	-6227.5541
4.75-9.5 mm	>9.5 mm	2286.0566	571.5355	.000	1151.4152	3420.6980
	0.5-4.75 mm	-2263.2550	565.6734	.000	-3386.2587	-1140.2512
	<0.5 mm	-5076.1389	565.6734	.000	-6199.1426	-3953.1352
0.5-4.75 mm	>9.5 mm	4549.3116	571.5355	.000	3414.6702	5683.9530
	4.75-9.5 mm	2263.2550	565.6734	.000	1140.2512	3386.2587
	<0.5 mm	-2812.8839	565.6734	.000	-3935.8877	-1689.8802
<0.5 mm	>9.5 mm	7362.1955	571.5355	.000	6227.5541	8496.8369
	4.75-9.5 mm	5076.1389	565.6734	.000	3953.1352	6199.1426
	0.5-4.75 mm	2812.8839	565.6734	.000	1689.8802	3935.8877

Table C.5. Statistic analysis of lead concentration in simulated bottom ash leachate

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	34.538	3	11.513	34.493	.000
Within Groups	31.708	95	.334		
Total	66.247	98			

LSD

(I) Bottom ash particle size	(J)Bottom ash particle size	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-0.3209	0.1651	.055	-0.6486	6.903E-03
	0.5-4.75 mm	-0.7836	0.1651	.000	-1.1113	-0.4558
	<0.5 mm	-1.5733	0.1651	.000	-1.9011	-1.2455
4.75-9.5 mm	>9.5 mm	0.3209	0.1651	.055	-6.9028E-03	0.6486
	0.5-4.75 mm	-0.4627	0.1634	.006	-0.7871	-0.1383
	<0.5 mm	-0.2524	0.1634	.000	-1.5768	-0.9280
0.5-4.75 mm	>9.5 mm	0.7836	0.1651	.000	0.4558	1.1113
	4.75-9.5 mm	0.4627	0.1634	.006	0.1383	0.7871
	<0.5 mm	-0.7897	0.1634	.000	-1.1142	-0.4653
<0.5 mm	>9.5 mm	1.5733	0.1651	.000	1.2455	1.9011
	4.75-9.5 mm	1.2524	0.1534	.000	0.9280	1.5768
	0.5-4.75 mm	0.7897	0.1634	.000	0.4653	1.1142

Table C.6. Statistic analysis of silver concentration in simulated bottom ash leachate

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	27.162	3	9.054	18.753	.000
Within Groups	45.866	95	0.483		
Total	73.029	98			

LSD

(I) Bottom ash particle size	(J)Bottom ash particle size	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-0.3514	0.1986	.080	-0.7456	4.284E-02
	0.5-4.75 mm	-1.1913	0.1986	.000	-1.5855	-0.7971
	<0.5 mm	-1.2034	0.1986	.000	-1.5976	-0.8092
4.75-9.5 mm	>9.5 mm	0.3514	0.1986	.080	-4.2839E-02	0.7456
	0.5-4.75 mm	-0.8399	0.1965	.000	-1.2301	-0.4497
	<0.5 mm	-0.8520	0.1965	.000	-1.2422	-0.4618
0.5-4.75 mm	>9.5 mm	1.1913	0.1986	.000	0.7991	1.5855
	4.75-9.5 mm	0.8399	0.1965	.000	0.4497	1.2301
	<0.5 mm	-1.2112E-02	0.1965	.951	-0.4023	0.3781
<0.5 mm	>9.5 mm	1.2034	0.1986	.000	0.8092	1.5976
	4.75-9.5 mm	0.8520	0.1965	.000	0.4618	1.2422
	0.5-4.75 mm	1.211E-02	0.1965	.951	-0.3781	0.4023

Table C.7. Statistic analysis of iron concentration in simulated bottom ash leachate

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	173.627	3	57.876	25.927	.000
Within Groups	212.065	95	2.232		
Total	385.691	98			

LSD

(I) Bottom ash particle size	(J)Bottom ash particle size	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-0.5618	0.4270	.191	-1.4095	0.2858
	0.5-4.75 mm	-2.5419	0.4270	.000	-3.3895	-1.6942
	<0.5 mm	-3.1884	0.4270	.000	-4.0360	-2.3408
4.75-9.5 mm	>9.5 mm	0.5618	0.4270	.191	-0.2858	1.4095
	0.5-4.75 mm	-1.9800	0.4226	.000	-2.8190	-1.1411
	<0.5 mm	-2.6266	0.4226	.000	-3.4655	-1.7876
0.5-4.75 mm	>9.5 mm	2.5419	0.4240	.000	1.6942	3.3895
	4.75-9.5 mm	1.9800	0.4226	.000	1.1411	2.8190
	<0.5 mm	-0.6465	0.4226	.129	-1.4855	0.1924
<0.5 mm	>9.5 mm	3.1884	0.4270	.000	2.3408	4.0360
	4.75-9.5 mm	2.6266	0.4226	.000	1.776	3.4655
	0.5-4.75 mm	0.6465	0.4226	.129	-0.1924	1.4855

Table C.8. Statistic analysis of zinc concentration in simulated bottom ash leachate

Source	Sum of squares	df	Mean square	F	Sig.
Between Groups	161.675	3	53.892	35.094	.000
Within Groups	145.887	95	1.536		
Total	307.561	98			

LSD

		Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
(I) Bottom ash particle size	(J)Bottom ash particle size				Lower Bound	Upper Bound
> 9.5 mm	4.75-9.5 mm	-1.8236	0.3541	.000	-2.5267	-1.1206
	0.5-4.75 mm	-2.8601	0.3541	.000	-3.5632	-2.1571
	<0.5 mm	-3.3639	0.3541	.000	-4.0669	-2.6608
4.75-9.5 mm	>9.5 mm	1.8236	0.3541	.000	1.1206	2.5267
	0.5-4.75 mm	-1.0365	0.3505	.004	-1.7323	-0.3407
	<0.5 mm	-1.5402	0.3505	.000	-2.2361	-0.8444
0.5-4.75 mm	>9.5 mm	2.8601	0.3541	.000	2.1571	3.5632
	4.75-9.5 mm	1.0365	0.3505	.004	0.3407	1.7323
	<0.5 mm	-0.5037	0.3505	.154	-1.1996	0.1921
<0.5 mm	>9.5 mm	3.3639	0.3541	.000	2.6608	4.0669
	4.75-9.5 mm	1.5402	0.3505	.000	0.8444	2.2361
	0.5-4.75 mm	0.5037	0.3505	.154	-0.1921	1.1996

Appendix D

Number of pattients in Ratchasima-Thonburi Hospital

Table D.1. Number of patients in Ratchasima-Thonburi Hospital

Month/Year	In patients (capita)	Out patients (capita)	Total (capita)	No. of patient per day
October, 2001	2,362	17,459	19,821	639
November, 2001	2,408	16,745	19,153	638
December, 2001	2,507	17,069	19,576	631
January, 2002	2,634	18,744	21,376	701
February, 2002	2,513	16,519	19,032	680
Average	2,485	17,307	19,684	658
SD	105.51	877.71	967.47	30.91

Biography

Miss Patcharin Racho was born in 28th October 1974. Her domicile is Roi-Ed. She studied in the secondary school at Satreesuksa Roi-Ed School, Roi-Ed. Her high school was Roi-Ed Wittayalai School. When she finished the high school she was going to study in bachelor degree at Suranaree University of Technology in 1993. She graduated the Environmental Engineering Program from Suranaree University of Technology in 1998. After that, she interested to lean more about environmental section and was going to study in Master of Environmental Engineering at Suranaree University of Technology in 1999.