COMPARATIVE EFFICIENCY OF TWO AND THREE CHAMBERED INCINERATORS FOR HOSPITAL WASTE MANAGEMENT

BY

Ihtesham Ul Haq

00000171734

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In

Environmental Science

Institute of Environmental Sciences and Engineering (IESE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

Islamabad, Pakistan

(2019)

It is certified that the contents and forms of thesis entitled

COMPARATIVE EFFICIENCY OF TWO AND THREE CHAMBERED INCINERATORS FOR HOSPITAL WASTE MANAGEMENT

Submitted by

Ihtesham Ul Haq

Has been found satisfactory for the requirements of degree of Master of Science in Environmental Science

Supervisor: ______________________
Dr. Muhammad Anwar Baig
Professor
IESE, SCEE, NUST

Member: ______________________
Dr. Yousuf Jamal
Assistant Professor
IESE, SCEE, NUST

Member: ____________________
Dr. Zeshan
Assistant Professor
IESE, SCEE, NUST

Annex A To NUST Letter No 0972/102/Exams/Thesis-Cert Dated___ May 2019

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Mr. Ihtesham Ul Haq, (Registration No. 00000171734) of **IESE (SCEE)** has been vetted by undersigned, found complete in all respects as per NUST Statutes/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ______________________________________
Name of Supervisor:_______________________________
Date:____

Signature (HOD): ________________________________
Date:____

Signature (Dean/Principal):________________________
Date:____

This thesis is dedicated to my dear Father& Mother

You are the main reason for being what I am

ACKNOWLEDGEMENTS

I am thankful to Allah Almighty for his blessings which made it possible for me to complete this MS work.

First and foremost, I would like to express my sincere gratitude to my thesis supervisor ***Professor Dr. Muhammad Anwar Baig (IESE)*** *for his continuous support throughout my thesis at IESE, for his patience, motivation, enthusiasm and immense knowledge. His guidance helped me through my research and writing of this thesis. I could not have imagined having a better advisor and mentor for my MS research work. I am also very thankful to* ***Dr. Yousuf Jamal (IESE)*** *and* ***Dr. Zeshan (IESE)*** *for their guidance and continuous support.*

I would like to acknowledge and thank my school (SCEE) for allowing me to conduct my research and providing any assistance requested. Special thanks go to ***Ihsan ul Haq*** *(Deputy DG PMO) and* ***Dr. Ayaz Qureshi*** *(Senior Director PMO) and* ***Mr. Irshad Ramay*** *(NCPC) for providing me with necessary logistics and guidance.*

I would also like to thank my parents for their wise counsel and sympathetic ear. They were always there for me. Finally, I am thankful to my friends. We were able to support each other by deliberating over our problems and findings, and also happy by talking about things other than just our research.

Ihtesham Ul Haq

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF Tables

LIST OF ABBREVIATIONS

APCDs	Air Pollution Control Devices
BMW	Biomedical Waste
CO	Carbon Monoxide
EPA	Environment Protection Agency
HCWM	Health Care Waste Management
HWM	Hospital Waste Management
MW	Medical Waste
NOx	Nitrogen Oxides
NRC	National Research Center
OT	Operation Theatre
PEPA	Pakistan Environmental Protection Act
PPE	Personal Protective Equipment
SO2	Sulphur Dioxide
WHO	World Health Organization
WMO	Waste Management Officer

ABSTRACT

Hospitals are established and operated for providing healthcare services to physically and mentally unhealthy human beings. Such facilities, therefore, generate more amount of waste than normal domestic waste. Environmental regulations promulgated in Pakistan during 2005, make it a binding on concerned authorities for proper management & disposal of hospital waste. Hospital Waste Management (HWM) is core to the function of a healthy society but unfortunately, the disposal of hospital waste in the developing countries like Pakistan is inappropriate and prone to sickening the environment and community rather than curing. The objective of this study was to compare the efficiency of two different types of incinerators installed at site A & B in order to fulfil the requirements of waste management rules. Incinerator A operates in the temperature ranges < 800^{o}C while incinerator B operates in the ranges of 600 to 1200^{o}C. Working capacity of these Incinerators is 45 kg/hr and 150 kg/hr respectively. To compare working efficiency, segregated waste types (plastics, mix waste and pathological waste) were incinerated alone and in combination at different temperatures to observe gas emissions and ash content along with its composition using XRF. The flue gases produced were analysed through flue gas analyzer Model Testo S-350 at the designated emission points. Emissions observed during incineration showed that incinerator "A" produced more CO emissions (4050 mg/m^3) than incinerator "B" (762 mg/m^3) in case of Pathological waste, whereas NOx and SO_2 remained within NEQs limits in both cases. Ash analysis showed its pH of basic in nature due to higher Calcium Oxide (CaO) concentration which was further confirmed in both cases using XRF. Moreover; quantity of ash produced after incineration was 11% and 4% for incinerator A & B, respectively which confirms that three chambered setup is suitable for meeting the HWM rules in the country.

Chapter 1

INTRODUCTION

Hospital waste management is a technique that helps in the management of waste produced by hospitals, further results in checking and controlling the spread of diseases (Rasheed et al., 2005). Waste produced from health care facilities is a unique kind although in small quantities but conveying a high capability of contamination and injury (Akter, 2000). This waste alludes to all waste, biologic/non-biologic waste that is disposed of and not expected for further use. Medical waste is a subdivision of hospital waste; it denotes the material produced because of diagnosis, treatment or vaccination of patients and pharmaceutical waste related to biomedical research (Rutala and Mayhall, 1992). Hospital waste can be further classified as per density, weight and constituents. World Health Organization(WHO) has classified medical waste into various categories; infectious, sharps, pathological, pharmaceutical and radioactive (Marinković et al., 2008). Besides, there are few categories of infectious waste like animal carcasses, human body parts and tissues, syringes, blades, drugs, vomits, urine, saws, chemicals and liquid from labs (Prüss-Üstün, 1999).

As per the US Medical Waste Tracking Act, medical waste can be additionally classified into seven categories, including pathological wastes, animal wastes, cultures and stocks, human blood and blood products, isolation wastes, sharps, and unused syringes (Lee et al., 2002).

1.1 Composition of Hospital Waste

Hospital waste is generally classified as risk and non-risk waste. The risk waste includes pathological and infectious material, sharps and chemical wastes (Al-Khatib and Sato, 2009). According to World Health Policy report (Organization, 2006) the infectious waste includes 15-25% of total health care waste among which are body part waste (1%), chemical or pharmaceutical waste (3%), sharp waste (1%), and radioactive and cytotoxic or broken thermometer(less than 1%) are notable. Hospitals solid waste contains disposable syringes (0.3-0.5%), plastics (7-10%), bandages, linen and other infectious waste (30-35%), glass (3-5%) and other general wastes including food (40–45%) (El-Salam, 2010).

Table 1.1. Hospital Waste Composition in Calcutta Hospital, India

Composition of Hospital Waste in Calcutta		
Ingredients	**Average (% by wet weight)**	**SD**
Bandage, cotton clothes etc	36.10	8.27
Plastic, PVC, and Rubber	6.86	1.97
Paper	7.65	3.27
Disposable Syringe	0.43	0.31
Food Waste	39.85	8.14
Glass	4.56	2.41
Inert	4.55	1.79

Source: Patil and Shekdar, 2001

But the hazardous waste out of this is 10-15% and while rest of the waste composition is non-risk and dominated by Food waste.

1.2 Importance of Hospital Waste Management

Despite the fact that waste management is a moderately new phenomenon, it has grabbed the eye of governments all over the world. Today waste management term covers waste collection, sorting of waste, waste processing, recycling and reusing materials from waste that would otherwise be considered as useless. The medical waste management is an important issue that is amplified by lack of awareness, training, and financial capitals to support solutions. The waste collection and disposal is also known to be a grave problem as it can directly impact the health risks to both public and environment. (Abdulla et al., 2008). The concern of public has been aroused about the collection, storage, treatment, transportation and disposal of infectious waste. In developing nations, hospital waste generally winds up on street sides and empty plots. Untreated waste bears an economic expense for inhabitants of the region and is likewise a natural peril. In such countries, management of hospital waste poses yet a bigger challenge. Nowadays, disposal of medical waste posed even more difficulties due to syringes, appearance of disposable needles and other similar items (Hossain et al., 2011). Various disposal and treatment methods have been proposed in recent years to decrease the negative impact of medical wastes. For the suitable medical waste disposal, information on the quantity and the characteristics of the waste is necessary (Uysal and Tinmaz, 2004).

1.3 Hospital Waste Disposal

The management of hospital waste is a herculean task in many countries. A study conducted by (Almuneef and Memish, 2003) on effective medical waste management showed that the effective waste management can save money and protect the environment by reducing the health risk. In every country, healthcare waste disposal depends on many factors like available resources, sensitization level of the health managers as well as other professionals and existing local legislations (Organization, 2002). In Pakistan, despite the presence of Pakistan Biosafety Rules 2005, neither proper hospital waste management systems have been created in various health sectors nor are the relevant health professionals and managers aware of the situation resulting therein (Kumar et al., 2010). The entire amount of the waste produced by the health facilities is normally disposed with the municipal waste or burned openly into the environment raising environmental concerns. Waste storage before disposal is usually open and the element of waste segregation for various sections is almost non-existent. Moreover, the reuse of syringes, blades etc. enhances the risk of disease transmission (Arshad et al., 2011).

1.4 Hospital Waste Management in Pakistan

Pakistan is a developing country and risks become exponential if not properly taken care of. Rules in this regard have been devised in 2005.

1.4.1 Hospital waste management rules 2005

Hospital waste management rules 2005, were notified vide S.R.O 1013(1)/2005 on 3rd, August 2005 (Kumar et al., 2010). According to these rules, each hospital is responsible for the safe and proper disposal of waste produced by it. Under the rules every healthcare facility requires to constitute a waste management team, make and implement a waste management plan. The guidelines for waste segregation, collection, transportation, storage and disposal are also available in the Hospital Waste Management Rules 2005.

1.4.2 Health facilities in Pakistan

According to recent study conducted by (Khalid and Abbasi, 2018) the total number of registered hospitals and allied facilities in Pakistan in year 2015 are shown in the Table below.

Table 1.2. Total avaiable health facilities in Pakistan

Sr. No.	Title	Numbers
1.	**Hospitals**	**1167**
2.	**Dispensaries**	**5695**
3.	**BHUs sub health centres**	**5464**
4.	**Maternity and child health centres**	**733**
5.	**Rural health centres**	**675**
6.	**TB centres**	**339**
7.	**Total number of beds**	**118869**
8.	**Population per bed**	**161**

A careful estimation shows population growth of 250 million by 2025 in Pakistan. This will eventually result in increase of generation of hospital waste. This increase in hospital waste generation alongside higher population growth rate will add to the complexities regarding its management. Furthermore, greater hospital waste generation may result in casual dumping of hospital waste along with municipal solid waste (Bdour et al., 2007).

Moreover, it has been found out to be the leading cause of various problems like air pollution and water pollution that poses health dangers for the people of Pakistan. Under the aforementioned circumstances, the country desperately needs an effective healthcare waste management system. In order to cater for this problem, HWM Rules were notified in 2005. It is hoped that these rules will serve to resolve all the problems that are awaiting our attention due to mismanagement of hospital waste (Ali et al., 2016).

1.5 Options Available for Management of Hospital Waste

Generally, there is not a single plausible solution for hospital waste disposal, so in most cases, following waste disposal practices have been applied for management of hospital waste:

1. Landfilling
2. Incineration
3. Autoclaving
4. Shredding/Microwaving/Steam sterilization

Each practice has its own advantages and disadvantages as explained below (Nemathaga et al., 2008).

1.6 Advantages of Incineration

Under proper conditions, incineration provides a number of benefits: It greatly reduces the volume of waste that must go to disposal in landfills, a vitally important objective. In conventional municipal incinerators, the volume reduction ranges from 80% to 95%. It can be used in combination with landfill mining to reclaim closed landfills and greatly extend the operating lifetimes of existing landfills. The ash generated is relatively homogeneous and thus more suitable than raw waste for treatment such as solidification in concrete. A comparatively large proportion of the organic compounds, including putrescible and hazardous wastes, is destroyed; thus, there is a net decrease in the quantity of toxics (Tammemagi, 1999). Energy can be generated as a useful byproduct, that preserves oil, coal and natural gas nonrenewable fuels. By burning the waste fewer air pollutants are produced as compared to burning coal or oil. Since about the mid-1980s, the use of incineration for burning has been increasing in the United States and currently the country burns about 16% of its municipal wastes (Pirkle et al., 1996). This figure is significantly lower in Canada—about 4%—but it can be much higher overseas. For example, Japan, which faced its waste disposal crisis in the 1950s, 20 years before the crisis reached North America, which incinerates approximately 34% of its municipal garbage (Hershkowitz and Salerni, 1987). Most Japanese incinerators generate electricity. In Sweden, the waste used as a resource, not something to be wasted by landfilling; approximately 41% of its waste is incinerated in 21 waste-to-energy incinerators, with almost all the energy being delivered to district heating systems (Persson and Werner, 2012). This energy corresponds to 4.5 terawatt-hours, or 15% of the total district heating requirements in Sweden. There are more than 400 waste incinerators in the world.

The major drawback of waste incineration is that the burning releases contaminants into the air, violating the principle of protecting health and environment. Thus, if incineration is to be used, it must incorporate rigorous emission controls. There is considerable opposition by the public to the use of waste incinerators, at least partly because older incinerators certainly caused air pollution. Modern waste-to energy plants have largely overcome this deficiency by including improved combustion processes, better pollution control technology, and the production of a useful product, energy (Tammemagi, 1999).

1.7 Present Study

In this study, primarily hospital waste data from various hospitals was collected and waste was segregated at site A and B before incineration. Different tests were conducted before, during and after incineration at selected sites.

1.8 Aims and Objectives

Following were the objectives of the study

(a) Comparative analysis of flue gas emissions (NOx, SO_2 and CO)

(b) Comparative analysis (qualitative and quantitative) of residual ash

(c) Recommendation based on analysis

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Biomedical or hospital waste includes any liquid and solid wastes produced during the treatment, diagnosis and immunization of human and animal in research. Basically, health care wastes refer to all wastes produced which are discarded and not intended for any further use in hospitals (Asante et al., 2014). Other than health care, the relevant activities include research involving animals, animal farms, clinical research, dead animals, and others. Biomedical waste generation is not limited to specific activity or organizations. Waste can generate from homes and medical facilities during dialysis and while using insulin injections, animal health activities in rural areas, butchering of sick animals in butcher houses, use of sanitary napkins and ear buds, use of diapers, and air ports when passengers throw away restricted medicines without prescription (Thomas-Hope, 1998).

Different types of synonyms for the medical waste are available and they are currently used interchangeably in different scientific journals and in different parts of the world. According to (Moritz, 1995) some of the easily come across synonyms are biomedical waste (BMW), hospital waste and clinical waste. For the medical waste WHO uses the term “healthcare waste” in reports and other official publications.

WHO (2005) considered the BMW is a byproduct of hospitals waste consisting of pharmaceutical products, chemicals, sharps, non-sharps, blood, body parts, medical devices and radioactive materials (Aseweh Abor and Bouwer, 2008). In general hospital waste is broadly grouped into infectious waste and non-infectious waste (Klangsin and

Harding, 1998). Medical wastes also includes a larger part of hazardous wastes (Jang et al., 2006). The production or generation of these wastes is an continuing phenomenon as long as human civilization persists (Mato and Kaseva, 1999). Biomedical wastes are considered a special case of care where hazards and risks are not just limited to the health of generators and operators of hospitals but also the health of other people.

2.2 Guiding Principles for Hospital Waste

Five principles are mostly used as underlying the active and controlled management of wastes (Williams, 2005). While developing of policies, legislation and guidance many countries used these principles:

1. Polluter pays principal

   The polluter pays principle suggests that the person or institute who generate waste is legally and financially responsible for the safe and environmentally friendly disposal of the waste they generate. This principle also efforts to assign charges to the party that causes damage (Tudor et al., 2005).

2. Precautionary principle

   It is an influential principle leading health and safety protection. Under the Rio Declaration on Environment and Development (UNEP, 1972) this principle was defined and adopted as Principle 15: "If there are serious or irreversible damage threats to the environment, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (Cameron, 1994).

3. Duty of care principle

   The duty of care principle specifies that any person managing or handling hazardous materials or wastes or something related is properly responsible for using the utmost care in that task. This principle is best completed when all the parties involved from hazardous waste (including health care waste) production to final disposal are registered and licensed to handle the waste (Chartier, 2014).

4. Proximity principle

   This principle recommends that hazardous waste treatment and disposal take place to the nearest possible location of waste generation to minimize the risks involved in its transportation. Likewise, every waste generator should be encouraged for waste recycling or disposing, inside its own territorial limits, unless it is unsafe to do so (Williams, 2005).

5. Prior informed consent principle

   In this principle various international treaties are designed to protect the health of public and the environment from infectious waste. It is necessary that affected peoples and other shareholders be explained of the hazards and risks, and that their consent be obtained. For the healthcare or hospital waste, this principle could apply on the transportation of waste and the siting and operation of waste treatment and disposal facilities (Prüss et al., 2014).

2.3 Historical Perspective

In 1983, Regional office of World Health Organization for Europe organized a meeting of concerned personal at Bergen, Norway, in which this issue was discussed for the first time.

The importance of inappropriate BMW management was carried to the attention during the "beach wash-ups" during summer **1988**, which was examined by the US EPA, and it concluded in the passing of Medical Waste Tracking Act (MWTA) Nov. 1988 (Yadav, 2001). Until recently, medical waste management was not usually considered an issue. In the 1980s and 1990s, concerns about exposure to hepatitis B virus (HBV) and human immunodeficiency virus (HIV) led to questions about potential risks inherent in medical waste. So the hospital waste generation has become a prime concern due to its multidimensional consequences as a risk factor to the hospital staff , health of patients and extending beyond the limits of the medical establishment to the over-all population (Arshad et al., 2011).

2.4 Hospital Waste Generation

health care teaching institutes, research institutions, hospitals, laboratories, clinics, blood banks, veterinary institutes and animal houses are the places where biomedical waste (BMW) is generated (Sharma, 2002). The amount of BMW generated will vary reliant on the hospital rules and practices and the type of care being provided. From 1-5 kg/bed/day is the waste generated according to the data available from developed countries, with substantial inter country and inter specialty differences. According to the meagre data from developing countries indicates that the range is lower i.e. 1-2 kg/day/patient (Mohammed et al., 2017). In Pakistan, about 4 to 2,000 kg of waste is generated daily by different health outlets; of which 75-90% is a non-risk waste produced by the administrative functions, housekeeping, and health care premises while only 10 to 25% is infectious waste and that needs more careful disposal (Arshad et al., 2011). Research studies in Pakistan show that almost 2 kg of waste/bed/day is generated out of which 0.1-0.5 kg/bed/day can be considered as risk waste (Ali et al., 2015). In Pakistan, 1.06 kg/bed/day hospital waste is generated leading to a total of 250,000 tons/year waste generation. Karachi is the hotspot with hospital waste generation rate of 100 tons/day (Organization, 1999).

Because of the variability in BMW definitions, a rather extensive range of medical waste generation rates have been reported in the literature. Occasionally, it is not clear whether non-hazardous waste (household type) are included in the total medical waste generation rates that are reported. E.g. In Jordan, (Bdour et al., 2007) measured BMW generation rates ranged 1.9-3.5 kg/bed/day; on the other side, for Jordan too (Abdulla et al., 2008) reported, an average bio medical waste production rate equal to 0.61 kg/bed/day. (Mato and Kassenga, 1997) have reported a BMW production rate range 0.84-5.8 kg/bed/day from 6 hospitals in Tanzania. The hazardous medical waste production rates of four big hospitals in Korea were found to vary 0.14-0.49 kg/bed/day (Jang et al., 2006). In Egypt (El-Salam, 2010), measured the production of BMW from eight different hospitals that belonged to different categories ranged 0.24-2.1 kg/bed/day. (Birpınar et al., 2009) measured 0.65 kg/bed/day, based from the analysis of 192 hospitals in Istanbul, Turkey. Same in Turkey (Eker and Bilgili, 2011) reported BMW production rates equal to 2.11±3.83 kg/bed/day. According to (Patwary et al., 2009), the average BMW production rate in Bangladesh was around 0.26 kg/bed/day, while the quantity of hazardous BMW were obviously affected by the size and type of health care facilities. (Taghipour and Mosaferi, 2009) stated that the hazardous BMW production rates in Iran ranged 0.4-1.91 kg/bed/day.

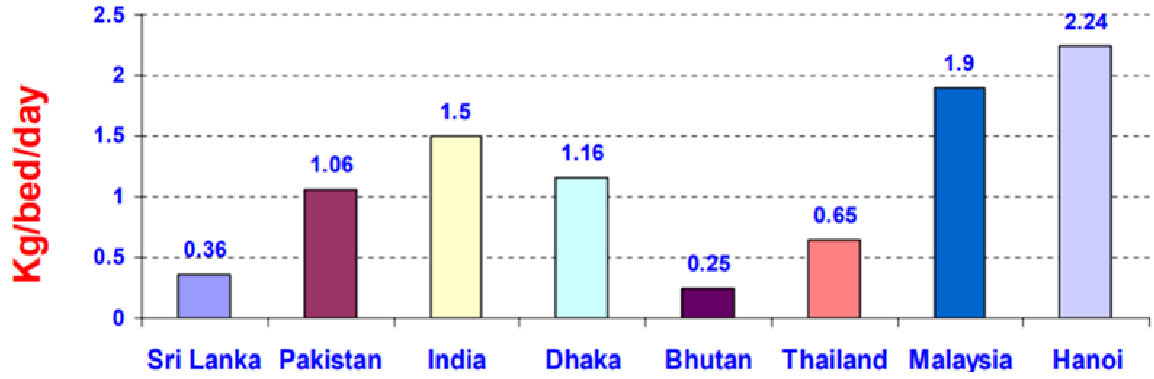


Figure 2.1. Medical Waste Generation in Asia (Visvanathan, 2006)

2.5 International Agreements and Conventions for Biomedical Waste

For the waste management of health care facilities, environment protection and sustainable development the following international conventions and agreements are available.

2.5.1 The Basel Convention

The Basel Convention is for the Control of Trans-Boundary Movements of Hazardous Wastes and their Disposal. This is the most detailed global environmental agreement on hazardous wastes. 170 countries are the members of Basel Convention and it aims to protect the health of human and the environment against the adverse effects resulting from the production, management, transboundary movements and disposal of hazardous wastes. Convention obliges its members to ensure that hazardous wastes should be managed and disposed in an environmentally friendly manner.

Basel Convention specifically refers as:

Clinical wastes from hospitals, medical centers and clinics-Y1

Pharmaceutical, drugs and medical waste-Y2

Basel convention also has a category of hazardous characteristics defined as "H 6.2-Infectious substances: the substances or wastes consisting of viable microorganisms or toxins that are known or suspected to damage humans and animals life." The convention secretariat has prepared the detailed document in addition; that is the Technical guidelines on the environmentally sound management of biomedical and health care wastes (Y1; Y3) (Pinderhughes, 2004).

2.5.2 The Stockholm Convention

This convention is for Persistent Organic Pollutants (POPs). It is a global treaty to protect health of human and the environment from POPs. These chemicals are produced and emitted to the environment by incineration of BMW. Countries must choose the best available techniques and promote best environmental practices for incineration of BMW within 4 years after the convention comes into force for the country (Buccini, 2003).

2.5.3 Aarhus Convention for Europe

This convention is based on "Access to Information and Justice in Environmental Matters and Participation of Public in Decision Making". Aarhus Convention was adopted at the "Fourth Ministerial Conference" in the 'Environment for Europe' on 25 June 1998 in Aarhus, Denmark. It was a new kind of agreement, linking the rights of human beings and environment. The convention acknowledges that we owe a responsibility of future generations (Steele, 2001).

2.6 Medical Waste Tracking Act (MWTA) 1988

In the United States hospital waste is highly regulated by the proper legislation of Medical Waste Tracking Act (MWTA) of 1988. This act was passed by the Congress as an amendment to the act of Solid Waste Disposal, which was on how to safely dispose of large quantity of industrial and municipal solid wastes (EPA, 2013), itself written in 1965. MWTA took attention in later 1980s, when the large volume of improperly disposed of medical waste were already found on beaches, creating public outrage (Wagner and Arnold, 2008). This act came into effect on June 24, 1989, and has been the basis for medical waste classification, handling, transportation, treatment and disposal in the US ever since (Lichtveld et al., 1992).

The MWTA established (Windfeld and Brooks, 2015):

- Medical waste definition
- Criteria on which determination of medical wastes would be subject to regulate
- Tracking system utilizing a generator-initiated tracking form segregation, packaging, labeling, and storage of the waste

For the waste collection, transportation and disposal MTWA also required US EPA to survey different treatment techniques available at the time for the reduction of disease caused by the medical waste (Windfeld and Brooks, 2015). Techniques that examined by EPA in 1990 included microwave units, autoclaves, incinerators and various chemical and mechanical systems (Windfeld and Brooks, 2015). The EPA continues to conduct research on improving infectious medical waste treatment methods.

2.7 Pakistan Environmental Protection Agency (PEPA) 1997

On 6 December 1997, Pakistan Environmental Protection Act (PEPA) was enacted, repealing the Pakistan Environmental Protection Ordinance, 1983. The PEPA’ 1997 provides the establishment of Provincial Sustainable development Funds, conservation of renewable resources, framework for implementation of NCS, Protection and conservation of species, establishment of Environmental Tribunals and appointment of Environmental Magistrates, Initial Environmental Examination (IEE), and Environmental Impact Assessment (EIA).

2.8 Hospital Waste Management (HWM) Rules 2005

In workout of the powers conferred under section 31 of the PEPA, 1997 (XXXIV), the Federal administration is pleased to make the rules for hospital waste management. These rules are approved in order to make HWM according to standard practices.

2.8.1 Delegation of ministry of environment to provincial governments

Through the 18th Amendment, some 44 subjects, including environmental pollution and ecology, became the sole legislative domain of the Provincial Governments.

2.9 Hospital Waste Management Rules 2014 (Punjab, Sindh)

As per the section 36 of the Sindh Environmental Protection Act, 2014 (VIII), the Environmental Protection Agency (EPA) with the approval of the Government of Sindh, is pleased to make the rules for the Sindh Hospital Waste Management, 2014. These rules are for the proper management of hospital waste and come into force at once.

As per the section 31 of the Punjab Environmental Protection Act, 1997 (XXXIV), the Governor of Punjab is pleased to make the rules Punjab Hospital Waste Management, 2014. These rules are accepted in order to manage hospital waste according to standard practices and come into force at once.

2.10 Handling of the Clinical Solid Waste

Unless hospital or clinical waste is properly disposed and handled, it can present risks to public, environment and healthcare staff (Al-Khatib and Sato, 2009). A lot of studies have been done in different countries to define the best appropriate management plan for clinical waste in order to minimize the health hazards (Alagöz and Kocasoy, 2008). Therefore, for handling disposal of hospital waste many developed countries have planned codes of guidelines and practices (Bdour et al., 2007). Further modification is still required for significant progress in all aspect of hospital or biomedical waste management practices. Though, in most developing countries, BMW has not got adequate attention despite the fact that it was labeled as hazardous or infectious waste (Alagöz and Kocasoy, 2008).

Due to enormous quantity of generation, serious threat as well as high disposal cost (Alagöz and Kocasoy, 2008), the management of hazardous solid waste is still considered as problematic.

2.11 Disposal and Management Technologies

2.11.1 Landfill

It is an easy and low cost method for disposal of waste. If a landfill is not properly managed, it increases the health risk of human and increased environmental pollution (But et al., 2008). Therefore, it is considered as an unsophisticated method, that requires careful separation of waste so that it does not pose high health effects on public and environment (Visvanathan, 1996). Landfills are operated as an open dump in the developing countries. The hospital waste dumped in the landfill mixed with other wastes, and later burned (Nemathaga et al., 2008). Waste dumped into landfill produces waste products during the waste degradation process in three phases. These are solid (degraded waste), liquid (leachate), and gas (referred as landfill gas) (But et al., 2008). Further, these three products may pollute air, water and land. Therefore, landfill disposal is not an ideal safe option for treatment of hospital waste (Narayana, 2009).

2.11.2 Autoclaving

Autoclaves used as the sterilization of different kinds of hospital waste (Salkin, 2003). Autoclaves are mostly used for the treatment of blades, syringes and contaminated items with blood, remains from surgery and from isolation wards, linen, gauze, gowns, bandages, and other similar materials. The temperature range of 50-250°C in autoclaves, but the optimum temperature for the autoclaves are 160°C to kill bacteria.

This technology is considered as an alternative technology of the incinerator for hospital waste management, but it is more costly method as compared to incineration (Al-Khatib and Sato, 2009). This is because of, autoclaving treatment of hospital waste require another treatment method for the final disposal of water (Jang et al., 2006). Furthermore, it can’t handle large volume of hazardous hospital waste. Autoclave also cannot treat wastes from volatile and semi-volatile organic compounds, mercury, chemotherapy treatment, and radioactive wastes (Lee et al., 2004). Large body parts, animal remains and other large items are also not possible to treat in autoclaves (Prüss-Üstün, 1999).

2.11.3 Microwaves

In microwaves there are electromagnetic waves having frequency between radio and infrared waves. For the treatment of waste in microwaves, in order to create the thermal process, it is important that the waste is wet, either by the naturally occurring moisture or by the addition of some steam. For the formation of steam some treatment processes utilise microwaves to heat water, which is then applied to the hospital waste stream. Low frequency radio waves are applied in some systems to inactivate microorganisms contained within the waste. The microwaves start heating the waste from the inside of the materials to their external surfaces.

Though, this method for waste treatment might be economically not feasible compared to the incinerator (Lee et al., 2004). Nevertheless, this technology is also not suitable for the treatment of large quantities. For the developing countries the treatment cost is also expensive and is not affordable. It is also reported in the literature that microwaving of hospital waste refers inadequate microorganism sterilization capability (Cha and Carlisle, 2001).

2.11.4 Incineration

It is a high temperature dry oxidation process in which the organic and combustible waste reduce to inorganic, incombustible matter. Incineration also reduces the significant volume and weight of waste. In incineration high heat thermal treatment processes take place at temperatures about 200°C to more than 1000°C. Chemical and physical breakdown of the organics take place by the processes of combustion, pyrolysis or gasification. Release of combustion byproducts into the atmosphere and production of ash is a disadvantage of these technologies (Supply and Programme, 2014).

2.12 Determination of Suitable Method

Safe disposal of hazardous waste is still a problem. According to the WHO guidelines "currently, there are practically no low cost, environmental friendly options available for the safe disposal of hazardous wastes" (Birchard, 2002). In the US, studies have found that almost 49 to 60% of medical waste is incinerated, 20 to 37% of the waste is autoclaved, and 4 to 5% of the waste is treated by other technologies (Zhao et al., 2009).

It seems that the existing infectious waste management options are not able to preserve human health and environment from infection and deterioration. The transmission of the viruses such as enteric, respiratory, and pathogenic infections through improper hospital waste treatment is not well described in the literature. Studies showed that if the incineration of waste is properly handled, it would be the best treatment method to treat and manage hospital solid waste. Harmful pollutants produced due to inappropriate incineration of hospital waste is still fearful and that's why requires proper handling (Jang et al., 2006).

2.13 Types of Incinerators

There are three major types of incinerators available; Controlled air incinerator, Excess air incinerator, and Rotary kiln incinerator. Of all these three, Controlled air or Starved-air is the most widely used.

2.13.1 Controlled air incinerator

Controlled air incinerator is also known as two-stage incineration, starved air incineration, or modular combustion. Combustion of waste in this type of incinerators occurs in two processes. In the first process, waste is fed into the combustion chamber, which is operated with less than the stoichiometric amount of air required for combustion. In the second process, excess air is supplied to the volatile gases formed in the first process to complete combustion.

2.13.2 Excess air incinerator

It is typically a small modular unit. That are also stated as batch incinerators, multiple chamber incinerators, or "retort" incinerators. It is typically a compact cube with a large number of internal chambers and baffles. They are usually operated in a batch mode.

2.13.3 Rotary-kiln incinerator

As the other incinerators rotary kiln incinerators are designed with primary chamber and secondary chamber, in a primary chamber waste is heated and volatilized, and in a secondary chamber combustion of the volatile fraction is completed (EPA, 1998).

2.14 Advantages and Disadvantages of Incinerators

Some of the benefits of the controlled air system include high thermal efficiency as a result of lower stoichiometric air use, higher combustion efficiencies, and less-intensive in terms of capital costs (which may increase as more controls are required). Similarly, almost with all types of incinerators, disadvantages include potential incomplete combustion under inappropriate operating conditions and complications associated with achieving proper operating temperatures during startup of a batch unit. Most incineration systems made before the early 1960s were of the multiple-chamber types (sometimes referred to as excess air types). They operated with high excess air levels and so required scrubbers to fulfil air pollution control standards. Few multiple-chamber incinerator units are being installed today. Instead, older units of this type are used primarily for non-infectious wastes. A small number of rotary kiln incinerators are presently operating, although greater use of them is being promoted by some. These incineration systems consist of a cylindrical, refractory-lined (usually brick) combustion primary chamber. This chamber alternates slowly (between 1 and 3 rpm) on a slightly inclined, horizontal axis. This rotation offers excellent turbulence (i. e., mixing). Yet, the rotary kiln systems tend to be costly to operate and maintain, usually require shredding (i.e., some size reduction of wastes), and often require emission controls (Tchobanoglous et al., 1993).

2.15 Best Practices for Incineration

Best practices for include the following elements (Batterman et al., 2004):

(1) Ensure that only minimum amount of waste is incinerated by the effective waste reduction and waste segregation

(2) Ensuring the combustions condition (i.e. enough residence temperature and time) is appropriate by engineered design of the incinerator

(3) Minimizing the risk and exposure by siting incinerators away from populated areas

(4) Avoiding the flaws by construction following detailed dimensional plans, that can lead to incomplete combustion and higher emissions

(5) Achieve the desired combustion conditions and emissions by proper operation e.g., appropriate startup and cooldown procedures, minimum temperature before waste is burned, use of appropriate loading rates, properly disposal of ash, and PPEs for safeguarding workers

(6) Regular maintenance to replace or repair defective components

(7) Enhanced training and management for operators, certification and inspection programs, the availability of an operating and maintenance manual.

Chapter 3

METHODOLOGY

The methodology adopted is as in the flow chart:

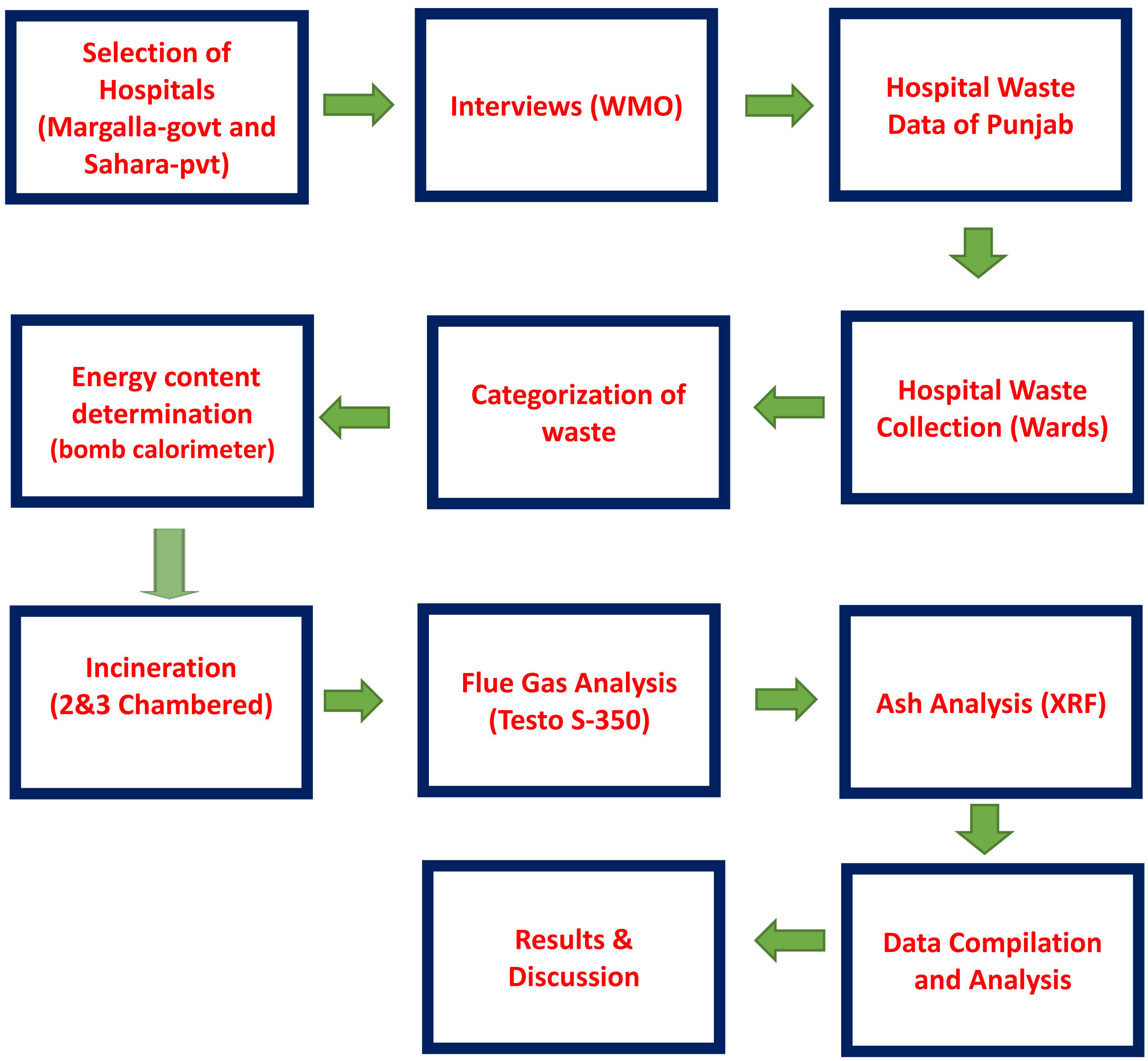


Figure 3.1. Methdology adopted for the study

All the research work complied with the following procedure:

3.1 Hospital Waste Management Rules 2005

EPA *Section 34*, (3): Waste management responsibility: Each hospital is responsible for the management of the waste generated till its final disposal.

3.1.1 Waste management team

Waste Management Officer responsible for day to day implementation and monitoring of the waste management plan.

3.2 Study Area Selection

Study area selected included two sites having incinerators for hospital waste management. The site A selected hospital is named as Margalla Hospital and had a small-scale 2 chambered incinerator without APCDs except sprinkling of water. It was compared with another standard incinerator, having 3 chambered installed at site B. This facility too had an allied hospital named Sahara Hospital. Moreover, this installation received waste from outside for incineration. The two different incinerators had different capacities respectively i.e. 45 kg/hr and 150 kg/hr. An amount of 10/15 kg of hazardous waste was generated in Margalla hospital while the second facility received more hazardous waste on daily basis. In Margalla hospital, incineration was carried out after every alternate day while at site B it was carried out on daily basis.

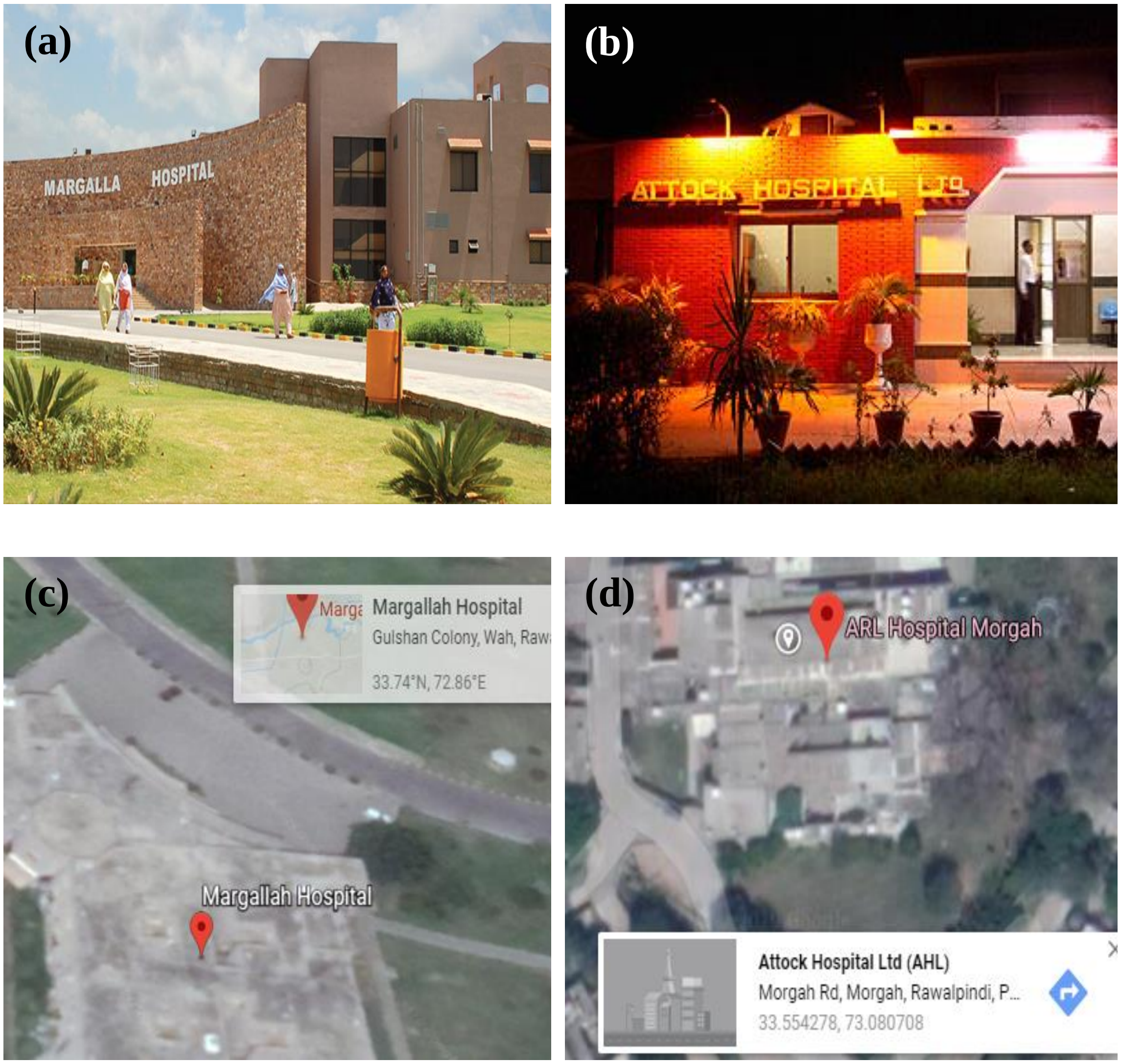


Figure 3.2. (a) Site A government hospital (b) Site B private hospital (c) Site A location and (d) Site B location

3.3 Data Collection

Initially data from two selected hospitals was collected i.e. Margalla (a govt hospital) and Sahara (a private). Interviews were conducted with their Waste Management Officers (WMO). During interview, the Operation theatre days were noted with higher generation of waste. Then in order to understand the scenario, a larger base point was selected. Hospital waste data of randomly selected hospitals of all 10 divisions of Punjab was collected. Further, data of DHQ hospital in Narowal was collected with different types of wastes from different wards. Furthermore, comparison was made for burial and incineration.

3.4 Generation of Waste

At the outset, weekly waste generation from the two hospitals was documented. Each of the two hospitals had different waste generations/bed/day. For Margalla, total 81 kilograms of waste was generated for 50 beds per day where for Sahara, 108 kilograms of waste was generated for the 60 beds per day. Site B, in addition, also received external waste for incineration. DHQ hospital in Narowal had different types of waste generation from different wards. That data was analyzed for different types of waste such as Placenta, Sharps and Mix waste.

Figure 3.3. Pharmaceutical waste lying ready for incineration at site A

3.5 Segregation of Waste

Waste in each hospital was categorized into hazardous and non-hazardous waste. Different colored bins were there for different waste types. Yellow bin was allotted for hazardous waste, white for glass waste, and green bin for non-hazardous waste. For highly hazardous waste collection, a bin of red color was to be used. All of the hospital waste was divided into sub-categories for the incineration i.e. plastic waste, mixed waste, and pathological waste. Plastic waste consisted of plastic shoppers, drips, bottles, syringes, gloves, discarded plastic material. Mixed waste was contributed by cotton swabs etc. in addition to other types of waste, Pathological waste was all of the human waste and bandages.

Figure 3.4. Color coding for waste bins

Waste collected was categorized as Mix waste, Plastic waste and Pathological waste.

3.6 Transportation of Waste

Since the waste was sorted for incineration on spot, and therefore lesser waste was made available for incineration and the transportation to the incinerator site was carried out on the same day. At site A, the incinerator was in the vicinity of the hospital and the waste was physically transported there. For the site B, waste was mechanically transported through a customized vehicle.

3.7 Incinerator Operations at Site A and B

The incinerator at site A was a two chambered incinerator that had a nominal burning rate of 45 kg/hr. Temperature ranged from 0-800^{o}C. Waste was fed at room temperature i.e. 25^{o}C.

The incinerator at Site B is a three chambered large incinerator which not only incinerates the waste of Site B but also the waste from external sources. There 150 kg/hr was incinerated. Waste was fed at 600^{o}C and could achieve a maximum of 1200^{o}C. While the temperature range was from 0 degrees to 1200^{o}C.

3.8 Incineration Process at Site A and B

Primarily, individual component incineration was carried out at site A. First of all, Plastic waste was incinerated at both sites. Different types of emissions were observed. Emission readings at different temperatures were noted and graphs were plotted accordingly. Similarly, mixed waste was incinerated, and readings were noted. Same procedure was carried out for pathological waste at both site A and B.

Figure 3.5. Incinerator at site B

Figure 3.6. Incinerator at site A

3.9 Tests

Following tests were carried out during the study

3.9.1 Flue gas emission analysis

Flue gas emissions were analysed through Testo S-350.The analyser could analyse four types of emissions i.e. CO, SO_2, NOx. The analyser recorded emissions in ppm which were converted to mg/m^3. All of the waste types were incinerated at both the incinerator sites. A number of readings were noted at different temperatures at both sites for all type of wastes. Readings were noted and graphs were plotted. They were then compared to the NEQs and conclusions drawn.

Figure 3.7. Flue gas analysis through flue gas analyser Testo S-350

Formula used for conversion of ppm to mg/m^3 (at standard temperature of 25ºC and 1 atm):

$$Concentration\ (mg/m^3) = \frac{Concentration\ (ppm) \times Molecular\ Weight}{24.5} \qquad \text{(i)}$$

Formula used for conversion ppm to mg/m^3 (at standard temperature of 0ºC and 1 atm):

$$Concentration\ (mg/m^3) = \frac{Concentration\ (ppm) \times Molecular\ Weight}{22.4} \qquad \text{(ii)}$$

3.9.2 XRF analysis

Ash samples were prepared for analysis through x-ray fluorescence. XRF analysis is carried out for the purpose of elemental detection. Ash was compacted into pellets by hydraulic presser. The pellets were introduced into **XRF.** Elemental analysis report was generated.

Figure 3.8. XRF analyser

3.9.3 Bomb calorimeter analysis

Pre-incinerated sample (mix waste, predominantly Plastic) was prepared by shredding into very small pieces for energy content determination. A total weight of 0.6g was weighed and placed in bomb calorimeter named Parr 6200 for energy content.

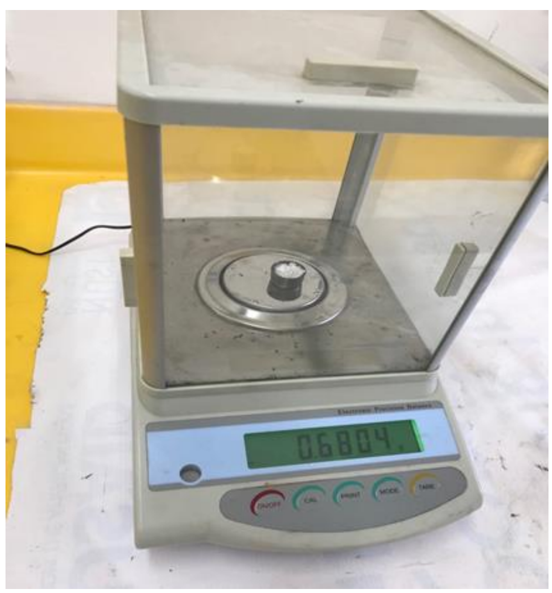


Figure 3.9. Shredded sample being weighed

Figure 3.10. Sample placed in bomb calorimeter

3.9.4 Moisture content

A weighed sample of pre-incinerated waste, w_1 was placed in oven at 105 degrees Celsius for **24 hours.** Sample was weighed again as w_2. Moisture content was then calculated according to the formula;

$$(w_1 - w_2) / w_1 \times 100.$$

Figure 3.11. Sample being weighed

Figure 3.12. Sample placed in oven at 105^{o}C

3.10 Waste Characteristics for Incineration

Incineration of waste is affordable and feasible only if the heating/calorific value of the waste reaches at least 2000 kcal/kg or 8370 kJ/kg. While the value for hospital wastes containing high levels of plastics can exceed 4000 kcal/kg or 16 740 kJ/kg, some hospital wastes have much lower calorific values due to presence of high proportion of moisture. For waste incineration moisture content in the waste should be less than 30 % (Supply and Programme, 2014).

3.11 Salient Features of Incineration

Following were the salient features of incineration

- Food waste was not disposed of as hospital waste in Margalla case
- Margalla hospital’s waste was transported physically to site A as it was in the immediate vicinity.
- Incinerator B received waste from private health establishments and small clinics
- Incinerator B had a well-organized hierarchy for incineration of hospital waste.
- Pre-heating was carried out in case of incinerator B.
- No pre-heating was done in the case of incinerator A.
- Similarly, pre-heating was carried out at the small-scale incinerators installed for hospital waste management by the government of Punjab.
- Ash produced after incineration was landfilled/buried in both cases i.e. A and B.
- The ash was buried under a three –feet soil cover in both cases.
- Human waste was buried instead of incineration in the case of DHQ Hospital Narowal.

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Waste Generation

Waste generation data was collected from two selected hospitals and data from DHQ Narowal. Each of these hospitals had different number of beds. The data from two hospitals was for a period of one week while that of DHQ Narowal was for a period of one month. The data was analyzed for waste generation rate on normal(weekdays) and selected days (OT days).

4.1.1 Waste generation at site A

Following graph shows waste generation at site A.

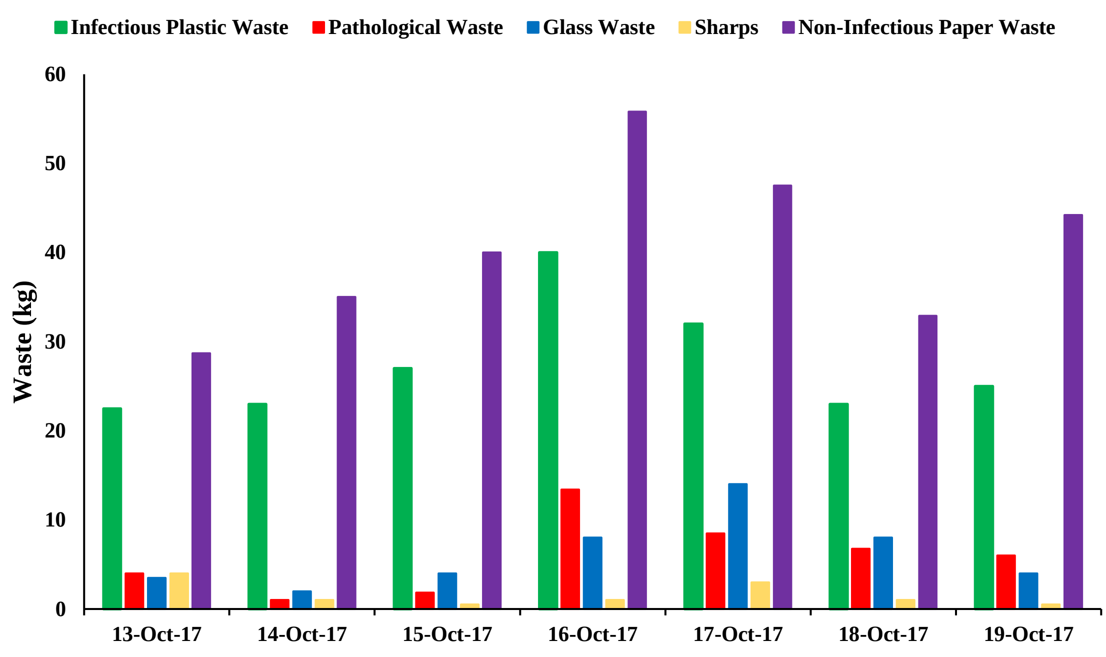


Figure 4.1. Weekly hospital waste generation at site A

A total of 572.6 kg of waste was generated from site A hospital. Two weekdays i.e. Monday and Tuesday being the Operation theatre (OT) days had the highest generation i.e. 118 kg and 105 kg respectively. Furthermore, the pathological and glass waste accounted for the highest waste generated on OT days. The waste generated per bed per day was calculated as 1.63 kg for a period of one week.

4.1.2 Waste generation at site B

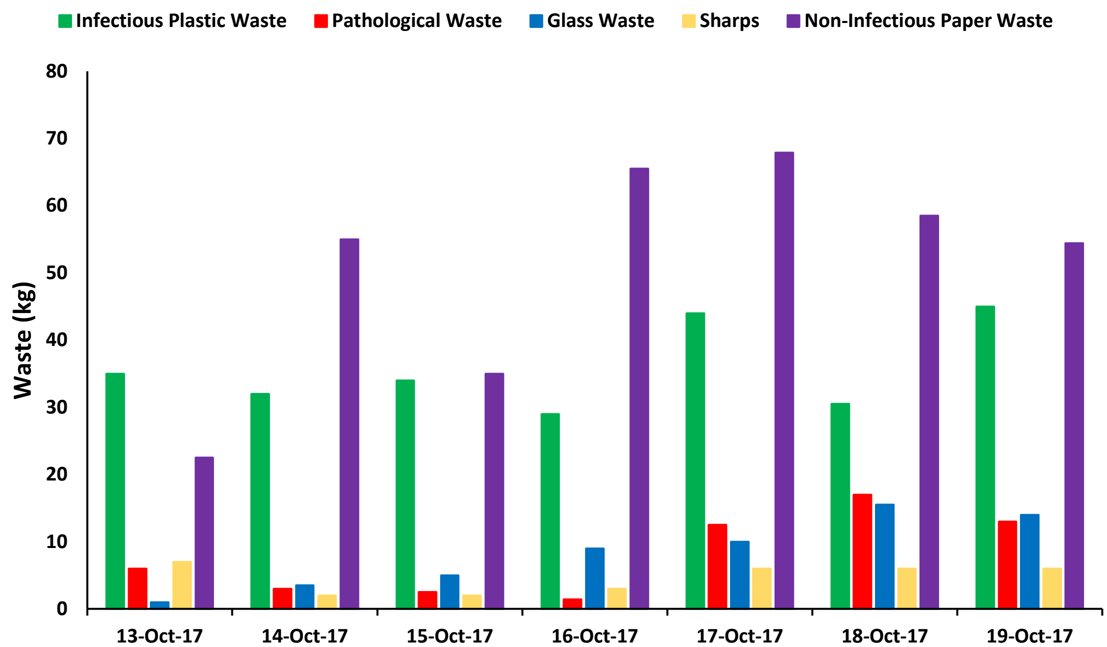


Figure 4.2. Weekly hospital waste generation at site B

A total of 753.7 kg of waste was generated at site B hospital over a period of seven (7) days. Again, higher amount of waste generation was recorded on Tuesday, Wednesday and Thursday being the OT days at Site B hospital. Moreover, similar trend was observed for higher amount of glass and pathological waste generation on OT days. The total waste generated per bed per day was calculated as 1.8 kg.

4.1.3 Comparison of waste generation between site A and B

Site A had a 5O bed hospital while Site B had a 60 beds hospital. Site A hospital had waste generation rate of 1.63 kg/bed/day while Site B had 1.8 kg/bed/day. Since Site A was a govt a hospital and Site B a private hospital and as evident from the data, Site B being private hospital had higher waste generation (El-Salam, 2010).

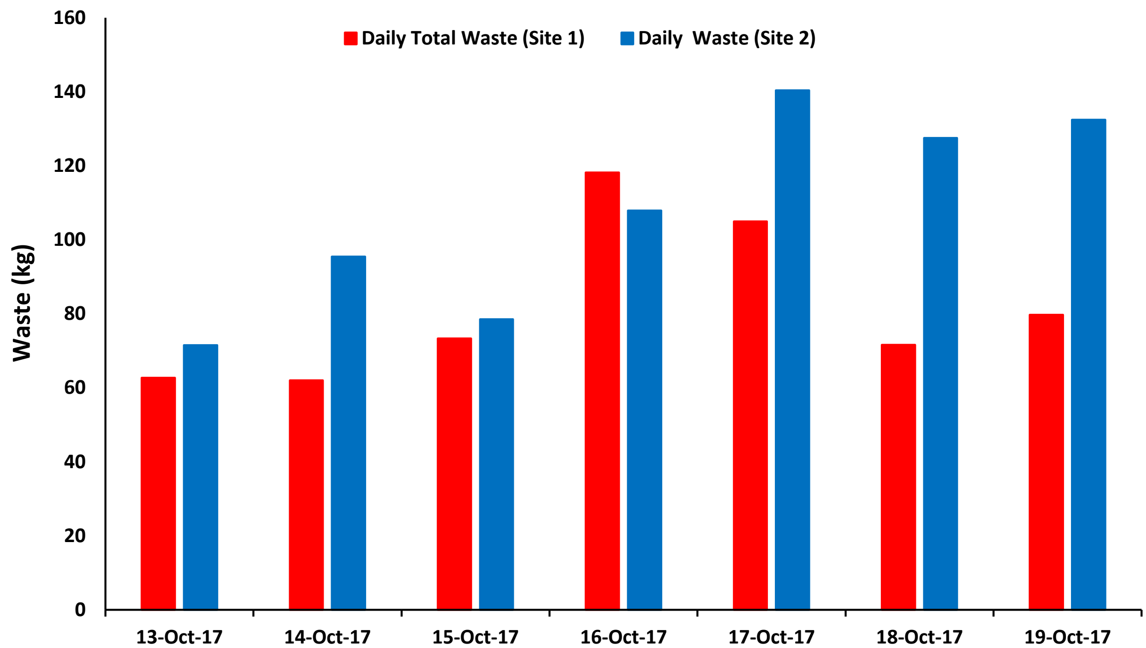


Figure 4.3. Waste generation comparision between site A and site B

4.2 Waste generation at DHQ Narowal

Waste generation at DHQ Narowal (300 bed) was 7816 kg for a period of one month. The waste per bed was calculated to be 0.86 kg/bed/day. Waste was segregated into Mix waste (white, red and yellow), Placenta and Sharps.

As can be seen in the graph, each ward contributed differently in the total waste generation. Emergency and Orthopedic ward generated the highest amount of waste.

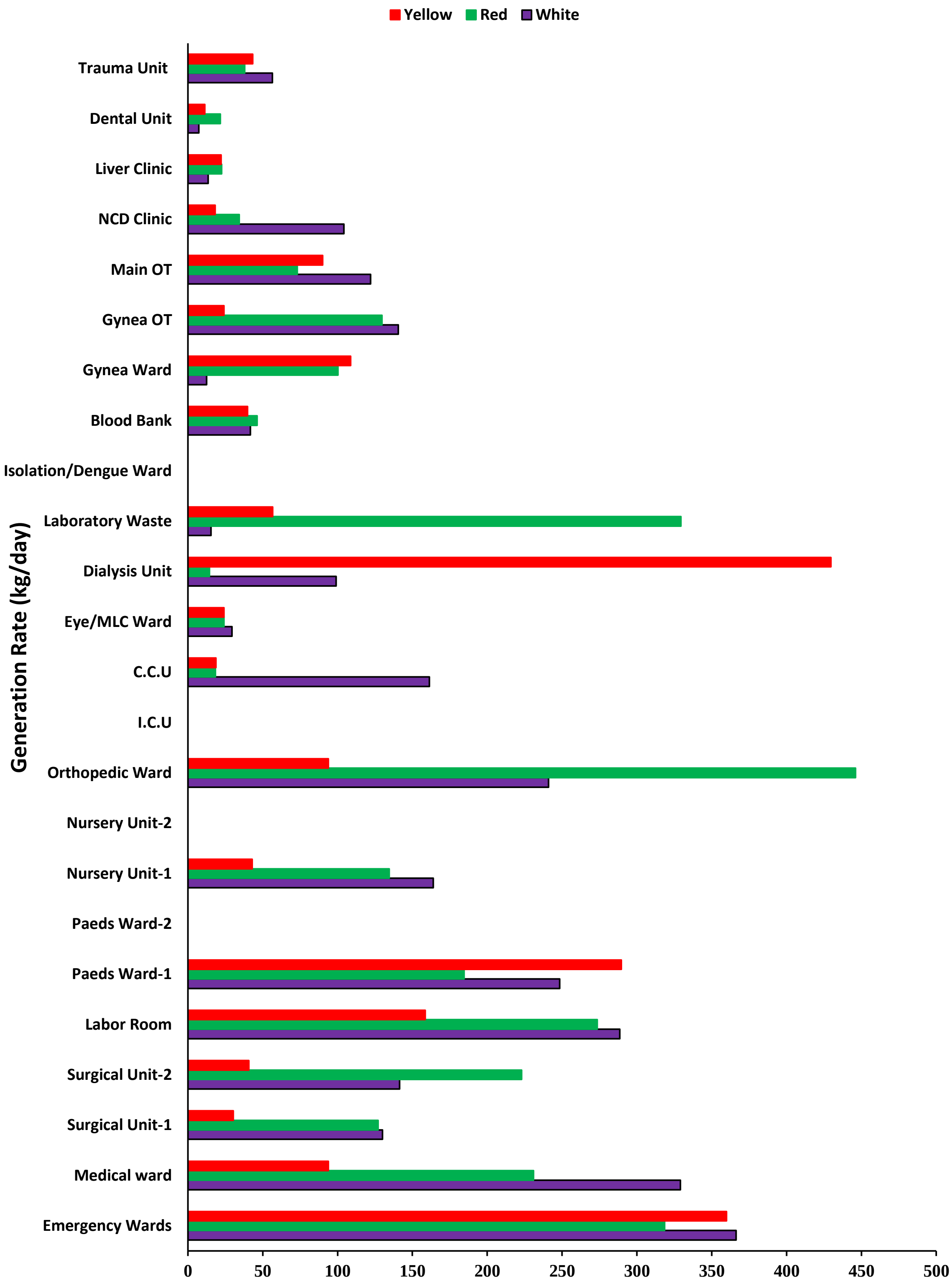


Figure 4.4. Waste generation at DHQ Narowal

4.3 Composition of Waste

Waste generated at each of these wards had different composition. Waste composition was analyzed in terms of Sharps and Placenta.

4.3.1 Sharps generation

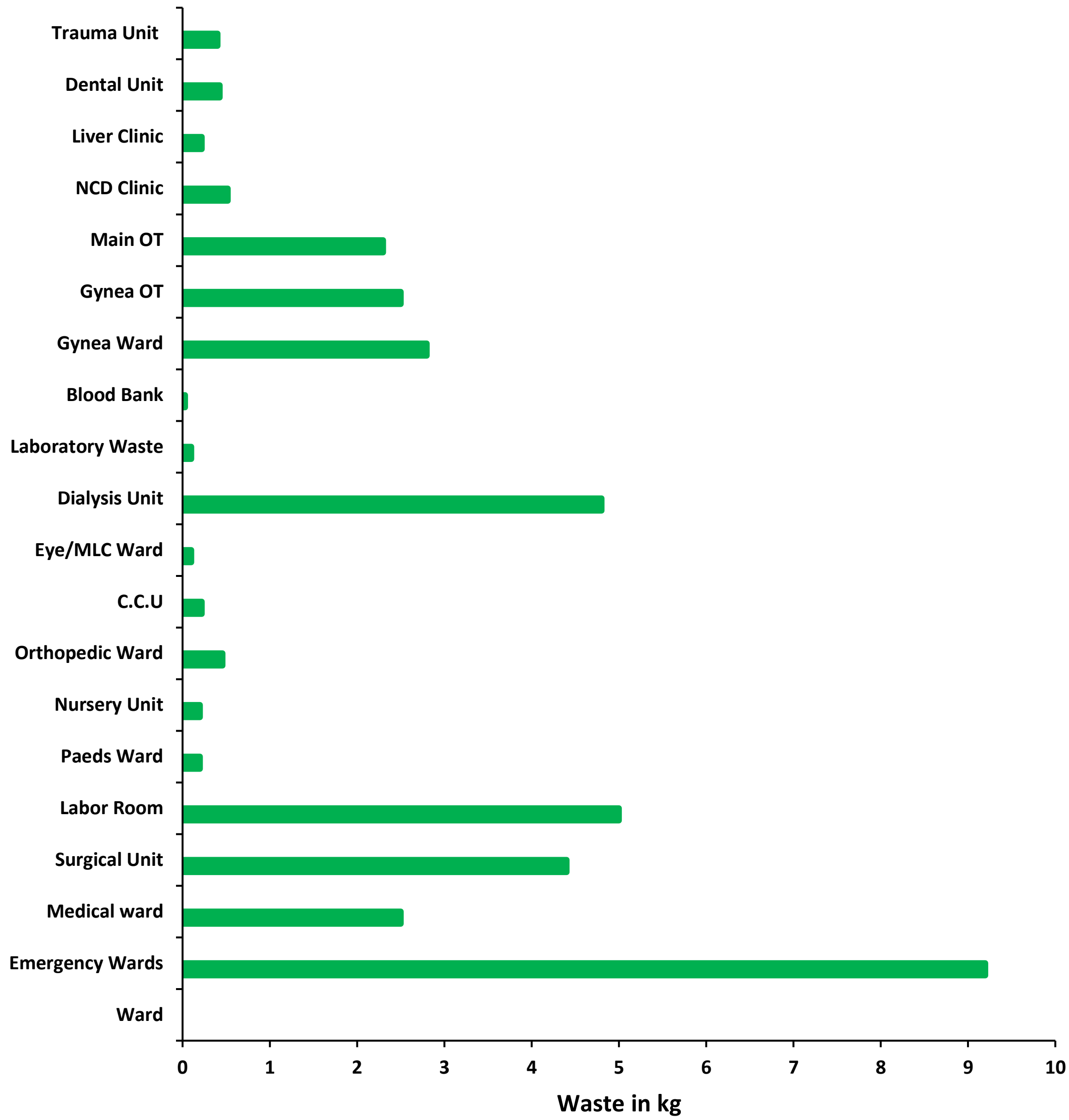


Figure 4.5. Sharp generation of watse in each ward

Sharps generation from respective wards at DHQ Narowal were analyzed. Emergency, Labor room and Dialysis unit generated the highest number of sharps with other wards such as surgical and medical wards also contributing considerably to the total waste generation.

4.3.2 Placenta generation

Total Placenta generation from the DHQ Narowal hospital for the entire month was 356 kg. Only Labor room and Gynae OT contributed for Placenta generation. Labour room generated 252.5 kg of Placenta while Gynae OT generated 103.4 kg.

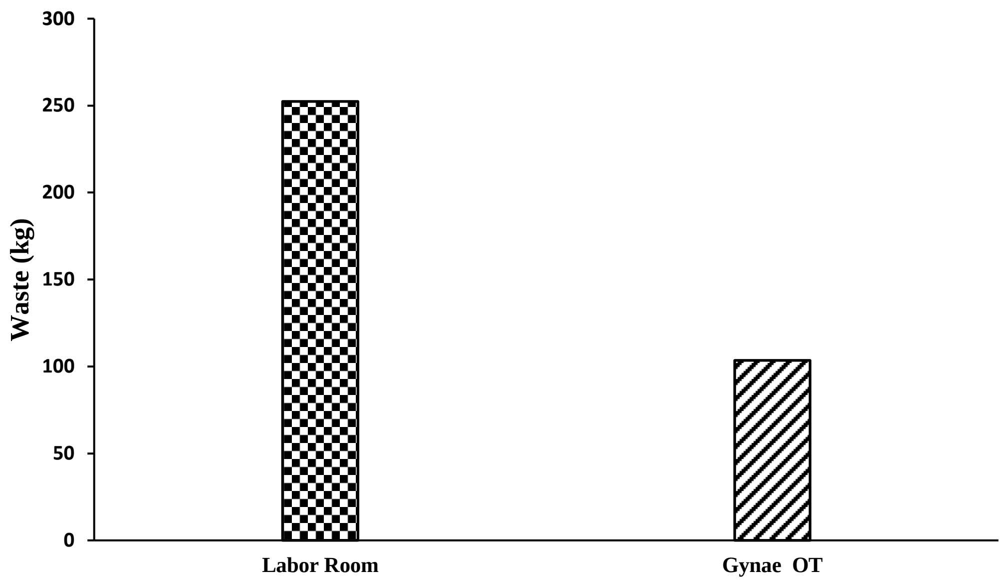


Figure 4.6. Placenta generation

4.4 Burial vs Incineration

The total amount of waste generated at DHQ Narowal was 7816 kg. Majority of the waste was incinerated except Placenta which was buried. This shows that Incineration was used as the safe method of hospital waste disposal.

- Total Waste Generation = 7816 kg
- Incinerated waste = 7460 kg
- Buried waste = 356 kg which is 4.5 % of the total hospital waste

4.5 Comparative Flue Gases Emissions

Pollutant emission levels depend on the chemical and physical processes taking place within the device. Pollutant concentration levels differ depending upon the chemical kinetics (Bowman, 1975). Interplay between the following reactions may be considered in the context of the flue gases such as CO, NOx and SO_2 (Wielgosiński, 2012).

$$C + \frac{1}{2} O_2 \rightarrow CO \qquad \text{(i)}$$

$$C + O_2 \rightarrow CO_2 \qquad \text{(ii)}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad \text{(iii)}$$

$$N + O_2 \rightarrow NO + O \qquad \text{(iv)}$$

$$N_2O + O \rightarrow N_2 + O_2 \qquad \text{(v)}$$

$$S + O_2 \rightarrow SO_2 \qquad \text{(vi)}$$

$$SO_2 + \frac{1}{2} O_2 \rightarrow SO_3 \qquad \text{(vii)}$$

$$S + H_2 \rightarrow H_2S \qquad \text{(viii)}$$

$$H_2S + \frac{3}{2} O_2 \rightarrow SO_2 + H_2O \qquad \text{(ix)}$$

4.5.1 CO emission from plastic waste

Following are the CO emissions at both site A and B from Plastics

4.5.1.1 CO emission from plastic waste at site A

It can be seen in the graph that CO emissions for plastic waste were high at the initial temperatures and saw an increase with the increasing temperature but observed a decrease as higher temperature for incineration was achieved. This behavior may be attributed to incomplete combustion, upset conditions as incineration was not carried out according to the best operating practices, particularly in Site A case. This could also be due to relatively higher moisture content in the waste. Similarly, Plastic itself is an organic compound and in oxygen-rich environment, the Carbon in Plastic can form CO with the help of Oxygen (McKone and Hammond, 2000).

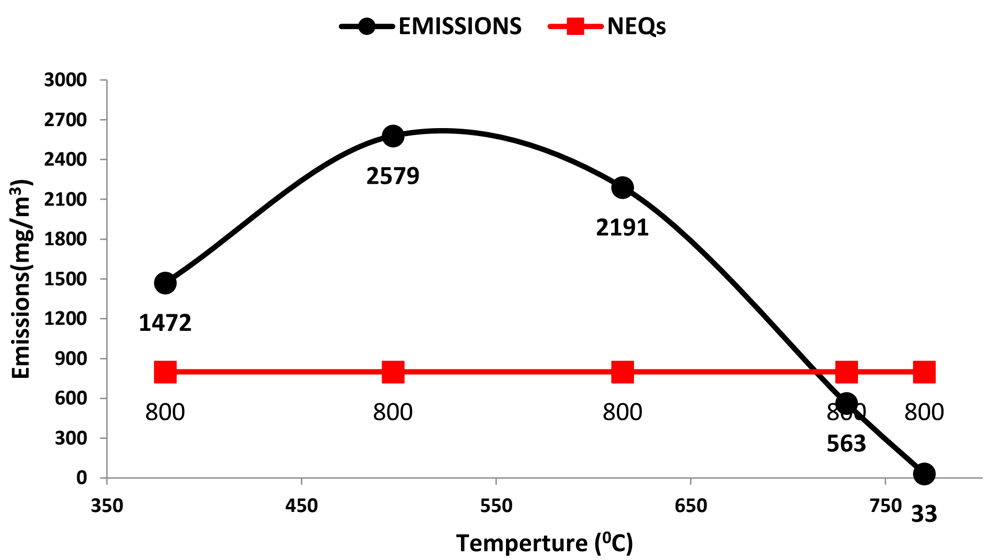


Figure 4.7. CO emission from plastic at site A

4.5.1.2 CO emissions from plastic at site B

Waste was fed at 600^{o}C at site B unlike site A where waste was fed at 0^{o}C in the incinerator. Emissions were relatively higher at initial temperatures but still remained below NEQs level (800 mg/nm^3). This site had better APC arrangements and all the relevant devices were functional during incineration. Various emission readings were recorded at temperatures of 950,1100 and 1200^{o}C.

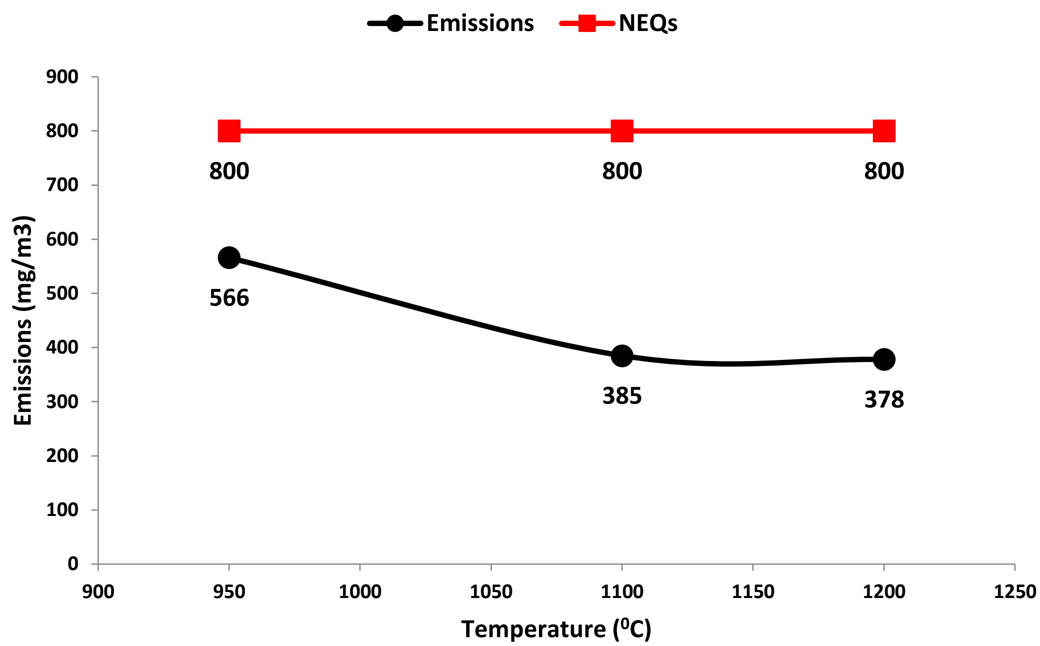


Figure 4.8. CO emission from plastic at site B

4.5.2 CO emission from mix waste

Following are the CO emission from mix waste.

4.5.2.1 CO emission from mix waste at site A

Again, the CO concentration at initial temperature was higher and decreased substantially with increase in temperature. Initial reading was taken at 660^{o}C and it gave emissions above the NEQs level. Another reading was taken at 705^{o}C and the emissions were even recorded higher. This could be due to the increase in intensity of incomplete combustion which lowered as the temperature went up further as can be observed at 770^{o}C. Higher temperature incineration caused fewer CO emissions. Now the same CO emissions were investigated for another incinerator at site B.

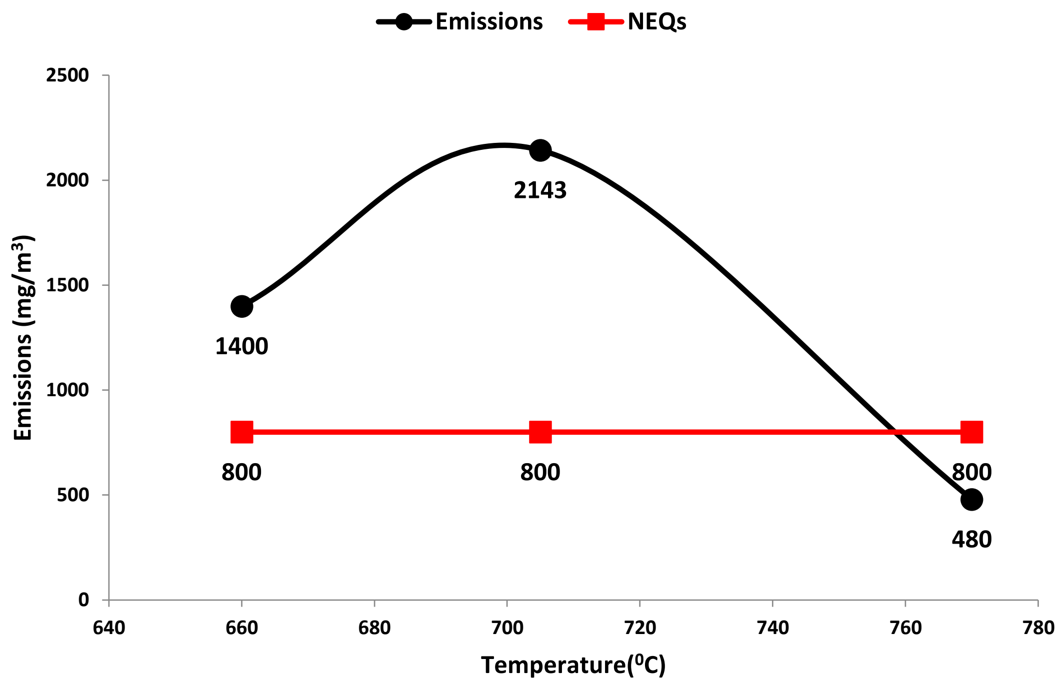


Figure 4.9. CO emission from mix waste at site A

4.5.2.2 CO emissions from mix waste at Site B

As mentioned earlier, waste was fed at 600^{o}C. Initial reading was taken at 720 and the emissions recorded were 635 mg/m^3. Another reading was taken at 800^{o}C which gave emissions of 596 mg/m^3 and then at 1100^{o}C,483 mg/m^3 of emission were recorded. No remarkable deviations were noted and the emissions satisfied the set limits for safe incineration.

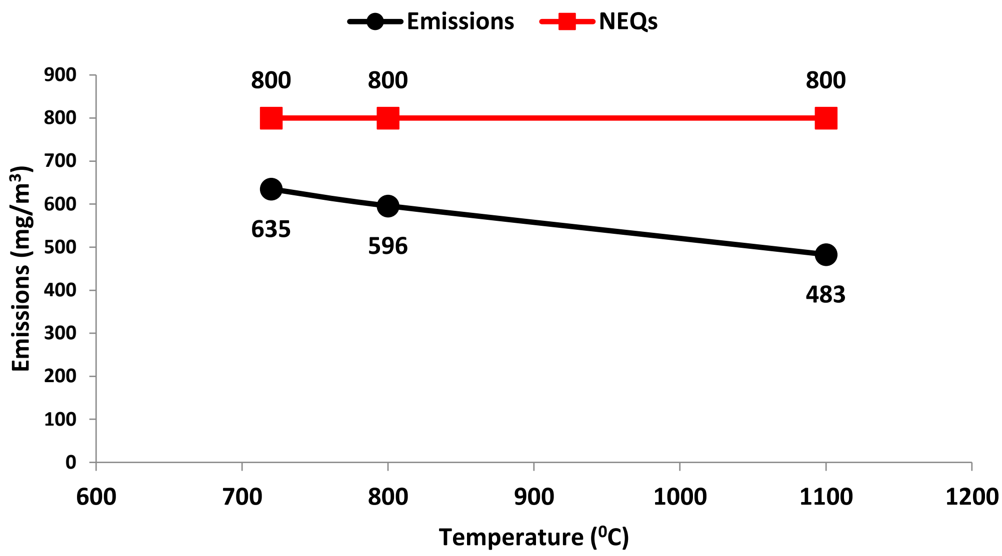


Figure 4.10. CO emission from mix waste at site B

4.5.3 Comparative CO emissions from pathological waste

Following are the comparative CO emissions from Pathological waste

4.5.3.1 CO emissions from Pathological waste at site A

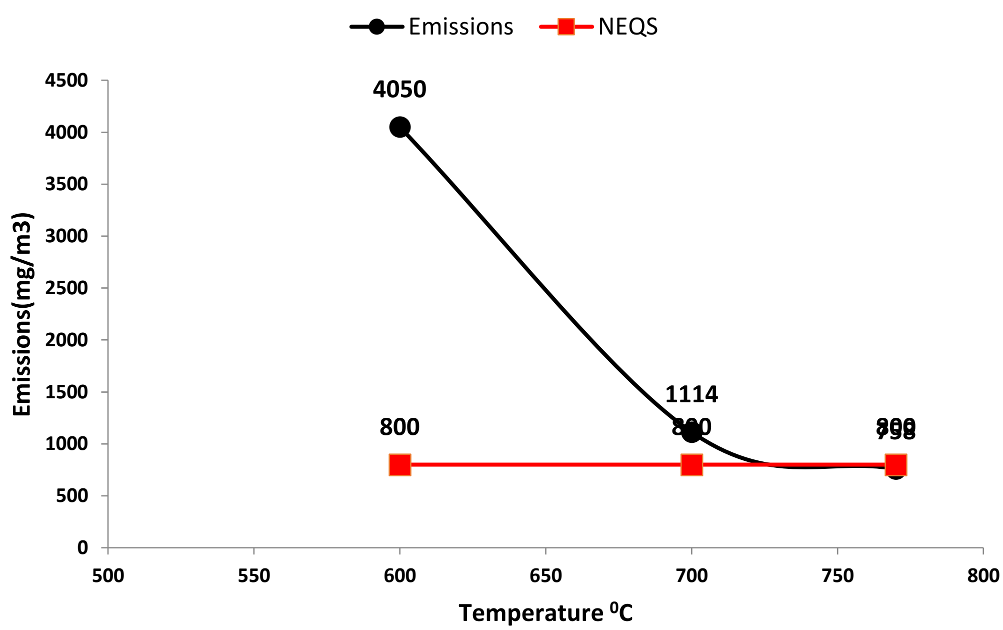


Figure 4.11. Human Waste and Bandages (Pathological waste), CO, at site A

Humongous emissions were noted for Pathological waste at site A during incineration. Since Pathological waste (Placenta) contains higher amount of moisture content and is almost aesthetically impossible to be oven-dried before incineration. So, this upon incineration causes very high CO emissions. Initial reading at 600° revealed CO emissions of 4050 mg/m^3. Another reading was taken 700°C and CO emissions observed were 1114 mg/m^3.There was significant drop in CO emissions and another reading at 770°C recorded CO emissions of 758 mg/m^3, thus bringing it under NEQs level. This significant drop could be attributed to Water gas shift reaction and better temperature for incineration (Frey et al., 2003).

4.5.3.2 CO emissions from Pathological waste at site B

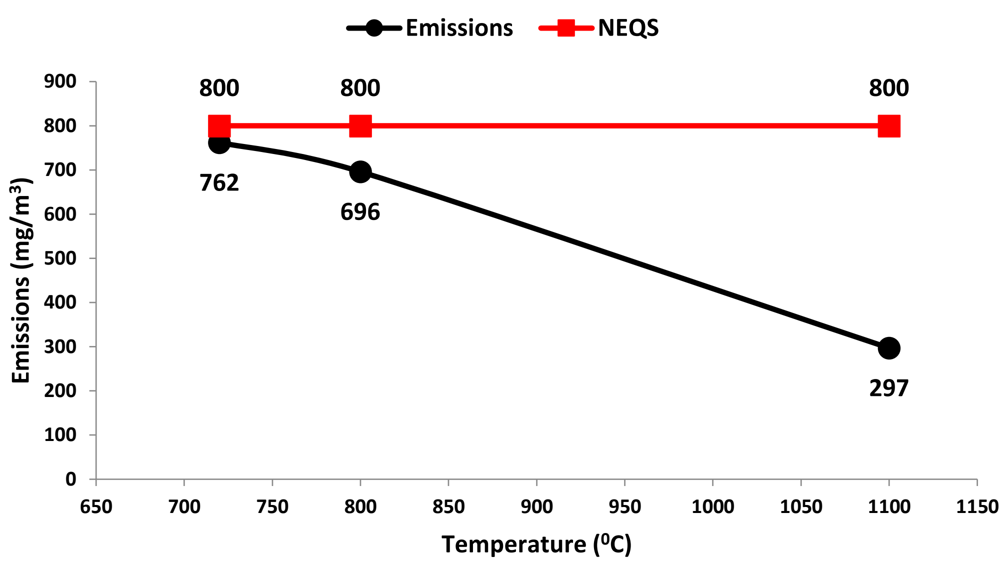


Figure 4.12. Human Waste and Bandages(Pathological waste),CO, at site B

Site B having better APC arrangements, devices and better standard operating procedure and higher incineration temperature gave emissions below NEQs level even in the case of pathological waste. Initial reading was taken at 720°C which gave relatively higher CO emissions of 762 mg/m^3.Another reading was taken at 800^{o}C and CO emissions recorded were 696 mg/m^3.Final reading was taken at 1100^{o}C where substantial decrease in emissions (297 mg/m^3) were recorded.

4.5.4 Comparative NOx emissions at site A and B

NO_x emitted from incineration processes consist in 95% of NO nitric oxide and 5% NO_2 nitrogen dioxide (Skalska et al., 2010). NOx figures among flue gases and was recorded at both site A and B for comparison.

4.5.4.1 NOx emissions from plastic at site A

NOx emissions were recorded at different temperatures at site A. Negligible NOx emissions were recorded initially but it started to increase as temperature went up. With increase in temperature, NOx emissions tend to increase. Various readings were taken at temperatures of 380, 497,615 and 730 and the emissions recorded were almost nil. But, however, it saw an increase at 770^{o}C and the emissions recorded were 35 mg/m^3.

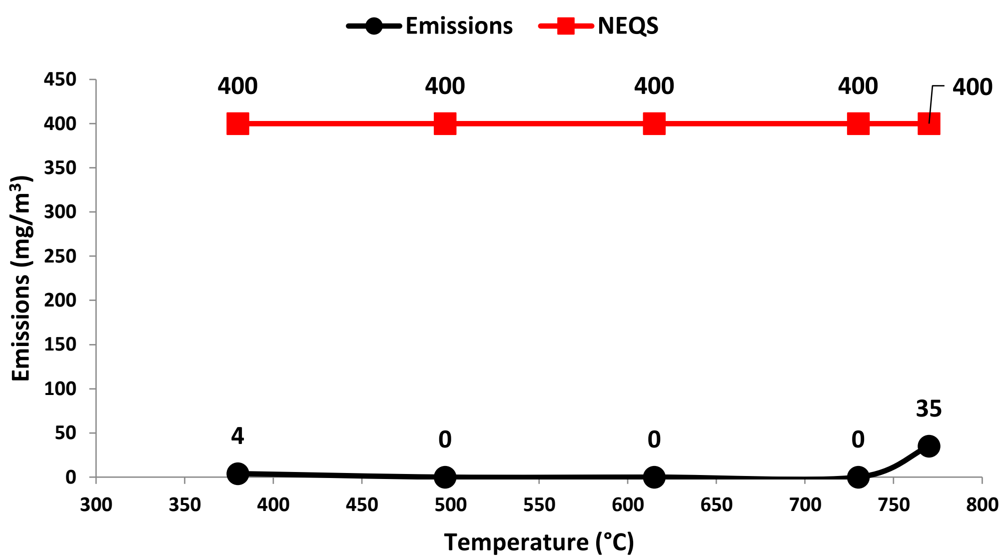


Figure 4.13. Comparative NOx emission at site A

4.5.4.2 NOx emission from plastic waste at site B

NOx emissions at site B were also recorded. Since site B had higher temperature range and thus produced considerably higher amount of NOx as compared to site A. Initial reading at 950°C observed emissions of 303 mg/m^3 and then it lowered and the emissions recorded were 157 mg/m^3 at 1100 and then again it went up with increase in temperature as observed at 1200°C which gave 241 mg/m^3.

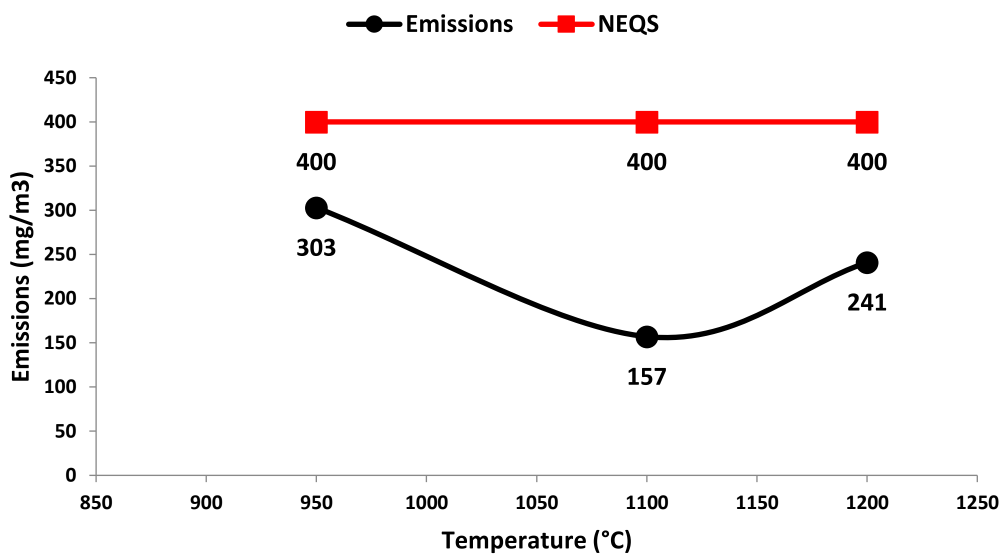


Figure 4.14. Comparative NOx emission at site B

4.5.5 Comparative NOx emissions from mix waste

Following are the NOx emission from mix waste at both sites

4.5.5.1 NOx emissions from mix waste at site A

NOx emissions were recorded for Mix waste at different temperatures at site A through Flue gas analyser Testo S-350. Initially at 670°C the emission from incinerator were 48 mg/m3 and at temperature 705°C and 770°C the emissions were 31 and 124 mg/m^3 respectively, which are lesser than NEQs standard of 400 mg/m^3.

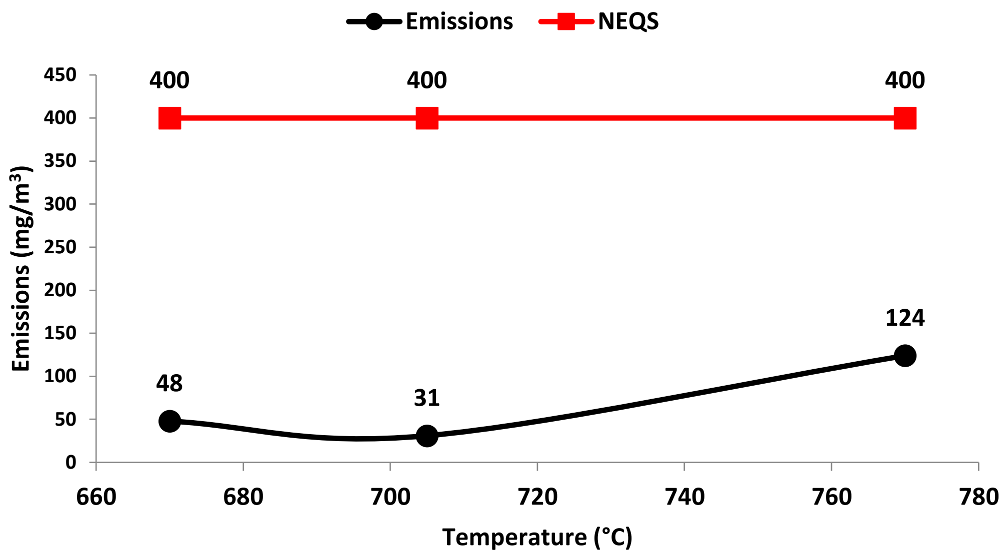


Figure 4.15. NOx emission from mix waste at site A

4.5.5.2 NOx emission from mix waste at site B

At site B, the incineration was also carried out at different temperatures as following, at temperature 720ºC the emissions were 254 mg/m^3 and then at 800 and 1100ºC the emissions were 291 and 332 mg/m^3 respectively. The NOx emissions increased proportional to increase in temperature.

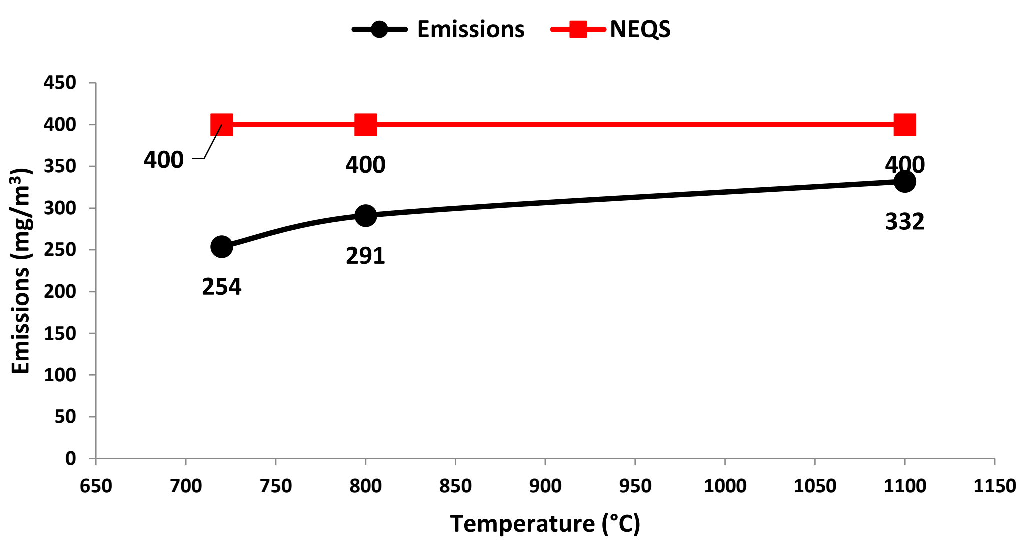


Figure 4.16. NOx emission from mix waste at site B

4.5.6 Comparative NOx emissions from pathological waste at both site A and B

NOx emission from pathological waste is as explained below.

4.5.6.1 NOx emission from pathological waste at site A

The Pathological waste was incinerated at different temperatures of 650, 700 and 760°C respectively and the emissions were 113, 182, 204 mg/m^3 respectively which are less than NEQs standard of 400 mg/m^3.These emissions were little higher than the corresponding temperatures and it could be attributed to the presence of higher Nitrogen content in the waste.

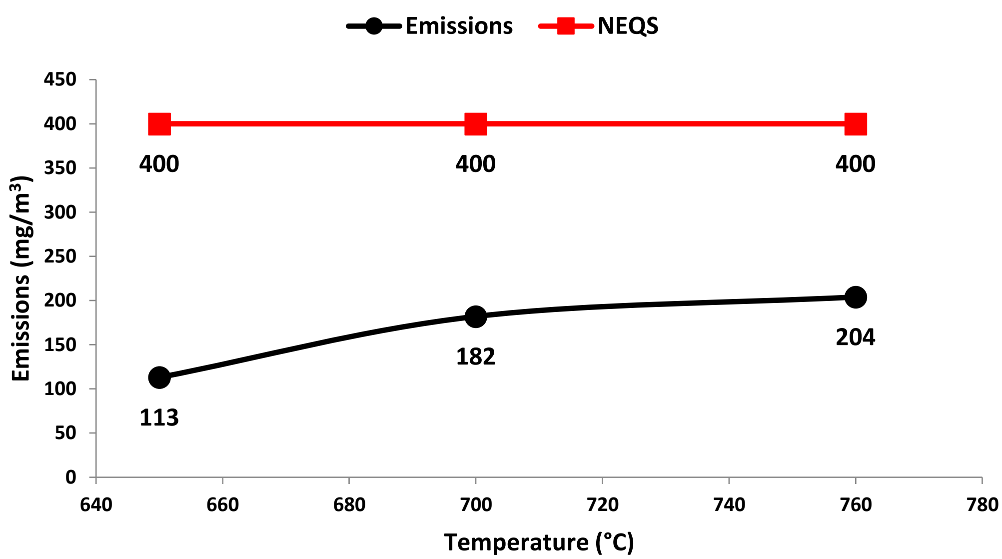


Figure 4.17. Comparative NOx emission from pathological waste at site A

4.5.6.2 NOx emission from pathological waste at site B

Following NOx emissions were recorded at following temperatures for Pathological waste at site B. At 720°C, 308 mg/m^3 of emissions were recorded. Since, at site B higher temperatures were achieved and that's why we could record NOx emissions at higher temperatures. NOx emissions went up in the corresponding higher temperature and were recorded 351 mg/m^3 at 800°C while 388 mg/m^3 at 1100°C.

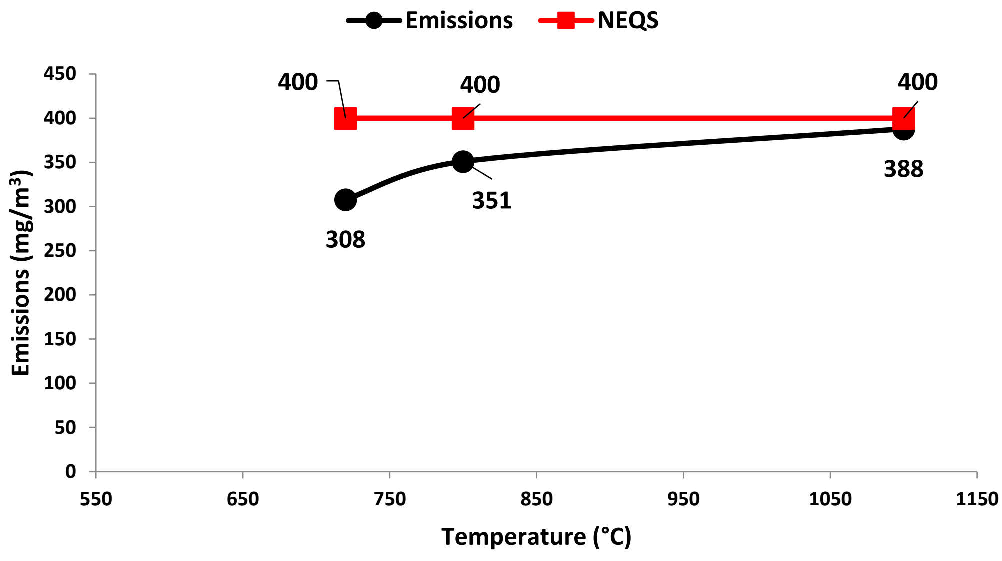


Figure 4.18. Comparative NOx emission from pathological waste at site B

4.5.7 Comparative SO_2 Emissions from plastics

Comparison of SO_2 emissions from plastic waste is explained below.

4.5.7.1 SO_2 emissions from plastic at site A

SO_2 being among the flue gases was also recorded in terms of emissions against temperature. The plastic waste was incinerated at different temperatures at site A having temperature range between 0 to 800^oC. Various readings were taken at 380, 497, 615, 730 and 770^oC respectively, and SO_2 emissions recorded at these temperatures were 480, 612, 554, 156 and 98 mg/m^3 respectively. Initially the emissions went up and decreased substantially as the optimum temperature for incineration was achieved. This could be attributed to conversion of SO_2 into H_2S.

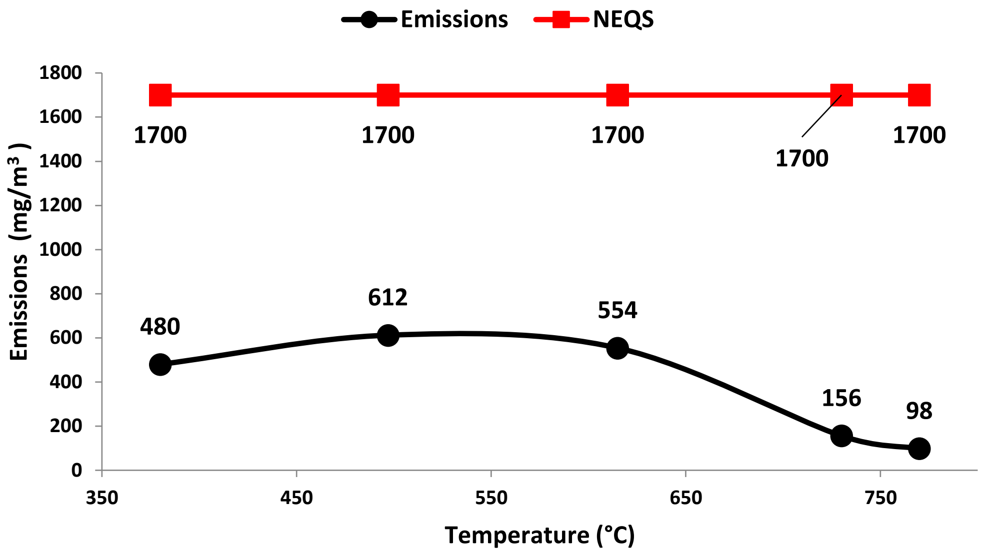


Figure 4.19. Comparative SO_2 emission from plastic at site A

4.5.7.2 SO_2 emission from plastic waste at site B

Since site B had better arrangements in terms of APCDs and higher temperature range and standard operating procedure for incineration. At site B, the temperatures noted were, 950, 1100 and 1200^{o}C, and the emissions observed against these temperature as 93, 127 and 98 mg/m^3. Emissions increased initially but then decreased later on.

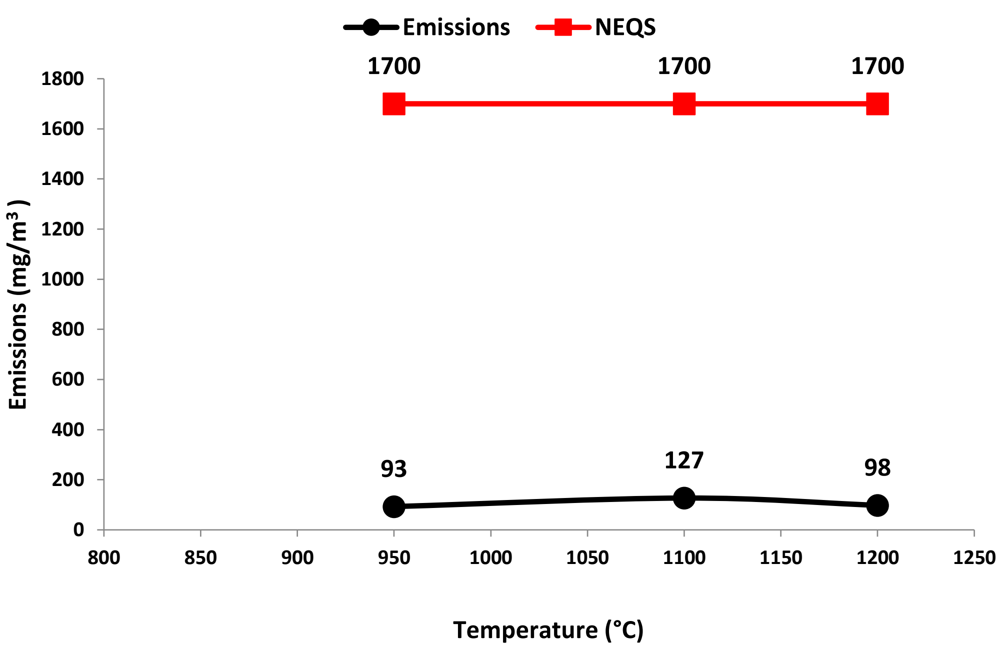


Figure 4.20. Comparative SO_2 emission from plastic at site B

4.5.8 Comparative SO_2 emissions from mix waste

Following comparison of SO2 emissions is as explained

4.5.8.1 SO_2 emissions from mix waste at site A

The Mix hospital waste was also incinerated at both sites, so at site A the Mix waste was incinerated at the temperatures of 670, 705 and 770°C respectively and the emission at site were recorded 42, 126, and 108 mg/m^3.Again, it can be seen that emissions increased initially and marginally decreased later and this too could be attributed to interplay of reactions resulting in interconversion of SO_2 and H_2S.

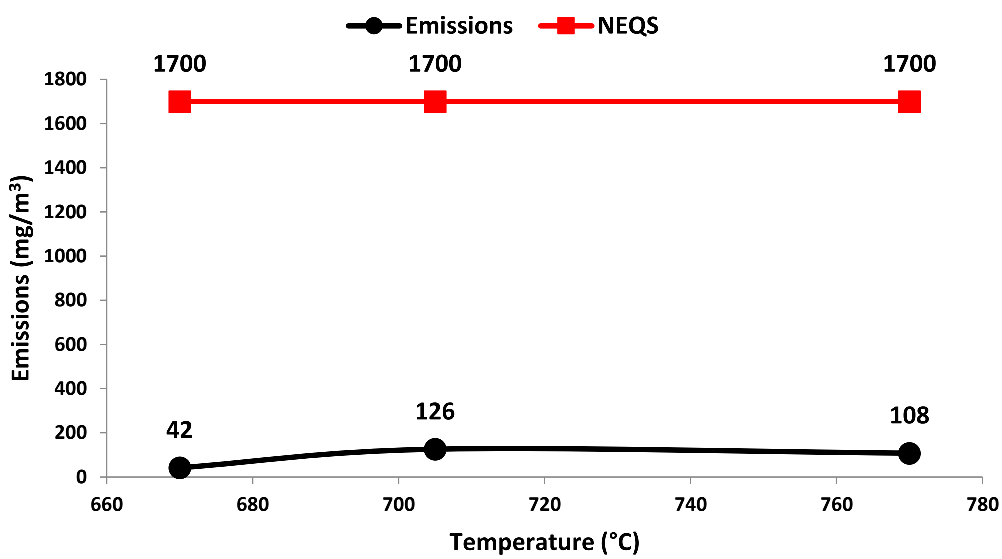


Figure 4.21. SO_2 emission from mix waste at site A

4.5.8.2 SO_2 emissions from mix waste at site B

At site B, Mix hospital waste was incinerated at various temperatures. Initially 110 mg/m^3 of SO_2 emissions were recorded at 720°C.Another reading was taken at 800°C and the emissions recorded were 124 and the final reading was taken at 1100°C and the emissions recorded were 182. SO_2 concentration increased with increase in temperature.

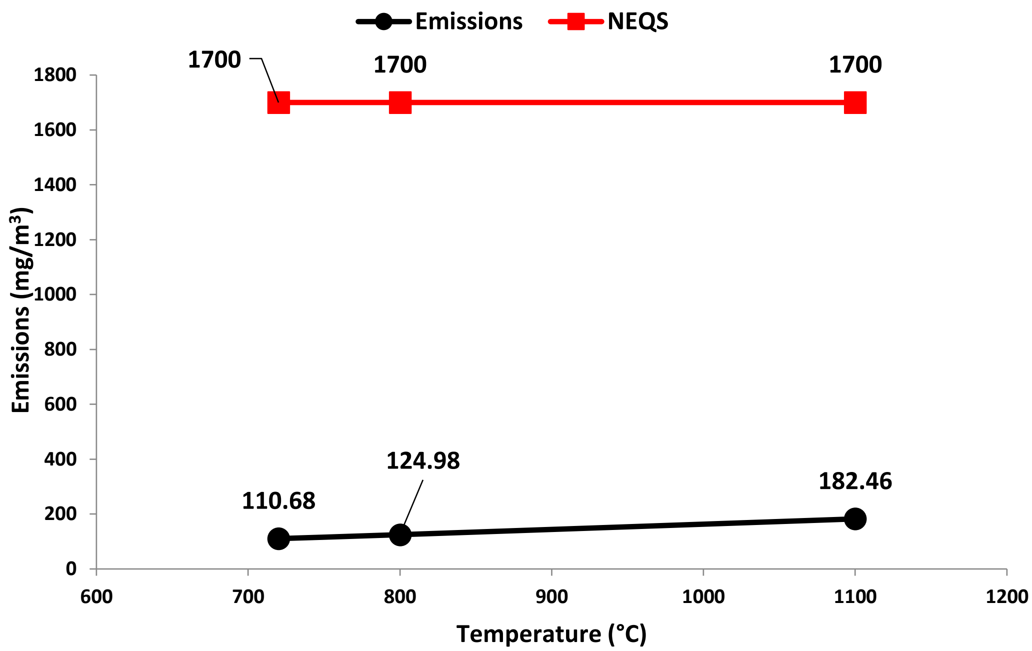


Figure 4.22. SO_2 emission from mix waste at site B

4.5.9 Comparative SO_2 emissions from pathological waste

Following comparison of emissions is made as in case of Pathological waste.

4.5.9.1 SO_2 emissions from pathological waste at site A

Pathological waste was incinerated at site A and negligible SO_2 emissions were recorded. The temperatures noted during incineration were 650, 700 and 770^{o}C respectively and the SO_2 emissions recorded against these all temperatures were zero.

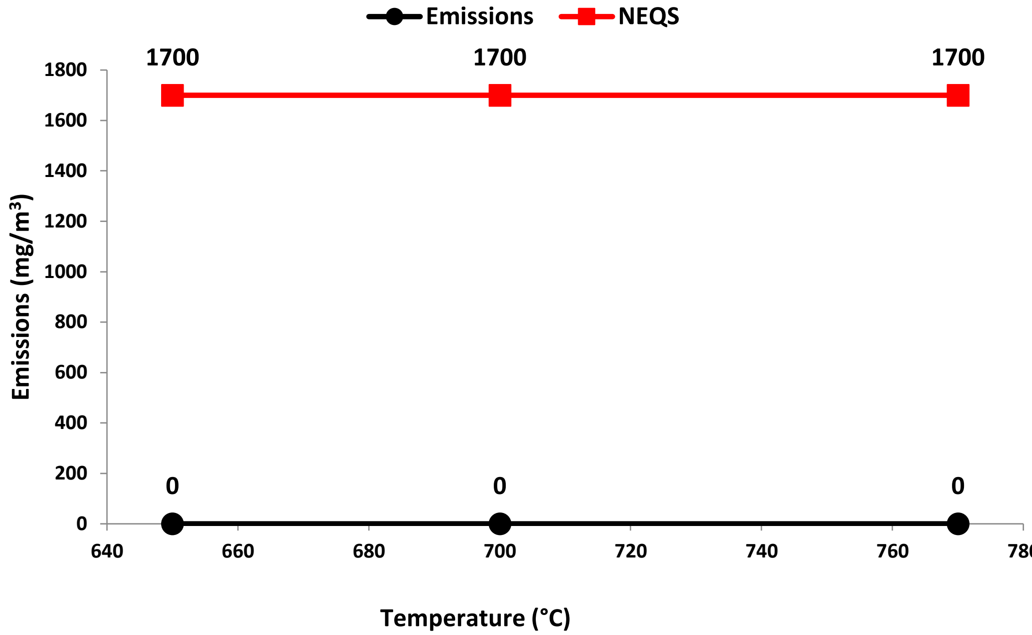


Figure 4.23. SO_2 emission from pathological waste at site A

4.5.9.2 SO_2 emissions from pathological waste at site B

Again, almost negligible emissions were recorded in case of Pathological waste at both sites. At site B the temperatures of 720, 800 and 1100°C were used, at first two temperatures the SO_2 emission were observed zero and at temperature 1100 the emissions were 18 mg/m^3. Only marginal increase or only detection of SO_2 could take place at 1100°C.

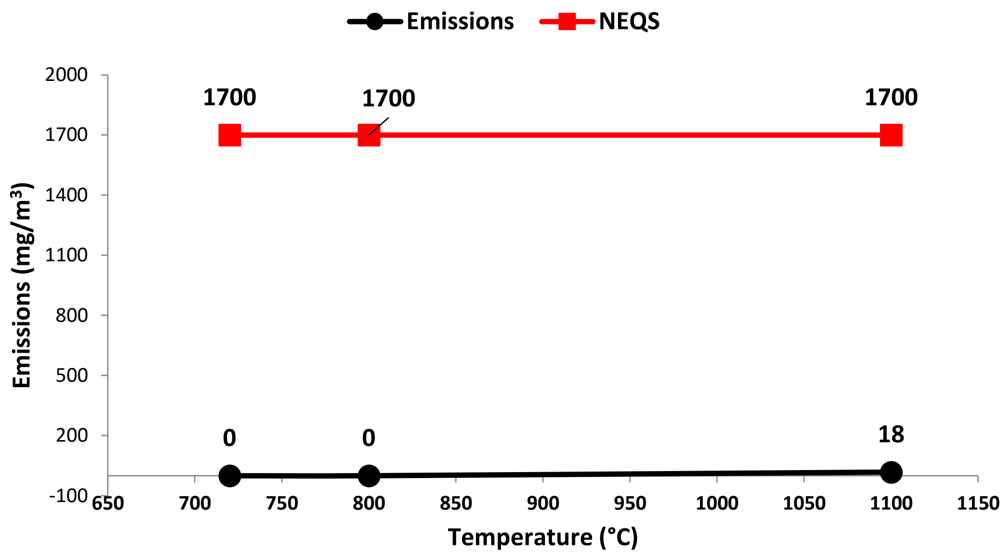
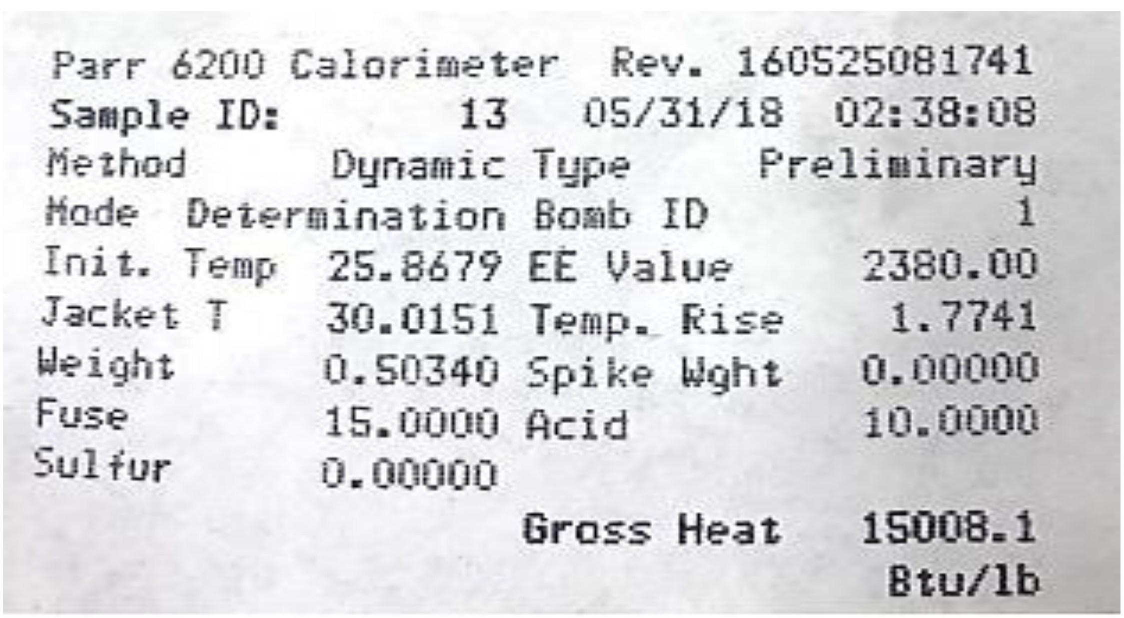


Figure 4.24. SO_2 emission from pathological waste at site B

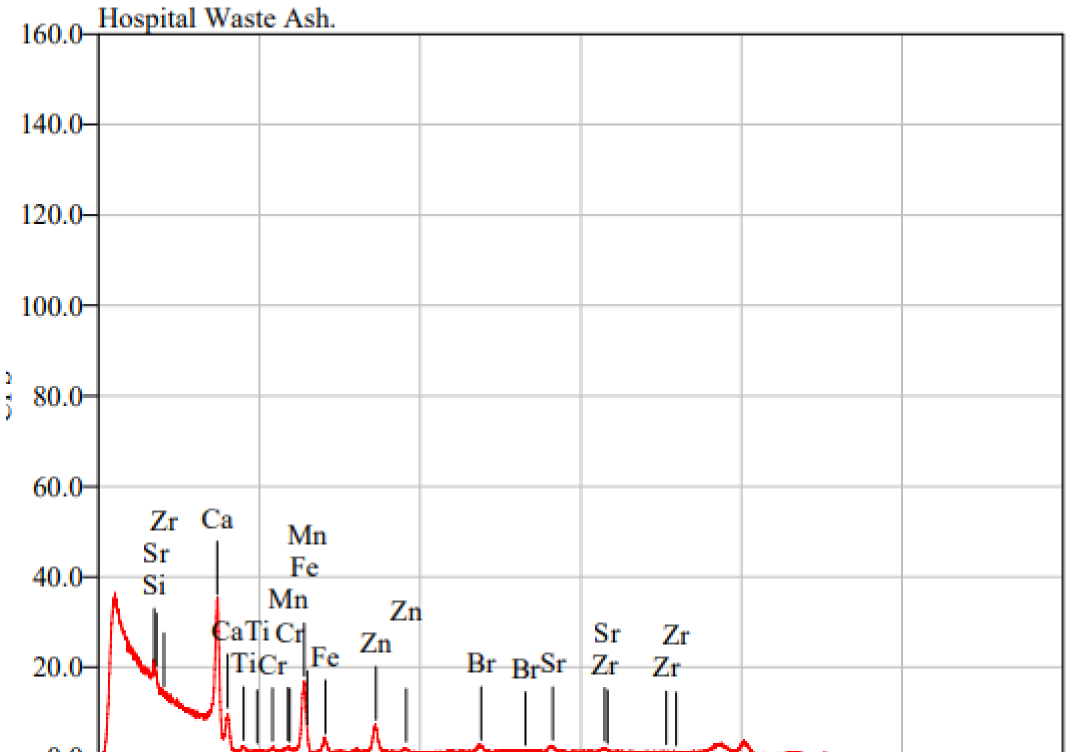
4.6 Energy Content of Waste

Pre-incinerated waste sample was prepared for energy content determination. The calorific value determined through bomb calorimeter was 15008 Btu/lb which is consistent with the fact that it contained substantial amount of plastic.



Parr 6200 Calorimeter		Rev.	160525081741
Sample ID:	13	05/31/18	02:38:08
Method	Dynamic	Type	Preliminary
Mode	Determination	Bomb ID	1
Init. Temp	25.8679	EE Value	2380.00
Jacket T	30.0151	Temp. Rise	1.7741
Weight	0.50340	Spike Wght	0.00000
Fuse	15.0000	Acid	10.0000
Sulfur	0.00000		
		Gross Heat	15008.1
			Btu/lb

4.7 XRF Analysis site A



Qualitative result

Analysis Elements: Si, Ca, Ti, Cr, Mn, Fe, Zn, Br, Sr, Zr

Fitting Coefficient: 0.4471

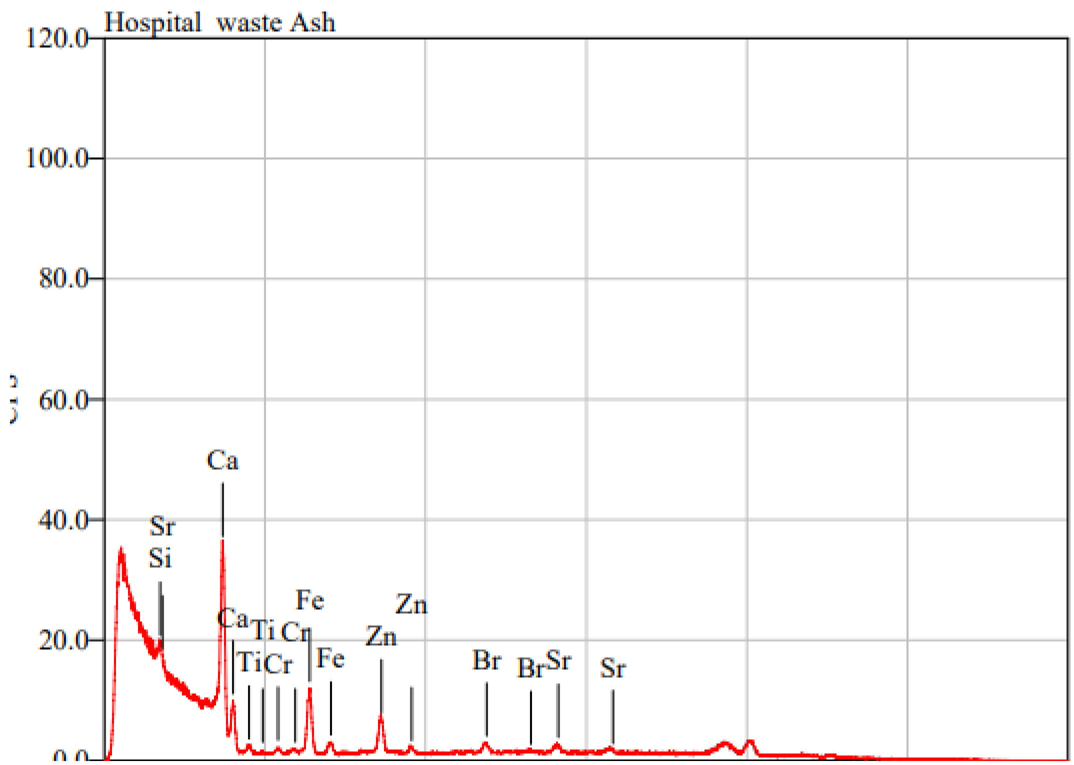
Quantitative condition

Quantitative result

Element	ms%	mol%	Sigma	Intensity	K ratio	Line
14 SiO2	13.9358	16.3625	1.6956	2699	0.0011657	K
20 CaO	49.1458	61.8246	0.5287	26060	0.0101986	K
22 TiO2	2.7224	2.4038	0.5946	968	0.0002915	K
24 Cr2O3	1.3509	0.6270	0.3736	844	0.0002094	K
25 MnO	0.5128	0.5100	0.3106	386	0.0000945	K
26 Fe2O3	21.4149	9.4604	0.3272	16751	0.0037235	K
30 ZnO	6.6902	5.8003	0.2994	6954	0.0015067	K
35 Br	1.3636	1.2039	0.2775	1897	0.0005469	K
38 SrO	1.5507	1.0557	0.4218	1776	0.0006531	K
40 ZrO2	1.3129	0.7517	0.5687	1414	0.0005661	K

This XRF Analysis of Ash sample 1(site A) showed the presence of Calcium Oxide in higher quantity and also indicated substantial presence of Iron Oxide besides Chromium and Strontium oxide and few others.

4.8 XRF Analysis site B



Qualitative result
Analysis Elements: Si, Ca, Ti, Cr, Fe, Zn, Br, Sr
Fitting Coefficient: 0.4458

Quantitative condition

Quantitative result

Element	ms%	mol%	Sigma	Intensity	K ratio	Line	Type
14 SiO2	13.7132	15.4157	1.7020	2601	0.0011172	K	
20 CaO	54.2753	65.3710	0.5440	27663	0.0107665	K	
22 TiO2	3.7774	3.1933	0.6499	1216	0.0003640	K	
24 Cr2O3	1.6764	0.7450	0.4090	944	0.0002327	K	
26 Fe2O3	15.9777	6.7580	0.3490	11588	0.0025618	K	
30 ZnO	7.3959	6.1392	0.2986	7623	0.0016427	K	
35 Br	1.5623	1.3206	0.2816	2117	0.0006072	K	
38 SrO	1.6219	1.0572	0.4256	1816	0.0006642	K	

This XRF analysis of ash (site B) showed the presence Silica Oxide besides Calcium Oxide in higher quantities. This implies that ash collected was more basic than acidic and that is consistent with the pH results through pH meter.

4.9 Quantity of Ash Generated

The below graph shows the quantity of ash produced for 100kg of waste at both site A and B. The ash produced during incineration of 100 kg of waste was 11 kg at site A and 4 kg of ash at site B.

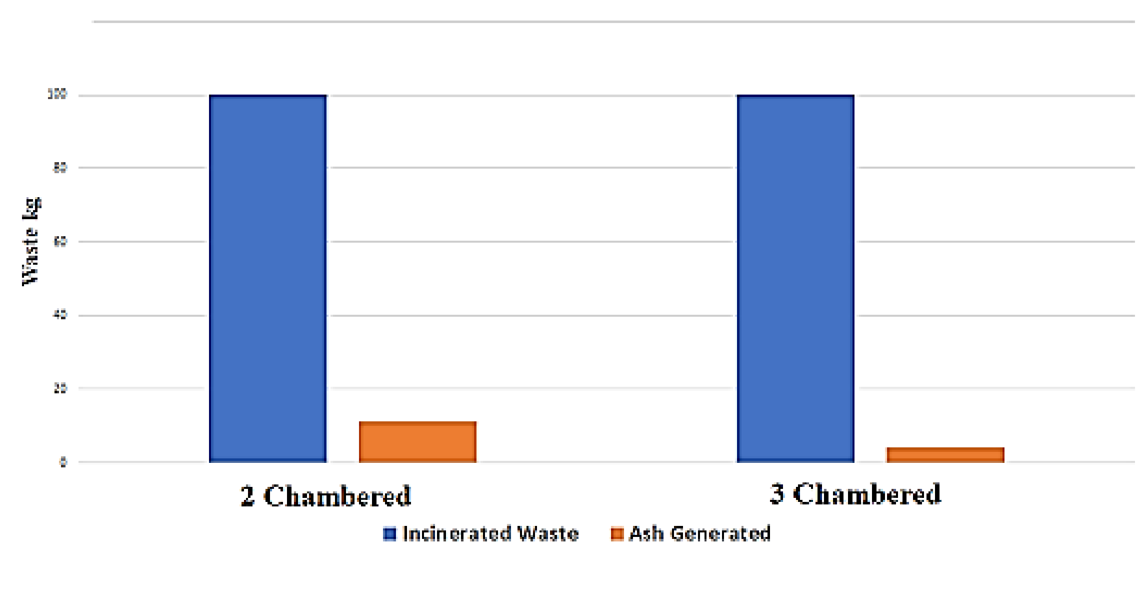


Figure 4.25. Ash produced at site A and B

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

From the analysis of this study following is being concluded that incineration carried out at lower temperatures generated exorbitantly higher amount of flu gases.

Pre-incineration temperatures were not achieved in case of site A and thus resulted in Incomplete Combustion which led to higher CO concentration.

Incineration above 600 Celsius showed substantial decrease in flue gas emissions and even remarkable results were achieved at temperature around 800^{o} C.

5.2 Recommendations

Following recommendations are being forwarded for further considerations.

Segregation of waste should be carried out.

Energy recovery is a viable option specifically in case of Plastic waste.

Siting of incinerator is of immense importance. It must not be near any public place and should be sited with all due considerations.

Policy intervention from the government is extremely mandatory for proper functioning of incinerators.

Inspection and Maintenance(I/M) record must be carried at different intervals.

Proper training and guidance of the staff is of utmost importance.

Awareness across the board, from patient to employee in and out of hospitals is key to successful management of Hospital Waste.

REFERENCES

ABDULLA, F., QDAIS, H. A. & RABI, A. 2008. Site investigation on medical waste management practices in northern Jordan. *Waste management,* 28**,** 450-458.

AKTER, N. 2000. Medical waste management: a review. *Environmental Engineering Program, School of Environment, Resources and Development Asian Institute of Technology, Thailand***,** 1-25.

AL-KHATIB, I. A. & SATO, C. 2009. Solid health care waste management status at health care centers in the West Bank–Palestinian Territory. *Waste management,* 29**,** 2398-2403.

ALAGÖZ, A. Z. & KOCASOY, G. 2008. Determination of the best appropriate management methods for the health-care wastes in Istanbul. *Waste Management,* 28**,** 1227-1235.

ALI, M., WANG, W. & CHAUDHRY, N. 2016. Management of wastes from hospitals: A case study in Pakistan. *Waste Management & Research,* 34**,** 87-90.

ALI, S., MAHMOOD, U., MALIK, A. U., AZIZ, F., NAGHMAN, R. B. & AHMED, I. 2015. Current hospital waste management practices in Pakistan: case study and curative measures. *Public Health Prevent Med,* 1**,** 125-9.

ALMUNEEF, M. & MEMISH, Z. A. 2003. Effective medical waste management: it can be done. *American journal of infection control,* 31**,** 188-192.

ARSHAD, N., NAYYAR, S., AMIN, F. & MAHMOOD, K. T. 2011. Hospital waste disposal: A review article. *Journal of Pharmaceutical Sciences and Research,* 3**,** 1412.

ASANTE, B., YANFUL, E. & YAOKUMAH, B. 2014. Healthcare Waste Management; Its Impact: A Case Study Of The Greater Accra Region, Ghana. *International Journal Of Scientific & Technology Research,* 3.

ASEWEH ABOR, P. & BOUWER, A. 2008. Medical waste management practices in a Southern African hospital. *International journal of health care quality assurance,* 21**,** 356-364.

BATTERMAN, S., WATER, S. & ORGANIZATION, W. H. 2004. Findings on an Assessment of Small-scale Incinerators for Health-care Waste. Geneva: World Health Organization.

BDOUR, A., ALTRABSHEH, B., HADADIN, N. & AL-SHAREIF, M. 2007. Assessment of medical wastes management practice: a case study of the northern part of Jordan. *Waste management,* 27**,** 746-759.

BIRCHARD, K. 2002. Out of sight, out of mind… the medical waste problem. *The Lancet,* 359**,** 56.

BIRPıNAR, M. E., BILGILI, M. S. & ERDOĞAN, T. 2009. Medical waste management in Turkey: A case study of Istanbul. *Waste management,* 29**,** 445-448.

BOWMAN, C. T. 1975. Kinetics of pollutant formation and destruction in combustion. *Progress in energy and combustion science,* 1**,** 33-45.

BUCCINI, J. 2003. The development of a global treaty on persistent organic pollutants (POPs). *Persistent organic pollutants.* Springer.

BUT, T., LOCKLEY, E. & ODUYEMI, K. 2008. Risk assessment of landfill disposal site-state of art. *Waste Management,* 28**,** 952.

CAMERON, J. 1994. The status of the precautionary principle. *Interpreting the precautionary principle*, 2**,** 262.

CHA, C. Y. & CARLISLE, C. T. 2001. Microwave process for volatile organic compound abatement. *Journal of the Air & Waste Management Association*, 51**,** 1628-1641.

CHARTIER, Y. 2014. *Safe management of wastes from health-care activities*, World Health Organization.

EKER, H. H. & BILGILI, M. S. 2011. Statistical analysis of waste generation in healthcare services: a case study. *Waste Management & Research,* 29**,** 791-796.

EL-SALAM, M. M. A. 2010. Hospital waste management in El-Beheira Governorate, Egypt. *Journal of environmental management*, 91**,** 618-629.

EPA, U. 1998. EPA's Contaminated Sediment Management Strategy. *OW, EPA-823-R-98-001*.

EPA, U. 2013. Inventory of US greenhouse gas emissions and sinks: 1990–2011. *Washington DC: United States Environmental Protection Agency,* 505.

FREY, H.-H., PETERS, B., HUNSINGER, H. & VEHLOW, J. 2003. Characterization of municipal solid waste combustion in a grate furnace. *Waste Management,* 23**,** 689-701.

HERSHKOWITZ, A. & SALERNI, E. 1987. *Garbage management in Japan; leading the way*, Inform, Inc.

HOSSAIN, M. S., SANTHANAM, A., NORULAINI, N. N. & OMAR, A. M. 2011. Clinical solid waste management practices and its impact on human health and environment–A review. *Waste management,* 31**,** 754-766.

JANG, Y.-C., LEE, C., YOON, O.-S. & KIM, H. 2006. Medical waste management in Korea. *Journal of environmental management*, 80**,** 107-115.

KHALID, F. & ABBASI, A. N. 2018. Challenges Faced by Pakistani Healthcare System: Clinician's Perspective. *Journal of the College of Physicians and Surgeons Pakistan,* 28**,** 899-901.

KLANGSIN, P. & HARDING, A. K. 1998. Medical waste treatment and disposal methods used by hospitals in Oregon, Washington, and Idaho. *Journal of the Air & waste management Association,* 48**,** 516-526.

KUMAR, R., KHAN, E. A., AHMED, J., KHAN, Z., MAGAN, M., NOUSHEEN, N. & MUGHAL, M. I. 2010. Healthcare waste management (HCWM) in Pakistan: current situation and training options. *Journal of Ayub Medical College Abbottabad,* 22**,** 101-106.

LEE, B.-K., ELLENBECKER, M. J. & MOURE-ERSASO, R. 2004. Alternatives for treatment and disposal cost reduction of regulated medical wastes. *Waste management,* 24**,** 143-151.

LEE, W.-J., LIOW, M.-C., TSAI, P.-J. & HSIEH, L.-T. 2002. Emission of polycyclic aromatic hydrocarbons from medical waste incinerators. *Atmospheric Environment,* 36**,** 781-790.

LICHTVELD, M. Y., RODENBECK, S. E. & LYBARGER, J. A. 1992. The findings of the Agency for Toxic Substances and Disease Registry Medical Waste Tracking Act report. *Environmental health perspectives,* 98**,** 243-250.

MARINKOVIĆ, N., VITALE, K., HOLCER, N. J., DŽAKULA, A. & PAVIĆ, T. 2008. Management of hazardous medical waste in Croatia. *Waste management,* 28**,** 1049-1056.

MATO, R. & KASEVA, M. 1999. Critical review of industrial and medical waste practices in Dar es Salaam City. *Resources, Conservation and Recycling,* 25**,** 271-287.

MATO, R. & KASSENGA, G. 1997. A study on problems of management of medical solid wastes in Dar es Salaam and their remedial measures. *Resources, conservation and recycling,* 21**,** 1-16.

MCKONE, T. E. & HAMMOND, S. K. 2000. Peer reviewed: managing the health impacts of waste incineration. *Environmental science & technology,* 34**,** 380A-387A.

MOHAMMED, A. M. A., KABBASHI, F. M. A. & HAMAD, H. K. A. 2017. *Production of Biogas From Biomedical Waste (Blood).* Sudan University of Science and Technology.

MORITZ, J. 1995. Current legislation governing clinical waste disposal. *Journal of Hospital Infection,* 30**,** 521-530.

NARAYANA, T. 2009. Municipal solid waste management in India: From waste disposal to recovery of resources? *Waste management,* 29**,** 1163-1166.

NEMATHAGA, F., MARINGA, S. & CHIMUKA, L. 2008. Hospital solid waste management practices in Limpopo Province, South Africa: A case study of two hospitals. *Waste management,* 28**,** 1236-1245.

ORGANIZATION, W. H. 1999. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. Part 1, Diagnosis and classification of diabetes mellitus. Geneva: World health organization.

ORGANIZATION, W. H. 2002. Prevention of hospital-acquired infections: a practical guide. Geneva, Switzerland: World Health Organization.

ORGANIZATION, W. H. 2006. *The world health report 2006: working together for health,* World Health Organization.

PATIL, A. & SHEKDAR, A. 2001. Health-care waste management in India. *Journal of Environmental Management,* 63**,** 211-220.

PATWARY, M. A., O'HARE, W. T., STREET, G., ELAHI, K. M., HOSSAIN, S. S. & SARKER, M. H. 2009. Quantitative assessment of medical waste generation in the capital city of Bangladesh. *Waste management,* 29**,** 2392-2397.

PERSSON, U. & WERNER, S. 2012. District heating in sequential energy supply. *Applied Energy,* 95**,** 123-131.

PINDERHUGHES, R. 2004. *Alternative urban futures: Planning for sustainable development in cities throughout the world*, Rowman & Littlefield.

PIRKLE, J. L., FLEGAL, K. M., BERNERT, J. T., BRODY, D. J., ETZEL, R. A. & MAURER, K. R. 1996. Exposure of the US population to environmental tobacco smoke: the Third National Health and Nutrition Examination Survey, 1988 to 1991. *Jama,* 275**,** 1233-1240.

PRÜSS-ÜSTÜN, A. 1999. *Safe management of wastes from health-care activities*, World Health Organization.

PRÜSS, A., EMMANUEL, J., STRINGER, R., PIEPER, U., TOWNEND, W., WILBURN, S., CHANTIER, Y. & ORGANIZATION, W. H. 2014. *Safe management of wastes from health-care activities*, World Health Organization.

RASHEED, S., IQBAL, S., BAIG, L. A. & MUFTI, K. 2005. Hospital Waste Management in theTeaching Hospitals of Karachi. *JPMA,* 55**,** 192.

RUTALA, W. A. & MAYHALL, C. G. 1992. Medical waste. *Infection Control & Hospital Epidemiology,* 13**,** 38-48.

SALKIN, I. F. 2003. Conventional and alternative technologies for the treatment of infectious waste. *Journal of Material Cycles and Waste Management,* 5**,** 0009-0012.

SHARMA, M. 2002. *Hospital waste management and its monitoring*, JAYPEE BROTHERS PUBLISHERS.

SKALSKA, K., MILLER, J. S. & LEDAKOWICZ, S. 2010. Trends in NOx abatement: A review. *Science of the total environment,* 408**,** 3976-3989.

STEELE, J. 2001. Participation and deliberation in environmental law: exploring a problem-solving approach. *Oxford Journal of Legal Studies,* 21**,** 415-442.

SUPPLY, W. U. J. W. & PROGRAMME, S. M. 2014. *Progress on drinking water and sanitation: 2014 Update*, World Health Organization.

TAGHIPOUR, H. & MOSAFERI, M. 2009. Characterization of medical waste from hospitals in Tabriz, Iran. *Science of the total environment,* 407**,** 1527-1535.

TAMMEMAGI, H. Y. 1999. *The waste crisis: landfills, incinerators, and the search for a sustainable future*, Oxford university press.

TCHOBANOGLOUS, G., THEISEN, H., VIGIL, S. A. & ALANIZ, V. M. 1993. *Integrated solid waste management: engineering principles and management issues*, McGraw-Hill New York.

THOMAS-HOPE, E. M. 1998. *Solid waste management: critical issues for developing countries,* Canoe Press.

TUDOR, T., NOONAN, C. & JENKIN, L. 2005. Healthcare waste management: a case study from the National Health Service in Cornwall, United Kingdom. *Waste management,* 25**,** 606-615.

UNEP 1972. Declaration of the United Nations conference on the human environment. UNEP.

UYSAL, F. & TINMAZ, E. 2004. Medical waste management in Trachea region of Turkey: suggested remedial action. *Waste management & research,* 22**,** 403-407.

VISVANATHAN, C. 1996. Hazardous waste disposal. *Resources, conservation and recycling,* 16**,** 201-212.

VISVANATHAN, C. Medical waste management issues in Asia. International Conf "Asia 3R Conference, 2006.

WAGNER, T. & ARNOLD, P. 2008. A new model for solid waste management: an analysis of the Nova Scotia MSW strategy. *Journal of cleaner Production,* 16**,** 410-421.

WIELGOSIŃSKI, G. 2012. Pollutant formation in combustion processes. *Advances in Chemical Engineering.* IntechOpen.

WILLIAMS, P. T. 2005. *Waste treatment and disposal*, John Wiley & Sons.

WINDFELD, E. S. & BROOKS, M. S.-L. 2015. Medical waste management–A review. *Journal of environmental management,* 163**,** 98-108.

YADAV, M. 2001. Hospital waste-a major problem. *JK PRACTITIONER,* 8**,** 276-282.

ZHAO, W., VAN DER VOET, E., HUPPES, G. & ZHANG, Y. 2009. Comparative life cycle assessments of incineration and non-incineration treatments for medical waste. *The International Journal of Life Cycle Assessment,* 14**,** 114-121.