SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

College of Graduate Studies

CENTRAL MEDICAL WASTE TREATMENT FACILITY

منشأة مركزية لمعالجة النفايات الطبية

Submitted in partial fulfillment of the requirement of M.Sc (Honor) Degree in Biomedical Engineering

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Dedication

To my family,

And friends…,

Iman Abdel Rahim Eissa

Acknowledgement

Heartfelt thanks, praises and glorification to Allah who gave us life, knowledge, and for making this research possible,

I would like to express my gratitude to Dr. Elyas, Dr. Eltahir and everyone who supported, helped and encouraged me, thankful for their aspiring guidance, invaluably constructive criticism and friendly advice during the project work. I am sincerely grateful to them for sharing their truthful and illuminating views on a number of issues related to the project.

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LIST OF APREVIATIONS

APCDs: Air Pollution Control Devices

CBWTF: Central Biomedical Waste Treatment Facility

ETP: Effluent Treatment Plant

HCEs: Health Care Establishments

HCFs: Health Care Facilities

HCW: Health Care Waste

HCWM: Health Care Waste Management

ICRC: International Committee of Red Cross

ID: Induced Draft

LSU: Louisiana State University

NNUH: Norfolk and Norwich University Hospital

PCC: Primary Combustion Chamber

PLC: Program Logic Control

PVC: Polyvinyl Chloride

RKI: Rotary Kiln Incinerator

SCC: Secondary Combustion Chamber

SPSS: Statistical Package for Social Sciences

UK: United Kingdom

UNDP: United Nations Development Program

WHO: World Health Organization

Abstract

The main purpose of the research is to design a Common Central biomedical waste treatment facility CBWTF and number of waste assembly points distributed in different geographical locations within state of Khartoum, and then treating and destroying hazardous wastes in a cost-effective and ecology friend. The design depends on high temperature thermal process, that reduce waste hazard, volume and destroying harmful substances by employing combustion or heat of the waste as primary treatment agent, with under controlled condition for converting them into inert material and filtered gases, use of Rotary Kiln Incinerator (RKI) technology, providing an overall reduction in the environmental impact that might otherwise arise from the waste. The rotary kiln is the most efficient processing system for the drying, volume reduction and destruction of almost all types of wastes.

The capital cost of the project about 22-25 million Dollars for waste capacity of 3,5 ton/hr, in addition to operational cost which is depend on power, water , staffing and maintenance cost which is typically 3 – 5% of capital investment cost.

The results of the project demonstrate the need for strict enforcement of legal provisions and a better environmental management system for the disposal of biomedical waste in hospitals as well as other healthcare establishments.

المستخلص

إن الغرض الرئيسي من هذا البحث هو تصميم منشأةٍ مركزيةٍ مشتركةٍ لمعالجة النفايات الطبية وعدد من نقاط تجميع النفايات الموزعة علي عدد من المناطق الجغرافية المختلفة داخل ولاية الخرطوم. ومن ثم معالجة وإعدام هذه النفايات بتصنفياتها المختلفة بأقل التكاليف وبطرق صديقه للبيئة.

وهذا التصميم يعتمد علي المعالجة الحرارية التي تعد من أفضل الطرق المستخدمة في إعدام النفايات والتخلص من المكونات المؤذية حيث أنها تقلل من حجم وخطورة النفايات الطبية بواسطة الإحتراق المتحكم به لتحويل النفايات لمواد خاملة وغازات؛ وذلك بإستخدام محرقة روتاري كلن حيث أنها من أكثر انظمة المعالجة الحرارية فعاليه في عمليات التجفيف , تخفيض الحجم والتخلص من معظم أنواع النفايات الطبية. كما أنها تعمل علي تخفيض تأثير المعالجة الحرارية للنفايات علي البيئة.

التكلفة الإنشائية الكلية لهذا المشروع حوالي 22-25 مليون دولار امريكي لسعة 3.5طن في الساعة, بالإضافة إلى تكلفة التشغيل التي تعتمد علي الطاقة, الوقود,الماء بالإضافة إلى تكلفة الصيانة التي تبلغ حوالي 3-5%من التكلفة الإجمالية.

نتائج المشروع تظهر الحاجة إلى التطبيق الصارم للأحكام والقوانين وتوفير نظم أفضل للتخلص من النفايات الطبية وإدارة البيئه.

CHAPTER ONE

INTRODUCTION

1.1 General View

The world modern life style is generating huge amounts of waste, hospitals and health centers are no exception. Medical waste can be infectious and hazardous; it poses serious contamination risks to both people and environment; that threats to hygiene environment, for this reason it requires specific treatment and management prior to its final disposal. If patients are to receive health care and recover in safe surroundings, waste must be disposed of safely [1].

State of Khartoum is currently facing a serious and imminent medical waste problem, especially with the noticeable increase of the hospitals and health care centers number. Despite the fewer efforts and progress made in waste reduction and treatment individually, there remains a huge untreated waste that needs to be disposed of properly.

Biomedical waste management has recently emerged as an issue of major concern not only to hospitals, and other health care establishment utilities, but also to the environment. Now it is a well established fact that there are many adverse and harmful effects to the environment including human beings which are caused by the health care waste generated during the medical practice patient care [2].

In order to ensure the safety of staff, patients, attendants, general public and environment, waste generated in the hospital, healthcare institutions should be properly segregated at the source of production, transported in special trucks and then scientifically disposed off as the available treatment technology[3]. The medical waste shall be transported to assembly point before reaching the central facility because of its harmful and toxicity. The biomedical waste shall be transported to nearest assembly point using, a special transportation vehicle according to agreed regulations and schedules where disinfection and repackaging processes will take place. The assembly points have all facilities like shredder, autoclave and chemical process for pretreatment of the medical waste.

Prior treatment segregation should be the responsibility of the Healthcare Establishments HCEs such as hospitals and others; whereas the final disposal should be done at the central treatment facility.

The Central Biomedical Waste Treatment Facility CBWTF is a set up based on the need for ensuring environmentally sounded management of bio-medical waste, to reduce the adverse effects that this waste may produce. The treated waste may finally be sent for disposal in a landfill or for recycling purpose. A CBWTF shall be designed to solve the medical waste disposal problems in Khartoum state, which most of the hospitals and other health care establishments suffer, it must be located at a place reasonably away from the residential and sensitive areas.

1.2 Problem Statement

In the developing countries, adoption of medical waste programs and proper disposal of waste was rarely set to be an organizational main objective due to its high cost of treatment within a limited facilities budget and lack of awareness of their environmental impacts. Nevertheless, setting up of incinerators in hospitals and healthcare centers has to be discouraged as the incinerator can be a source of pollution.

1.3 Objectives

The objectives of the project are

1.3.1 Specific Objectives

Scientific waste management leads to:

1. Develop cleaner and hygiene surroundings by reduction of waste management cost and infection control, thus less possibility of disease and death due to reuse and repackaging of infectious disposables.
2. Insure low incidence of community and occupational health hazards by ensuring that on-site waste management systems are well integrated with off-site collection services [3].

1.3.2 General Objective

A major purpose of this research is to design and establish standard common central medical waste treatment facility in the State of Khartoum that ensures safe collection, transportation, treatment and disposal of biomedical waste by either qualified entrepreneur, a co-operative or the government on a pay and use basis; normally infectious waste cannot be so easily decontaminated within the healthcare establishment and that's the reason the common facility operator picks up the infectious waste and transports it in a safe way to an offsite facility, treats and decontaminates the waste. The CBWTF is normally established in the outskirts of the city or town and the medical waste collected from different healthcare establishments is brought to the facility for treatment and disposal in a cold storage van [3].

1.4 Methodology

A survey using structured questionnaire was used to collect information, addressing the generation and management of medical waste according to amounts and sources from different HCEs.

Gathered information was analyzed and used to identify the specifications to design a central biomedical waste treatment facility system using three dimensional solid work programs, the system shown on block diagram below

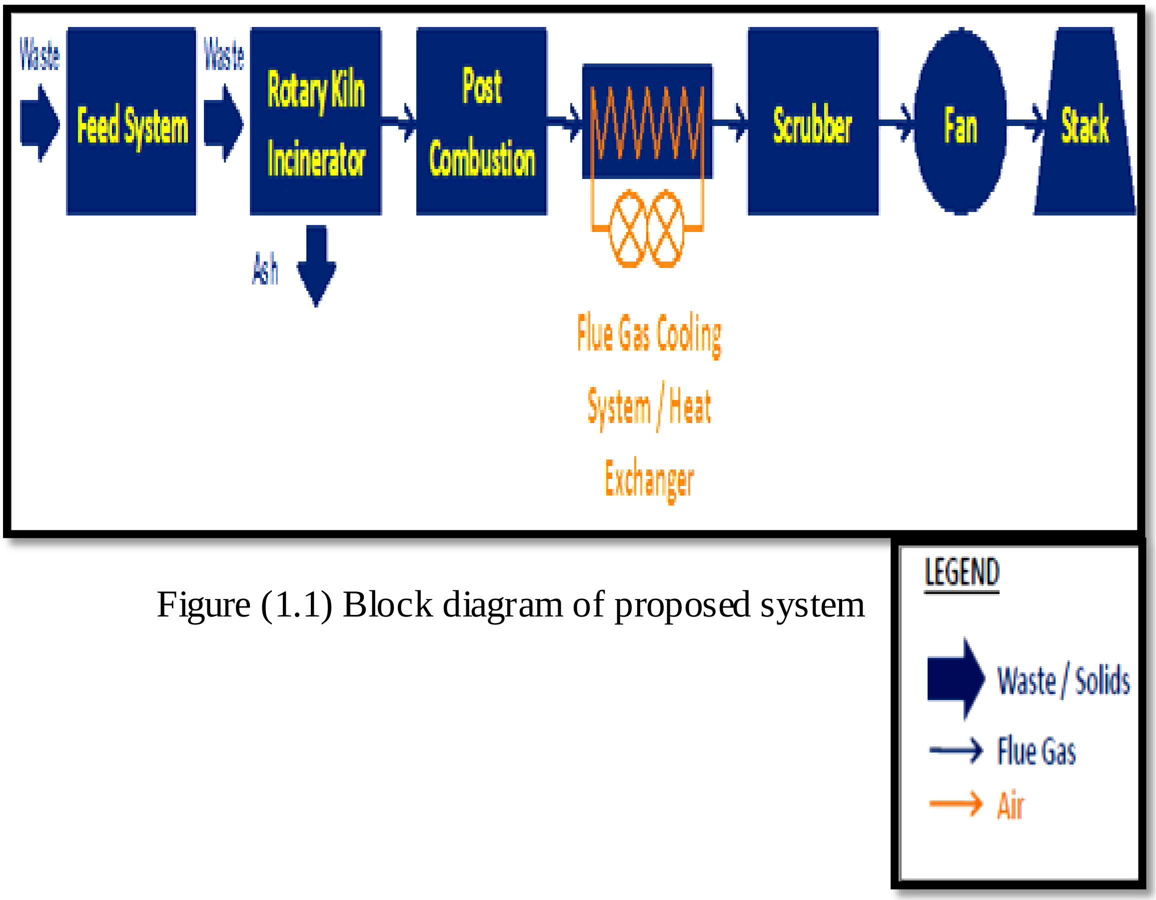


Figure (1.1) Block diagram of proposed system

1.5 Thesis layout

This research consists of seven chapters:

Chapter one, is an introduction about medical waste including, problem statement of medical waste, objectives from this project and methodology used to build this system. Previous studies about medical waste management on different countries are presented in chapter two. Chapter Three deals with theoretical background about medical waste including its generation sources, classification of medical waste and general guidelines steps for proper biomedical waste management process.
Date collection and analysis from surveyed questionnaire and interviews are given in chapter four.
The design of assembly points and central biomedical waste treatment facility including three dimensional design of rotary kiln incineration system with air pollution control devices are in chapter five.
Discussions about analysis results are illustrated in chapter six, finally chapter seven, covers conclusion and recommendations.

CHAPTER TWO

PREVIOUS STUDIES

1. United Nations Development Program (UNDP), World Health Organization (WHO),in (2009), the assessment done on health care facilities(over 67,740) in African countries, in relation to infectious waste treatment ; concluded that there are considerable numbers of health care facilities HCFs with different capacities and its waste disposal need to be highly considered. Many of these health care facilities HCFs are public driven and they depend much on the government budget to run various services.

The generation of waste in Africa varies considerably between same levels of HCFs due waste management methods, type of HCFs, proportion of patients treated daily and the degree of specialization of the health facility. In some countries surveyed e.g. Gambia, Lesotho the waste generation data shows that the ratio of infectious waste and general waste is almost the same which indicate that segregation is not well conducted. Many countries which use De Montfort incinerators there has been reports on inoperative or operating below standards. In some hospitals they have re-built their incinerators in a number of times due to frequently break down. Furthermore, many of HCFs lack specific budget for Health Care Waste Management (HCWM) and depend much on the government budget to run various services including that of having a HCWM system. Beside, lack elaborated legal policy specifically for health care waste HCW [4].

2. Kevin Paul Pudussery in (2011), on UK; found that the high generation rate of medical waste is a proof that medical waste management in UK is problematic. Based on a case study undertaken at Norfolk and Norwich University Hospital (NNUH) that looks into the various issues in the field of medical waste management. The research explores the staff‘s perception towards the medical waste management. Also, the study aims to examine the knowledge level, attitude and role of health care workers towards the medical waste management. Besides, looks into the various medical waste treatment technologies available and choose the best available technology for the onsite treatment of medical waste. A multi criteria decision analysis is used for the same.

The results of the study show that the health care workers have a critical role in achieving efficient medical waste management, and improvements have to be made at the medical waste management at various levels. Beside, looked in to the various medical treatment technologies of medical waste at NNUH and found incineration as the best available technology.

The most of the legislations in medical waste management is related to the health and safety issues and less importance is given to waste minimization. The study has found that the hospital can be benefited both environmentally and economically by improving the medical waste management at NNUH. [5]

3. K.V.Radha, et al in (2009), this study were conducted in India to assess the quantities and proportions of different constituents of wastes, their handling, treatment and disposal methods in different health-care settings. Various health care units were surveyed using a modified survey questionnaire for waste management. This questionnaire was obtained from the World Health Organization (WHO), with the aim of assessing the processing systems for biomedical waste disposal. Hazards associated with poor biomedical waste management and short comings in the existing system were identified.

The development of waste management policies, plans, and protocols are recommended, in addition, to establishing training programs on proper waste management for all healthcare workers, all the hospital biomedical waste is being disposed along with municipal solid waste. The untreated liquid waste from the health institutions is let into drainage, waste sharps are discarded without disinfection and mutilation; which may result in their being re-used thus spreading an infection. The waste collection and transportation workers in the hospital segregate the recyclable material for sale. In a similar way, all disposable plastic items are segregated by the waste pickers.
The survived hospitals are severely lacking in actions to dispose of its waste and uphold its statutory responsibilities; this is due to the lack of education, awareness and trained personnel to manage the waste in the hospital, as well as the paucity of the funds available to proper waste management system.

The results of the study demonstrate the need for strict enforcement of legal provisions and a better environmental management system for the disposal of biomedical waste in hospitals as well as other healthcare establishments. A policy needs to be formulated based on 'reduce, recover, reuse and dispose'. The study concludes that healthcare waste management should go beyond data compilation, enforcement of regulations and acquisition of better equipment. It should be supported through appropriate education, training and the commitment of the healthcare staff, management and healthcare managers within an effective policy and legislative framework [6].

4. Adel Ahmed in (2011), the study was about the management of medical waste having been published in Yemen. This research in 5 government and 12 private hospitals in Sana'a aimed to evaluate waste-workers' and hospital administrators' knowledge and practices regarding medical waste handling. Interviews and observations showed that the waste-workers were collecting medical and nonmedical wastes together manually in all hospitals without receiving adequate training and without using proper protection equipment.

There was poor awareness about medical waste risks and safe handling procedures among hospital administrators, and most hospitals were not differentiating between domestic and medical waste, workers were disposing liquid waste directly into the sewage system without any processing. None of the hospitals had allocated budget for waste management purposes; which caused shortages in waste facilities, handling equipment, supplies and absence of training programs for staff which lead to poor knowledge. Poor knowledge and practices and a high rate of injuries among waste-workers were noted, together with a risk of exposure of staff and visitors to hazardous waste [7].

5. M. Manzurul , et al in (2008),the study done on Dhaka city/Bangladesh, reveals that disposal of medical wastes is a growing environmental problem in Bangladesh due to lack of awareness, appropriate policy and laws, which are responsible for the improper management of medical waste in Dhaka City.

The study reveals that there is no proper, systematic management of medical waste except in a few private HCEs that segregate their

infectious wastes. Some cleaners were found to salvage used sharps, saline bags, blood bags and test tubes for resale or reuse.
The process of collection, segregation and disposal of medical waste is not performed according to recommended standards, and concerned people are exposed to the danger of such wastes. The management of medical wastes has recently received little attention despite their potential environmental hazards and public health risks [8].

6. John Sutherland et al in (2003), studies of incineration of surrogates for hazardous wastes are conducted in the pilot-scale rotary kiln incinerator (RKI) at Louisiana State University (LSU) in Baton Rouge, Louisiana. The purpose of the research is to investigate methods of treating and destroying hazardous wastes in a cost-effective and environmentally sound way.
The objective is to provide process data that will contribute to increased knowledge for RKI design and operation. The LSU facility has a College of Engineering Combustion Laboratory that is unique in its large size as a university laboratory. It is equipped with individual instruments for analysis of O_2, CO, CO_2, HCl, SO_x and NO_x and a mass spectrometer to continuously monitor products of combustion for rigorous evaluation of efficiencies of operation.

Experiments conducted to investigate parameters and variables affecting the design and operation of the kiln substantiate mathematical treatment of material and energy balances. These investigations add new and useful data to be used in design of rotary kilns [9].

CHAPTER THREE

THEORTICAL BACKGROUND

3.1 Biomedical Waste

Bio-medical waste is any waste, solid, fluid or liquid waste, including its container and any intermediate product which is generated during the diagnosis, treatment or immunization of human beings or animals [3]. Sources of bio medical waste include:

Major sources

1. Governmental hospitals, private hospitals, dispensaries.
2. Primary health centers and Medical colleges and research centers, paramedic services.
3. Veterinary colleges and animal research centers.
4. Blood banks, mortuaries, autopsy centers.
5. Biotechnology institutions and Production units.

Minor sources

1. Physicians, dentists clinics
2. Animal houses, slaughter houses [2].

3.2 Quantification of Medical waste

The quantity of medical waste produced in health care establishments (HCEs) depends on the level of national income and the type of facility concerned. A university hospital in a high-income country can produce up to 10 kg of waste per bed per day; hospitals with 100 beds will produce an average of 1.5 to 3 kg of waste per patient per day [1].

According to most recently statistics on 2014, from Sudan ministry of health, the medical waste produced in the country is approximately 3kg/bed/day from 6533 hospitals and 221 health care centers, resulting in about 20.0 ton/day of a total produced waste. This number is continuously increasing by the establishment of new medical and health care centers.

3.3 Classification of Biomedical waste

World health organization states that 85% of hospital wastes are actually non-hazardous, whereas 10% are infectious and 5% are non-infectious but they are included in hazardous wastes. About 15% to 35% of hospital waste is regulated as infectious waste, as shown on figure (3.1). This range is dependent on the total amount of waste generated [2].

The world health organization (WHO) has classified medical waste into: [2]

1. General Waste.
2. Pathological.
3. Radioactive.
4. Chemical.
5. Infectious to potentially infectious waste.
6. Sharps.
7. Pharmaceuticals.
8. Genotoxic waste.
9. Heavy metals waste.
10. Pressurized containers.

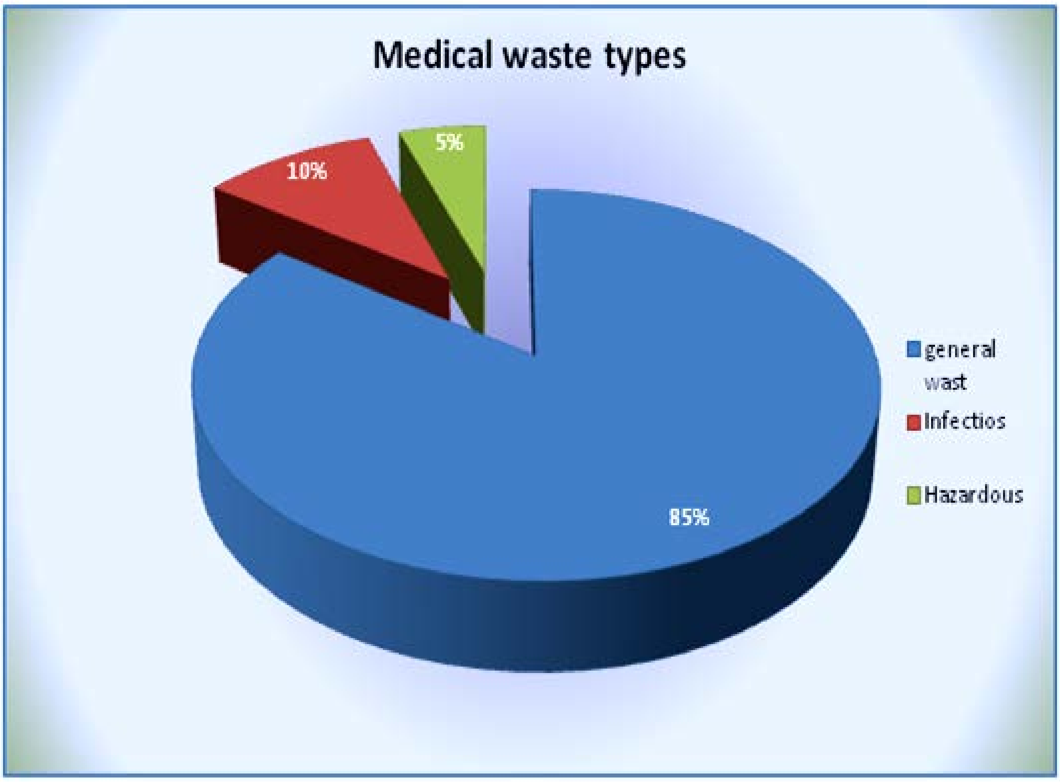


Figure (3.1) Types of medical waste

There are other classifications according to International Committee of the Red Cross (ICRC) [1]:

1. General waste: 75 % to 90 % of hospital wastes are similar to household refuse or municipal waste and do not entail any particular hazard.
2. Hazardous waste: The other 25% to 10% is called hazardous medical waste or special waste. This type of waste entails health risks.

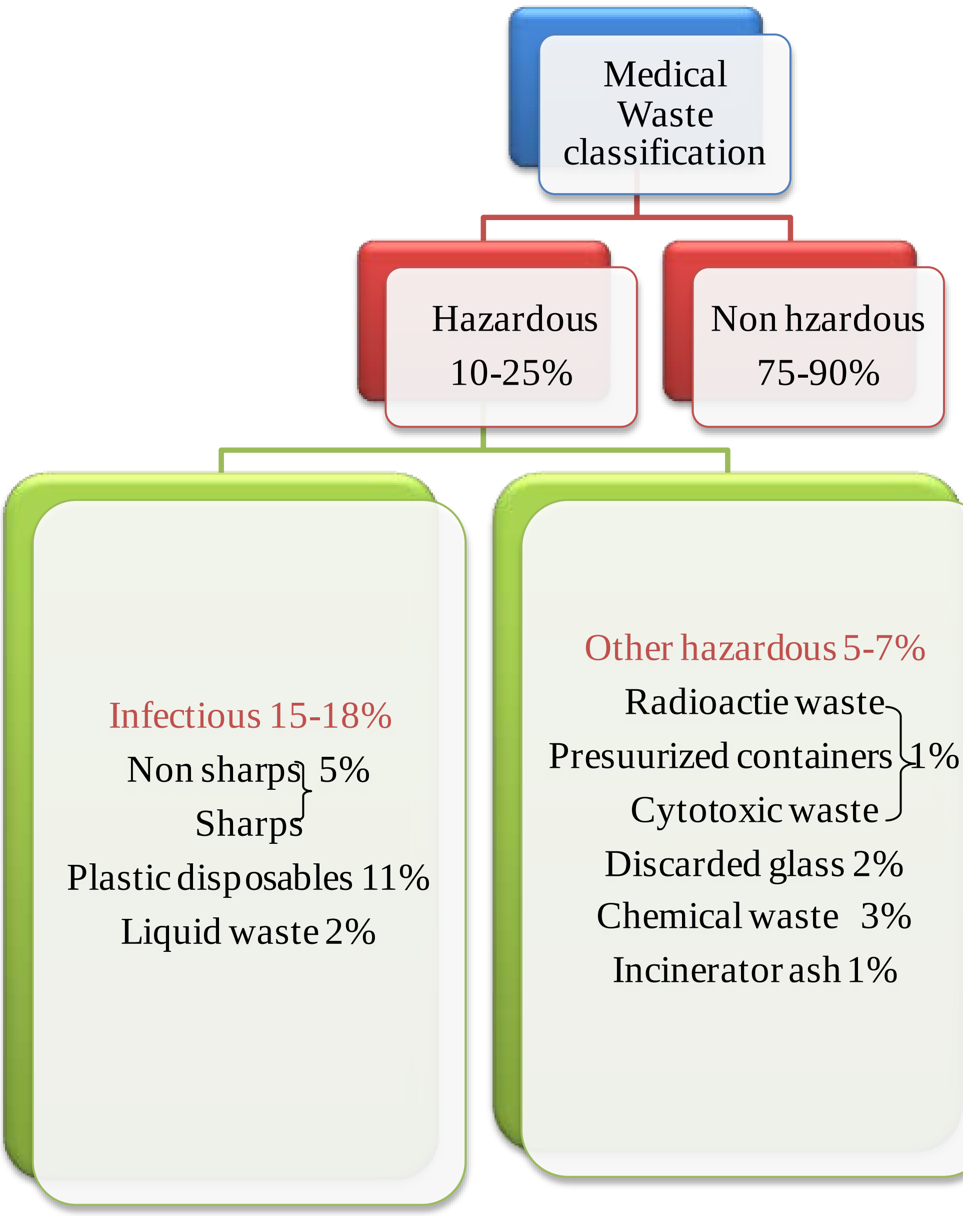


Figure (3.2) Medical waste classification according to ICRC

Classification of hazardous medical waste according to risk involved with respect to ICRC shown on table below.

Table (3.1) Classification of hazardous medical waste [1]

1.	Sharps	Any wastes that entailing risk of injury as: needles, scalpel blades, microscope slides … etc. It makes up most of the volume of medical waste.
2.	a. Waste entailing risk of contamination	Waste containing blood, secretions that causes risk of transmission of infectious diseases as urine collection bags, bags of blood, …etc.
	b. Anatomical waste	Body parts, tissue as: placentas, organs that have been removed, amputated limbs, fetuses.
	c. Infectious waste	Containing large quantities of material, substances or cultures entailing the risk of propagating infectious agents. : cultures of infectious agents waste from infectious patients placed in isolation wards).
3.	a.Pharmaceutical waste	Unused/unwanted drugs and receptacles which contained medicines as: expired drugs, unused drugs, contaminated drugs, bottles and vials containing drug residues.
	b. Cytotoxic waste	Substances that are mainly used for cancer chemotherapy as: waste consists of the equipment that is contaminated during the preparation and administration of these drugs, expired or left over cytotoxic drugs and the secretions or excreta of patients undergoing cytotoxic treatment.

	c. Waste containing heavy metals	Mercury waste as: broken thermometers or blood pressure gauge, equipment/items used to gather up a mercury spill, fluorescent.
	d. Chemical waste	Waste containing chemical substances: leftover laboratory solvents, disinfectants, liquids used for photographic development(radiology)
4.	Pressurized containers	Gas cylinders, combustible gas cylinders, pesticide spray cans.
5.	Radioactive waste	Waste containing radioactive substances: radionuclides used in laboratories or nuclear medicine, urine or excreta of patients treated nuclear medicine.

3.4 General Guidelines

There are several guidelines for proper biomedical waste management process which are illustrated below.

3.4.1 Segregation and Sorting of Medical waste

The key to minimization and effective management of biomedical waste is segregation (separation) and identification of the waste. There is an urgent need to keep the infectious waste separate from non-infectious waste, because the infectious waste which is only 10-15% if mixed with non-infectious waste which is 80-85% can render the entire waste infectious, segregation of medical waste at the source of generation; helps in minimizing the amount of waste to be treated. Besides enabling more efficient treatment of each category of waste [3]

The most appropriate way of identifying the categories of biomedical waste is by sorting the waste based on color coding. This has to be segregated into containers/ bags at the point of generation according to table below (3.3).
Sorting consists of clearly identifying the various types of waste and how they can be collected separately. There are two important principles that must be followed:

1. Waste sorting must always be the responsibility of the entity that produces them. It must be done as close as possible to the site where the wastes are produced.
2. There is no point in sorting wastes that undergo the same treatment process, with the exception of sharps, which must at all times be separated at source from other wastes [1].

Segregation steps of Medical waste

a. Medical waste will be segregated at the point of generation in each work area. Waste will be placed in biohazard bags labeled with the words "Biohazardous waste" or with the biohazard symbol and the word "Biohazard." Biohazard bags will be sealed at the point of origin to prevent leakage or expulsion of contents when they are ready for transport, treatment and disposal.
b. Biohazard Bags will be placed in labeled, leak proof secondary containers with tight-fitting covers. Medical waste bags will not be removed from the secondary container except for transfer to another secondary container or to the secondary storage container at the storage/accumulation site.
c. Bagged medical waste will be transport in secondary containers to the designated storage/accumulation site and removed only when transferred into other secondary containers [10].

Segregation Rules

a. Biomedical waste must be stored in a secure environment at all times.
b. Whenever possible, biomedical waste must not be mixed with chemical, radioactive or other laboratory trash. This may be unavoidable (i.e. radioactive carcasses) and in such instances special handling may be required.
c. The various types of biomedical waste should be segregated from each other.
d. Fluid waste should be contained separately from solid waste [11].

3.4.2 Containment and Labeling

Containers for biomedical waste must be appropriate for its contents; there are several different kinds of containers and bags available for the containment and disposal of biomedical waste.

Medical waste will be placed in red/yellow biohazard bags within an approved secondary container, or in approved sharps containers, at the point of generation. It may be stored at room temperature up to seven (7) days after generation prior to treatment [10].

All containers for biomedical waste must display the biohazard symbol and the words 'Biohazard' in a colour contrasting the container, shown below [1].

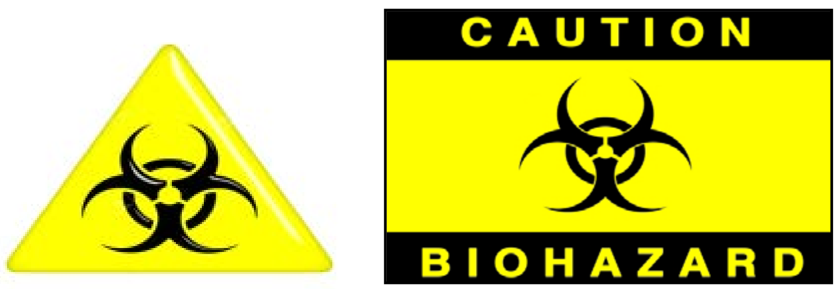


Figure (3.3) Medical waste biohazard symbols

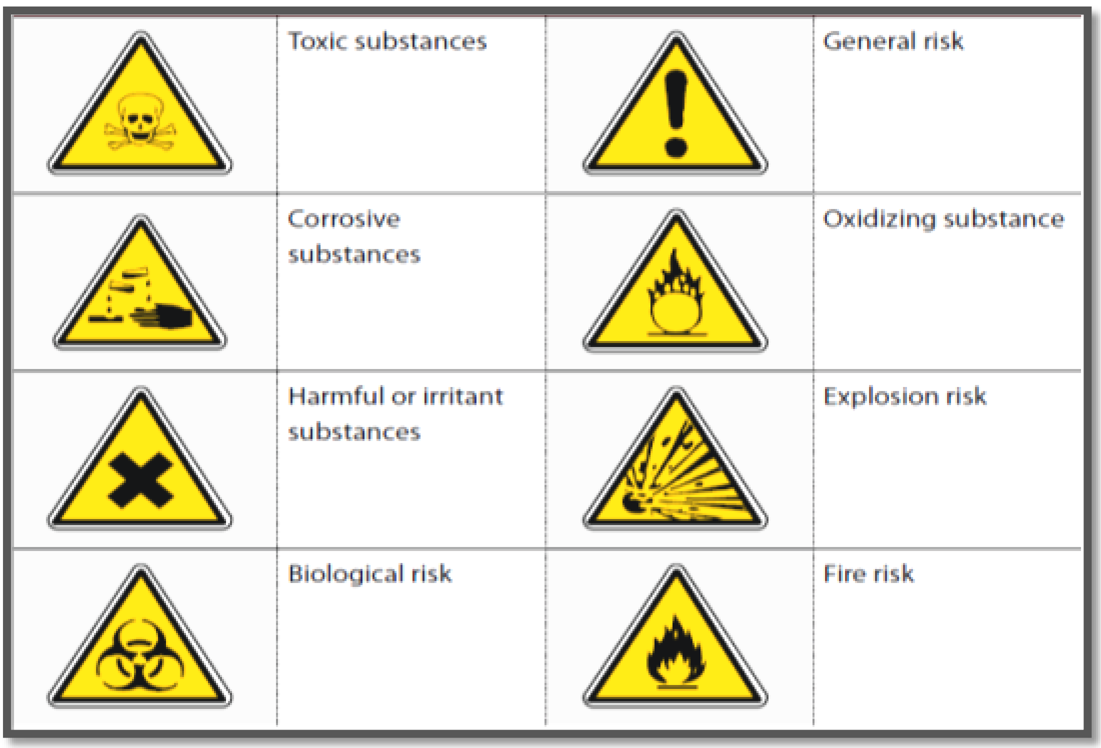


Figure (3.4) Warning and hazard signs

The following are some guidelines to remember when packaging waste

1. Double bag if necessary to prevent perforations.
2. Add absorbent material if the possibility of large volumes of liquid exists.
3. Ensure the bags are well sealed and do not overfill the containers/bags.
4. If the outside of the bag is contaminated, double bag.
5. Secondary containment should also be labeled with the biohazard symbol [11].

3.4.3 Handling of Medical waste

Bags and containers must be closed whenever they are two-thirds full. This is the responsibility of the nursing staff. Never pile bags or empty them; grasp them from the top (never hold them against the body) and wear gloves. [1]

Figure (3.5) Handling of medical waste

Handling Rules

1. Untreated waste should be handled as little as possible.
2. Avoid contaminating exterior surface of waste container, or ensure exterior surfaces are decontaminated.
3. Avoid transport of untreated waste through non-lab or high traffic corridors.
4. Secondary containers must be used when transporting waste (especially for liquids). The secondary containers should be decontaminated after use.

5. Whenever possible use carts with raised sides for transport.
6. Ensure containers or bags are tightly closed or taped shut during transport [11].

3.4.4 Collection and Storage

Waste must be collected regularly - at least once a day. It must never be allowed to accumulate where it is produced. A daily collection program and collection round must be planned. Infectious wastes must never be stored in places that are open to the public. Use of stands or containers equipped with special plastic bags or with double bags where there is a lot of liquid. The bags must not be piled up or emptied, must be grasped from the top and not to be filled more than two thirds. The bags that have been collected must be replaced immediately with new bags. For cultural reasons, anatomical waste will not always be possible to collect these wastes in bags [1].

Sharp wastes must be collected in puncture-proof, impermeable containers that can be closed with having labels. The care staff must drop sharps into the container immediately after use, without putting the cap back on the syringe needle, without removing the syringe needle by hand and without setting the unsafe item down on any surface. The care staff must make sure that they seal the containers once they are two-thirds full before they are removed to the interim storage area [1, 3].
The pharmaceutical waste collection and packaging is managed by the hospital Pharmacy. Unused cytotoxic substances must be returned to the supplier. The waste must be placed in sealed, leak-proof receptacles.

An appropriate packaging must be used for chemical waste; generally high-density polyethylene, PVC or glass for highly oxidative inorganic acids. Chemicals must not be mixed. In case of Photographic liquids must be collected in leak-proof containers with labels [1].
Storage refers to the holding of Bio-medical waste for a certain period of time, after which it is sent for treatment and disposal. In other words it means the duration of time for which waste is kept at the site of generation and transit treatment and final disposal is done [3].

Specific considerations for storing medical waste area must meet the following criteria [1]

1. It must be closed, and access must be restricted to authorized persons only, separate from any food store, covered and sheltered from the sun.
2. The flooring must be waterproof with good drainage and easy to clean.
3. It must be protected from rodents, birds and other animals.
4. There must be easy access for on-site and off-site means of transport.
5. It must be well aired and well lit.
6. It must be compartmented (so that the various types of waste can be sorted).
7. It must be near the incinerator, if incineration is the treatment method used.
8. There must be wash basins nearby and the entrance must be marked with a sign ("No unauthorized access", "Toxic", or "Risk of infection.

3.4.5 Transportation

Used for transporting medical waste and must be reserved only for that purpose. There are two types of medical waste transportation techniques.

1. On-site Transport

Inside the facility, waste must be transported during slacker periods avoiding clean zones (sterilization rooms), sensitive areas (operating theatres, intensive care units) or public areas as possible. Different means of conveyance may be used inside the facility – wheelbarrows, containers on wheels, carts that are not used for any other purpose. The trolleys have to be cleaned daily, shown on figure (3.6) [1].

Figure (3.6) Secondary Medical waste container

2. Off-site Transport

Off site transportation vehicle should be marked with the name and address of carrier. Biohazard symbol should be painted. Suitable system for securing the load during transport should be ensured. Such a vehicle should be easily cleanable with rounded corners [6].

Disposal occurs off-site, at a location that is different from the site of generation. Treatment may occur on-site or off-site. On-site treatment of large quantities of biomedical waste usually requires the use of relatively expensive equipment, and is generally only cost effective for very large hospitals and major universities who have the space, labor and budget to operate such equipment. Off-site treatment and disposal involves hiring of a biomedical waste disposal service (also called a truck service) whose employees are trained to collect and haul away biomedical waste in special containers (usually cardboard boxes, or reusable plastic bins) for treatment .at a facility designed to handle biomedical waste [12].

Medical waste guidelines for vehicles and means of conveyance

These means of conveyance must meet the following requirements [3]

1. They must be easy to load and unload.
2. They must not have any sharp corners or edges that might tear the bags or damage the containers, they must be easy to clean; (with a 5% active chlorine solution).
3. They must be clearly marked.

Furthermore, off-site means of transport as on figure below, must meet the following requirements

1. They must be closed in order to avoid any spilling on the road and must equip with a safe loading system (to prevent any spilling inside or outside the vehicle).
2. The vehicles and means of conveyance must be cleaned daily.
3. Wastes have to be transported according to the motor vehicle Act which prescribes standards for the transport of hazardous wastes.
4. The vehicle should be a covered one with proper markings to indicate that infectious bio-medical wastes are being transported in it.

5. The vehicle may have to be refrigerated in case the ambient temperature is very high as in the summers and the wastes have to be transported over long distances for a substantial period of time.
6. It must be useful to have different compartments to separate infectious wastes from general wastes and to avoid contamination.

Figure (3.7) Bio-medical waste van

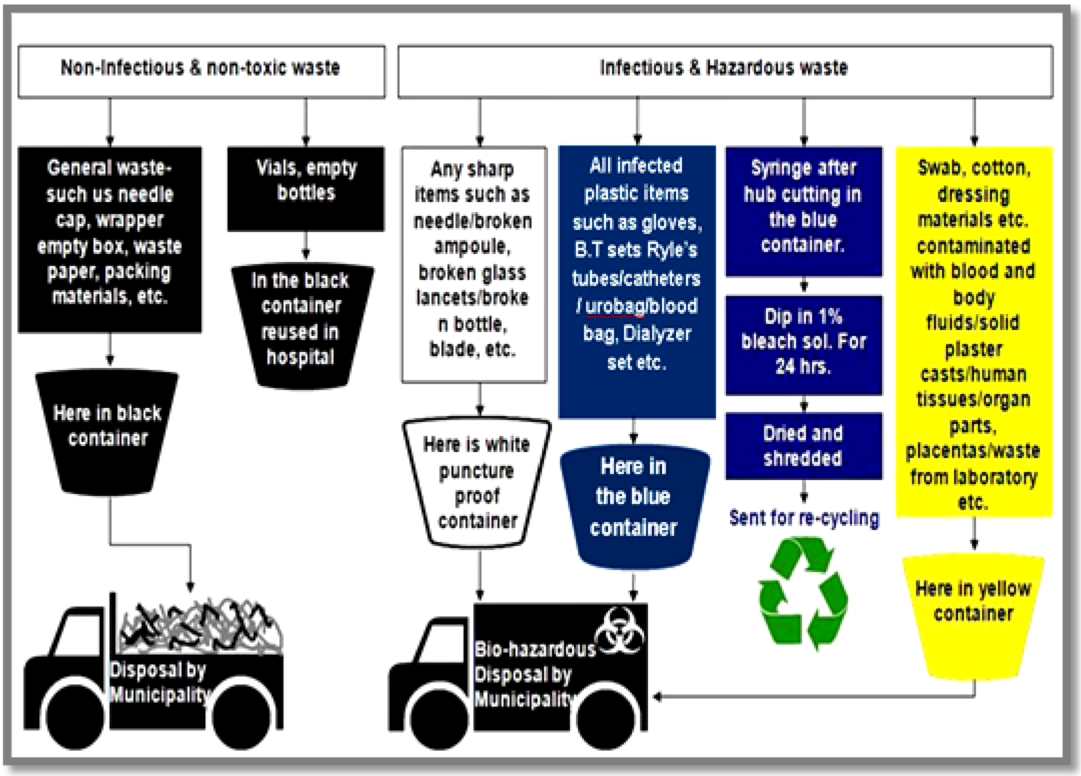


Figure (3.8) Bio-medical waste collection and transportation procedure

3.4.6 Treatment

The goals of biomedical waste treatment are to reduce or eliminate the waste's hazards, and usually to make the waste unrecognizable. Treatment should render the waste safe for subsequent handling and disposal. There are several treatment methods that can accomplish these goals. Biomedical waste is often incinerated. An efficient incinerator will destroy pathogens and sharps. Source materials are not recognizable in the resulting ash [12].

The following treatment or disposal techniques may be used for hazardous medical waste, depending on the circumstances and the type of waste concerned [1]

1. Incineration technology: Uses high temperature (200° to over 1000°C) Incineration (combustion, pyrolysis and/or gasification)
2. Non incinerator technology:
   a) Disinfection: Chemicals; addition of disinfectants (chlorine dioxide, sodium hypochlorite, peracetic acid, ozone, alkaline hydrolysis) at least 1%.
   b) Thermal process: low temperatures (100° to 180°C), vapor (autoclave, micro-waves) or hot air (convection, combustion, infrared heat).
   c) Mechanical processes: shredding.
   d) Burial: sanitary landfills, trenches, pit.

Methods such as (low temperature, mechanical and chemical process) used to sterilize medical waste to minimize their negative impacts to health and the environment through minimizing the size of wastes, which will then be transported to central facility.

Table (3.2) Categories and disposal technique of Bio-medical waste [3]

Option	**Treatment & Disposal**	**Waste Category**
Cat. No. 1	Incineration /deep burial	Human Anatomical Waste (human tissues, organs, body parts)
Cat. No. 2	Incineration /deep burial	Animal Waste Animal tissues, organs, Body parts carcasses, bleeding parts, fluid, blood.
Cat. No. 3	Local autoclaving/ micro waving/ incineration	Microbiology & Biotechnology waste (wastes from laboratory cultures, micro-organisms live.
Cat. No. 4	Disinfections (chemical treatment /autoclaving/ mutilation shredding ◈	Waste Sharps (needles, syringes, scalpels blades, glass etc. that may cause puncture and cuts.
Cat. No. 5	Incineration / destruction & drugs disposal in secured landfills	Discarded Medicines and Cytotoxic drugs (wastes comprising of outdated, contaminated and discarded medicines)
Cat. No. 6	Incineration, autoclaving/micro waving	Solid Waste (Items contaminated with blood and body fluids including cotton, dressings, other material contaminated with blood)
Cat. No. 7	Disinfections by chemical treatment autoclaving/micro waving& mutilation shredding. ◈	Solid Waste (waste generated from disposable items other than the waste sharps such as tubing, catheters, intravenous sets etc.)
Cat. No. 8	Disinfections by chemical treatment and discharge into drain	Liquid Waste (waste generated from laboratory & washing, cleaning, house-keeping and disinfecting activities)
Cat. No. 9	Disposal in municipal landfill	Incineration Ash (ash from incineration of any bio-medical waste)
Cat. No. 10	Chemical treatment & discharge into drain for liquid & secured landfill for solids	Chemical Waste (chemicals used in production of biological, chemicals, insecticides, etc)

Chemical treatment using at least 1% hypochlorite solution or any other equivalent chemical reagent, it must be ensured that chemical treatment ensures disinfections.

◈Mutilation/shredding must be such so as to prevent unauthorized reuse. The most essential part of hospital waste management is the segregation of Bio-medical waste.

Table (3.3) Colour coding and type of container for disposal of Bio-medical waste

Colour Coding	**Type of Containers**	**Waste Category**	**Treatment Options as per Schedule 3.2**
Yellow 	Plastic bag	1,2,3,6	Incineration/deep burial
Red 	Disinfected Container/ Plastic bag	3,6,7	Autoclaving/Micro waving/ Chemical Treatment
White translucent 	Plastic bag/puncture proof container	4,7	Autoclaving/Micro waving/ chemical treatment and destruction/shredding
Black 	Plastic bag	5,9,10 (Solid)	Disposal in secured landfill

CHAPTER FOUR

DATA ANALYSIS

4.1 Methodology

The methodology for this paper includes empirical field observation and field-level data collection through inventory, questionnaire survey and interviews. A structured questionnaire was designed to collect information addressing the generation of different medical wastes according to amount and sources from different HCEs.

A number of specific questions were asked to different health care establishment's environmental health managers, nurses and cleaners to elicit their knowledge.

The collected data with the questionnaire survey were analyzed, mainly with simple descriptive statistics; while the qualitative mode of analysis is mainly in narrative form.

4.1.1 Study Design

The study is descriptive cross-sectional community-based study. It is a process of inspecting, cleaning, transforming, and modeling data with the goal of discovering useful information. Data analysis is a process for obtaining raw data and converting it into information useful for decision-making.

4.1.2 Study Duration

A period of 2 months (from Jan 2015 to Mar 2015)

4.1.3 Study Population

Forms were filled through survey and personal interviews with the official responsible for waste at each HCE. The form contained 9 items and was administered to the 25 health care establishments, one questionnaire paper at each.

4.1.4 Sampling Techniques

Non probability convenience sampling was used to recruit participants

4.1.5 Data Collection Techniques and Tools

- Interviews guided by questionnaires.

Questionnaires are composed of 9 questions about medical waste management techniques, such questions prepared in accordance with the observation statistical standards for easy to understand and answer questions in a scientific and comprehensive.

4.1.6 Data Analysis

Analysis of the questions was to produce comments, and tables; to find the answers of the questionnaires by visualization and interpretation. The results were tabulated in Microsoft Excel and were analyzed using both descriptive and analytical statistics, which was done by a statistician using computer-based program Statistical Package for Social Sciences (SPSS) version 21.

4.1.7 Ethical Consideration

1. A written informed consent from the university was obtained.
2. The study was approved by the university ethical review board (ERB).
3. A verbal informed consent was obtained from the participants.
4. The participant confidentiality will be conserved.

The collected data divided into:

I. Type of health care establishment

During the analysis we found that 40% of specialized hospital, 28% general, 12% University, 4% charity and 16% medical centers as follow as the table and chart (4.1) below.

Table (4.1) Types of health care establishments.

Types of HCEs		Frequency	Percent %	Valid percent %	Cumulative percent %
Valid	Specialized	10	40.0	40.0	40.0
	General	7	28.0	28.0	68.0
	University	3	12.0	12.0	80.0
	Charity	1	4.0	4.0	84.0
	Medical Centers	4	16.0	16.0	100.0
	Total	25	100.0	100.0	

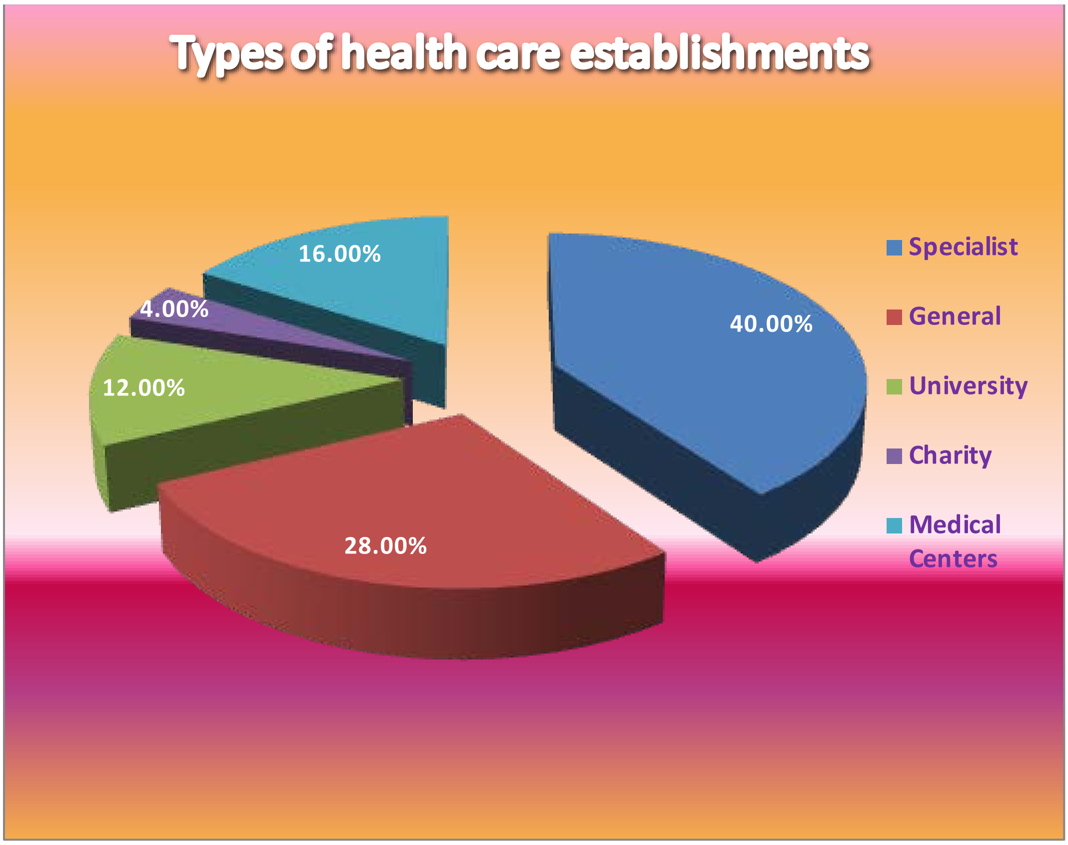


Figure (4.1) Types of health care establishments

In order to collect enough data about waste management in hospitals around state of Khartoum, the survey covered a various type of health care institutions including: specialized hospitals, general hospitals, university hospitals, charity hospitals and medical centers.

II. Availability of medical waste on HCEs

The study found that the availability of General, Chemical, Sharps, Pharmaceutical and Pressurized containers medical waste, on HCES are 100% of sample study and 90% of availability for Pathological and Infectious waste and 10% for radioactive waste, table and figure (4.2) below showing that

Table (4.2) Availability of medical waste on HCEs

Availability of medical waste		Frequency of availability	Frequency %	Percent %	Valid Percent %	Cumulative Percent %
Valid	General	25	100	14.49	14.49	14.49
	Pathological	23	90	13.04	13.04	27.54
	Radioactive	3	10	1.45	1.45	28.99
	Chemical	25	100	14.49	14.49	43.48
	Infectious	23	90	13.04	13.04	56.52
	Sharps	25	100	14.49	14.49	71.01
	Pharmaceutical	25	100	14.49	14.49	85.51
	Pressurized containers	25	100	14.49	14.49	100.00
	Total		690	100	100	

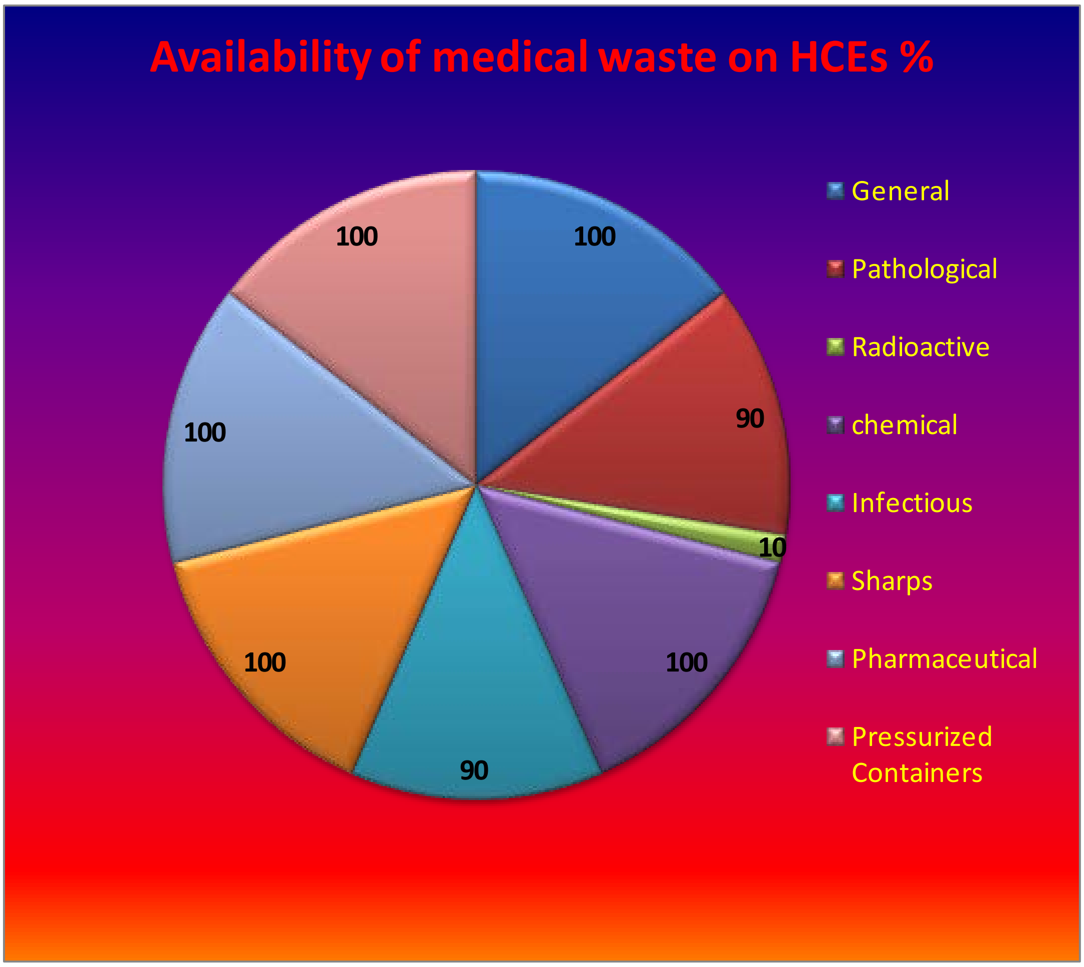


Figure (4.2) Availability of medical waste on HCEs

As part of the survey most of the types of medical waste do exist in health care establishment with different amounts.

Figure (4.2); showing that general, chemical, sharps, pressurized container and pharmaceutical waste categories do exist in all covered health care facilities, while other types are produced in some facilities with different amounts.

III. Segregation of medical waste

The study found that 57% of sample study of general waste, 71% pathological, 52 chemical, 19% Radioactive, 48% infectious, 100% for sharps and 81% for pharmaceutical waste and 100% for pressurized containers, the table and chart (4.3) below showing that.

Table (4.3) Segregation of medical waste within health care facilities

Segregation of medical waste		Frequency	%	Percent %	Valid percent%	Cumulative percent%
Valid	General	14	57	10.80	10.80	10.80%
	Pathological	18	71	13.45	13.45	24.24%
	Radioactive	5	19	3.60	3.60	27.84%
	Chemical	13	52	9.85	9.85	37.69%
	Infectious	12	48	9.09	9.09	46.78%
	Sharps	25	100	18.94	18.94	65.72%
	Pharmaceutical	20	81	15.34	15.34	81.06%
	Pressurized containers	25	100	18.94	18.94	100.00%
	Total		528	100	100	

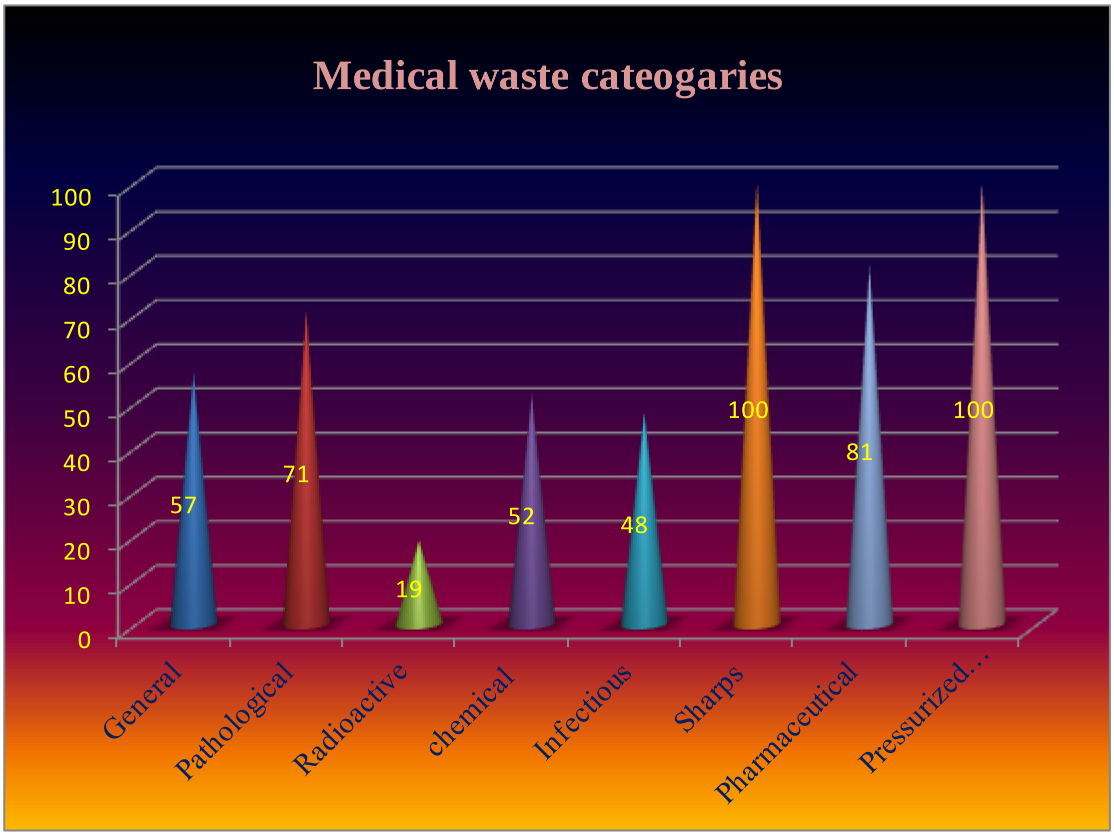


Figure (4.3) Segregation of medical waste within health care facilities

Hospitals were questioned about segregation of waste according to above mentioned categories and the results were – as shown in figure (4.3).
57% of HCEs segregate general waste; 71% segregate the pathological waste, 19% segregate radioactive waste.
52% segregate chemical waste, 48% segregate the infectious waste, 90% of infectious wastes are not treated before final disposal and only 10% of (HCEs) are using color coding system for bags and hazard sign on containers.
100% segregate sharps into sharp boxes, 81% of those (HCEs) segregate the pharmaceutical waste.

IV. Disposal technique for medical waste on (HCEs)

Table (4.4) Show the percentage of disposal technique for medical waste on (HCEs)

Disposal technique		Frequency		Percent %	Valid Percent %	Cumulative Percent
			%			
Valid	General	25	100	19.57	19.57	19.57%
	Pathological	17	67	13.11	13.11	32.68%
	Radioactive	5	19	3.72	3.72	36.40%
	Chemicals	16	62	12.13	12.13	48.53%
	Infectious	17	67	13.11	13.11	61.64%
	Sharps	16	62	12.13	12.13	73.78%
	Pharmaceutical	12	48	9.39	9.39	83.17%
	Pressurized Containers	22	86	16.83	16.83	100.00%
	Total		511	100	100	

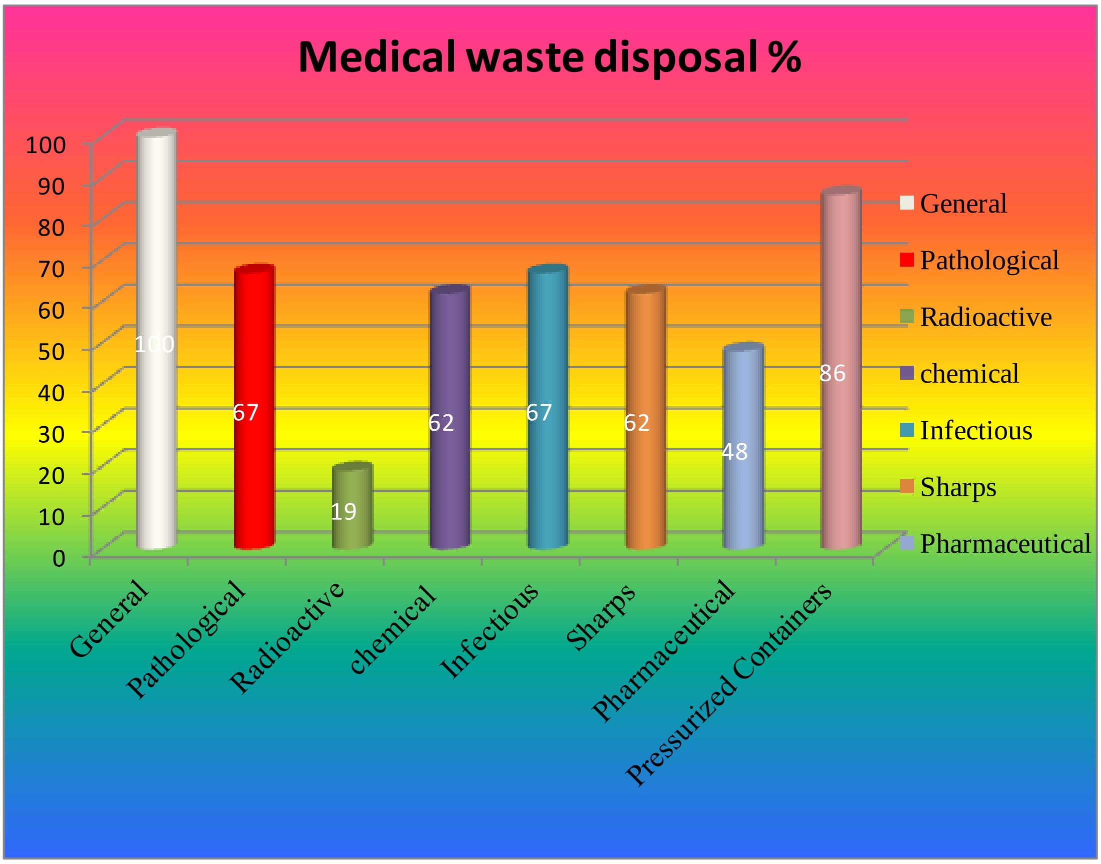


Figure (4.4) Show the percentage of disposal technique for medical waste on (HCEs).

Disposal

100% of (HCEs) dispose of the general waste with municipal waste van, 67% give the amputated parts to co patient and the rest of pathological waste go with other types of waste to municipal vans or to incinerator by the HCEs special transportation, 19% of radioactive waste (x-ray films) store on special room till ending of their half life then go with municipal van.

62% of HCEs dispose of chemical waste in ordinary sewer drainage. The rest of them send it with municipal vans.

67% of (HCEs) send the infectious waste with general waste without pre treatment. The others send it to incinerator with their own vehicles, 62% dispose of the sharp boxes by send it with municipals; others send it by their own transportation to incinerator.

48% of (HCEs) send the pharmaceutical waste to medicine board by their special committee; 86% of HCEs send the pressurized containers to the source for refilling. The rest of HCEs have medical gas net work. 90% of medical waste although if segregated at source of generation it mix during storage and transportation with general waste, 24% of HCEs were transporting and disposing of medical wastes outside hospitals using their own vehicles.

V. Waste management team percentage

During the analysis we found that 28% of sample study says availability of medical waste team on HCEs, and 72% saying no.

Table (4.5) Availability of medical waste team on HCEs

Medical waste team		Frequency	Percent %	Valid percent %	Cumulative percent %
Valid	Yes	7	28	28	28
	No	18	72	72	100
	Total	25	100	100	

15 % of hospitals depended on private cleaning companies for collecting waste. These same companies are responsible of supervising their waste-workers; thus making the process susceptible to weaknesses aggravated by lack of adequate monitoring performed by the targeted hospitals.
The majority of sample study 72 % of HCEs there's no medical waste management team.

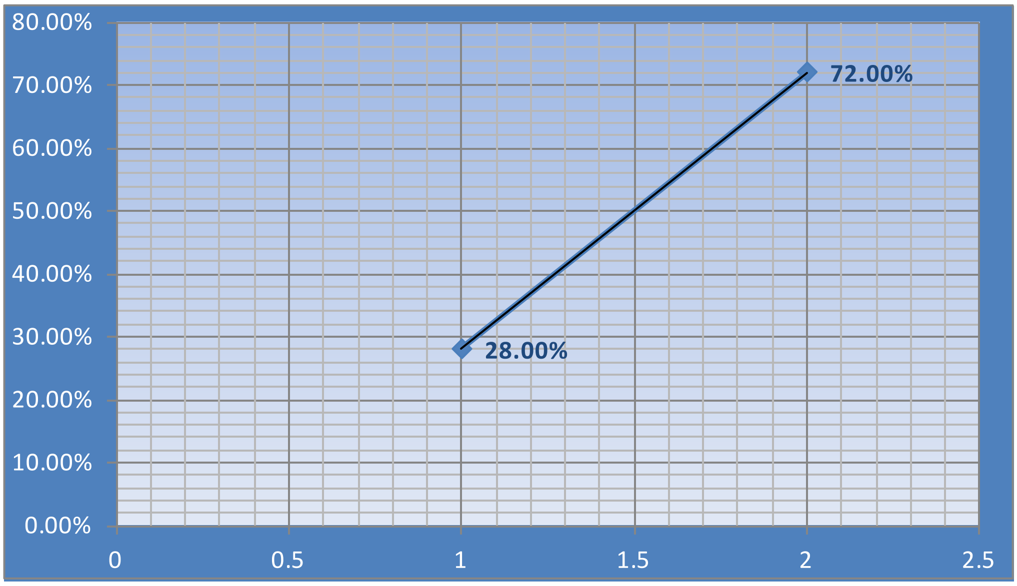


Figure (4.5) Availability of medical waste team on HCEs

The team includes:

- Health Supervisor.
- Quality Control
- Employee for collecting medical waste.
- Administrator.

VI. Medical waste management plan on HCEs.

The study showing that 36% of sample study have medical waste management plan on HCEs , and 64% not have medical waste management plan or they have but not applied.

Table (4.6) Percentage of medical waste management plan on HCEs

Management plan		Frequency	Percent %	Valid percent %	Cumulative percent
Valid	**Yes**	9	36	36	36.0%
	No	16	64	64	100.0%
	Total	25	100	100	

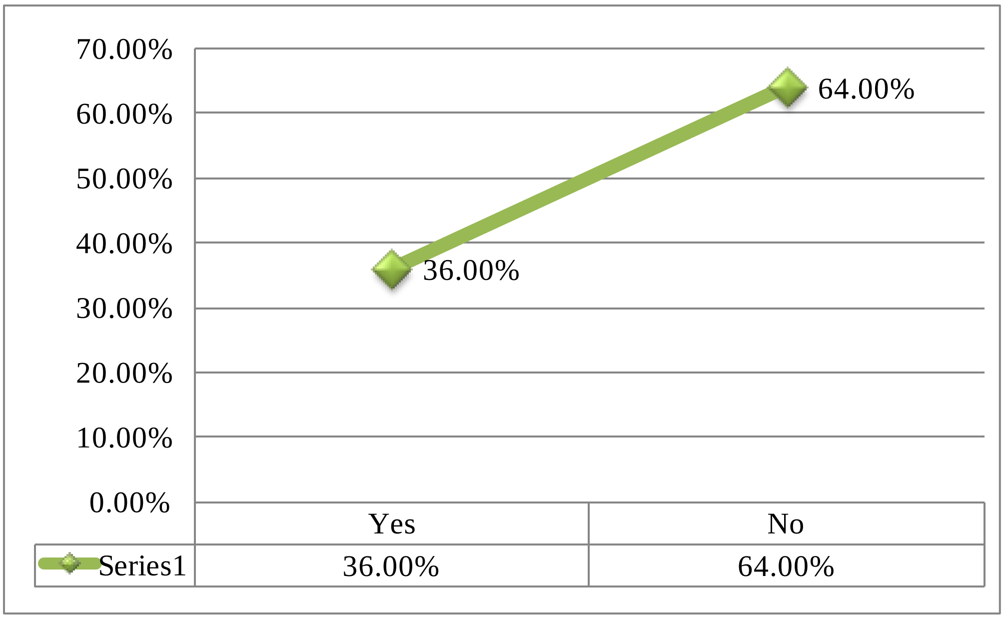


Figure (4.6) the percentage of medical waste management plan on HCEs

The majority of sample study 64 % of HCEs there's no medical waste management plan on HCEs.

VII. Availability of waste management training for new staff

During the analysis we found that 32% of HCEs have training on medical waste management for newly staff. And 68% haven't, showing that on table and figure (4.7) below:

Table (4.7) Availability of waste management training for new staff

Training for staff		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	8	32.0%	32.0%	32.0%
	No	17	68.0%	68.0%	100.0%
	Total	25	100.0%	100.0%	

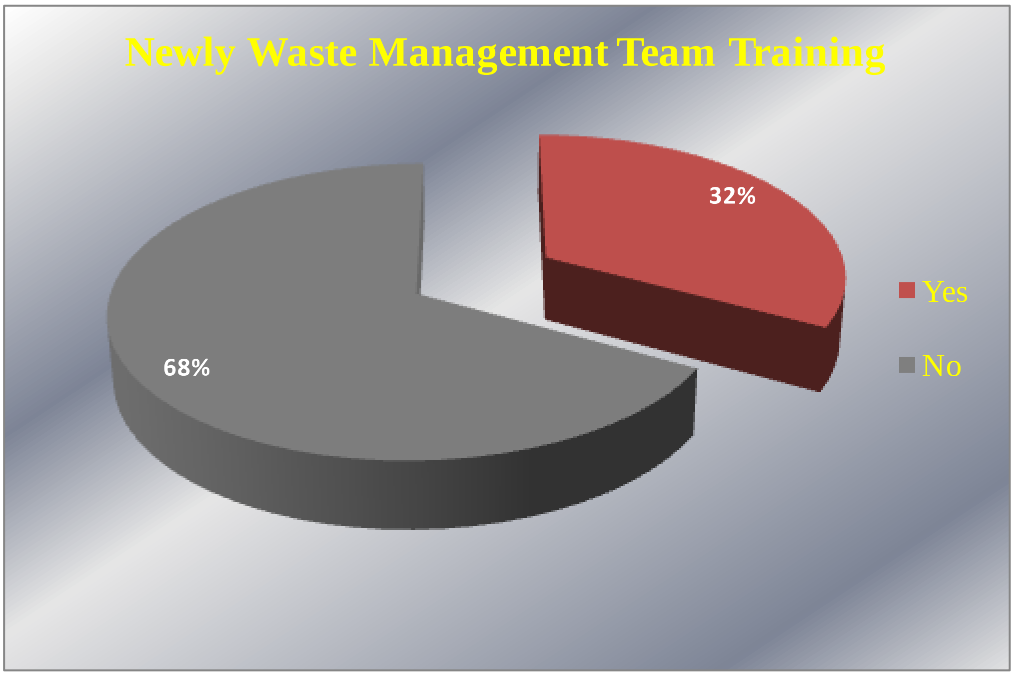


Figure (4.7) Availability of waste management training for new staff

The majority of sample study 68 % of HCEs there's no medical waste management training for new staff.

About 86% of workers were responsible of collecting all types of waste in addition to all other cleaning tasks. Therefore, workers were not giving much care to the nature and types of waste they were collecting as all waste was collected into the same bags.

This complicated the sorting processes, exposed transport workers to infection risks and caused leakage of liquid wastes and possible pollution.

Correlations

Table(4.8) Correlation using Pearson factor

		Availability of medical waste team on HCEs	Segregation of medical waste within health care facilities.
Availability of medical waste team on HCEs	Pearson Correlation	1	.861**
	Sig. (2-tailed)		.006
	N	25	25
Segregation of medical waste within health care facilities.	Pearson Correlation	.861**	1
	Sig. (2-tailed)	.006	
	N	25	25

Correlation is significant at the 0.01 level (2-tailed).

Correlations

Table(4.9) correlation using Spearman's factor

			Availability of medical waste team on HCEs	Segregation of medical waste within health care facilities.
Spearman's rho	Availability of medical waste team on HCEs	Correlation Coefficient	1.000	.779*
		Sig. (2-tailed)	.	.023
		N	25	25
	Segregation of medical waste within health care facilities.	Correlation Coefficient	.779*	1.000
		Sig. (2-tailed)	.023	.
		N	25	25

Correlation is significant at the 0.05 level (2-tailed).

Analysis and measurement of the correlation coefficients for each of the Pearson and Spearman, show that there is a strong relationship between availability of medical waste team and segregation of medical waste, due to positive tested factors of 0.861 and 0.779 which are greater than critical scale value of 0.5 for each factor that are in positive and negative directions, this lead to reject null hypothesis (tested hypothesis) and accept the alternative hypothesis (true hypothesis), so there is significant linear correlation.

CHAPTER FIVE

DESIGN

5.1 Introduction

Waste management facilities should be well designed, so that they contribute positively to the character and quality of the area in which they are located. Poor design is undesirable, undermines community acceptance of waste facilities and should be rejected.

Good design is something that is likely to be critical to good planning decisions, but design is important for the whole of a waste management project from the initiation phase through to project completion and the operation of the facility on the ground.

Good design draws together a number of different themes, disciplines, stakeholders and integrates them to realize an effective and well-executed development. Approaching design as a considered process should result in a quality outcome. With waste facilities, as with any other development, good design should be a core part of the project plan; it will reduce planning risk which in turn may reduce some of the associated up-front costs. A waste management facility will need to ensure it offers the right balance in terms of quality, time and cost:

a. **Quality:** must be considered not only in terms of the immediate functional needs of a waste facility but in terms of vision based design issues.
b. **Time:** refers to the need to meet appropriate time scales in terms of getting the facility financed, permitted, designed, built, fitted out and ready for service.
c. **Cost:** covers the construction, materials and all related expenses including operational costs. The cost of planning, and securing the input of professional advisors can also be significant.

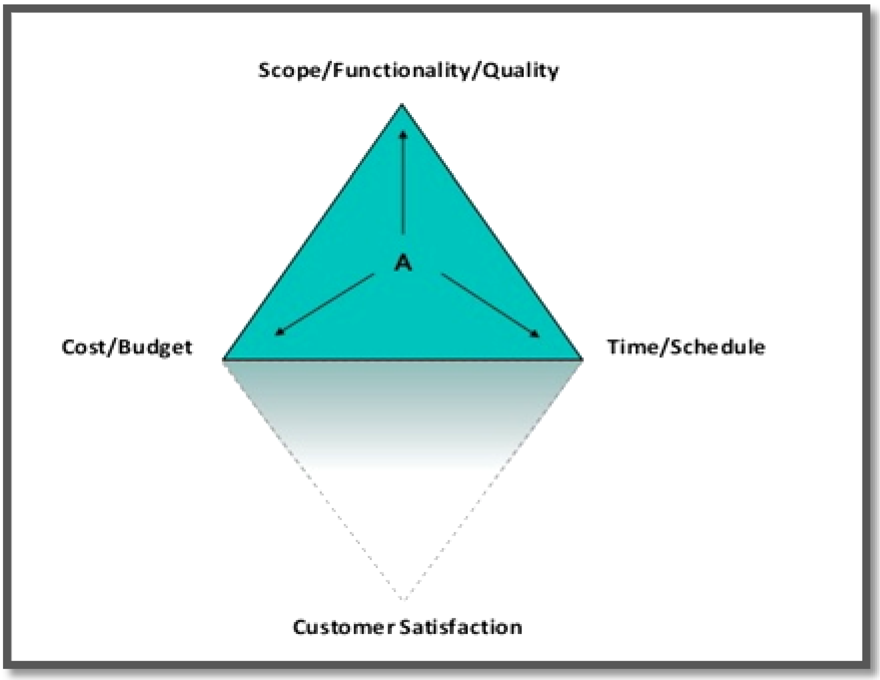


Figure (5.1) Balancing time, Quality and Cost

These three elements are a key to getting the most out of a development.

There are three principal phases in the design of a waste facility, which can be simply broken down into prepare, design and construct. There is a degree of overlap between these phases, and it is at the start of the project that most can be done to add value through careful preparation and adequate time for design. Long-term management, maintenance and decommissioning should be important considerations in the design process [13].

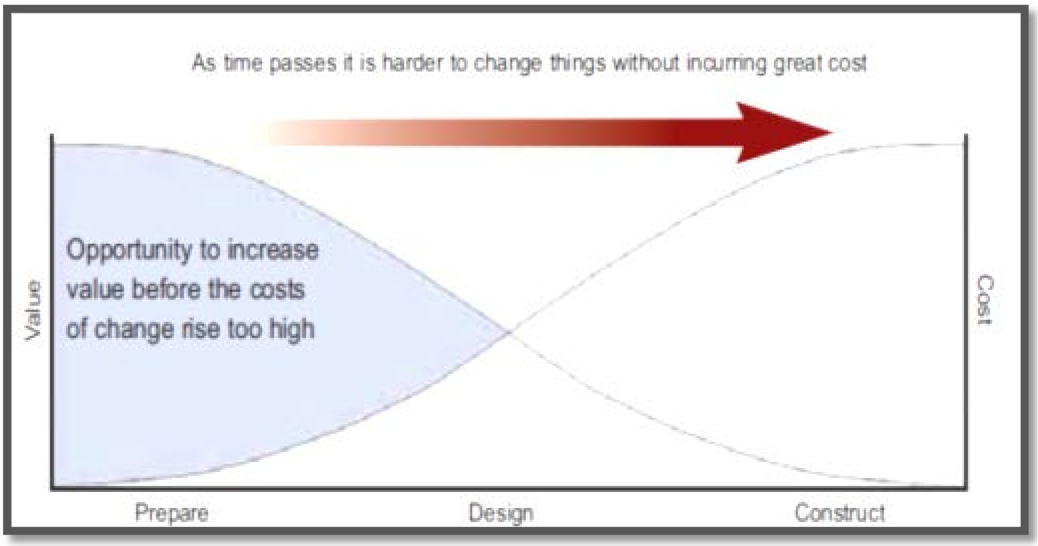


Figure (5.2) An opportunity to increase value

5.2 Design of Assembly Points

The location of assembly points shall be located at a place as near to health care establishments (HCEs) as possible for every provenance; in order to minimize the travel distance in waste collection, thus minimizing the risk of medical waste and enhancing its operational flexibility.

Sufficient land will be allocated for assembly points to provide all requisite systems; the assembly points shall have enough space for installation requirements; treatment equipments, incoming and outgoing waste storage area, vehicle- parking, washing area, and staff room. The desired area for assembly points depends upon the projected amount of bio-medical waste to be handled. This design can be achieved by providing smooth and fine floor for all facility and wall surfaces (to a height of 2 meters) preferably of tiles. The number of joints in such surface shall be minimal and must have good ventilation [3].

Attached to each equipment room, there have to be two waste storage rooms; one for storage of untreated wastes and another for treated wastes. The main waste storage room must be provided near to the entry of the assembly point to unload and store all bio-medical wastes that have been transported to the facility by vehicles. The size of the main storage room shall be adequate to store all the wastes transported to the assembly point from HCEs. The front portion of the room will utilize for unloading the wastes from the vehicle, back or side portion utilize for shifting the wastes to the respective treatment equipment room. In the front of the room, where vehicle is parked for unloading, the floor shall be made impermeable; so that any liquid spilled during unloading does not percolate into the ground.

In the main storage room, wastes shall be stacked with clear distinction color coding containers, then the colored containers send to the respective treatment equipment, also the room must have provisions similar to the equipment rooms as roofing, well ventilated and air conditioning, smooth and fine surface for easy washing floors and walls. Also, on assembly points there must be washing room or washing area for vehicles and containers on every time vehicle unloaded, the vehicle and empty waste containers have to be washed properly and disinfected.

The equipment rooms: autoclave, shredder, and chemical treatment, have a separate cabin to supervise and control the operation of the equipment and to record the waste handling and equipment operational data.

Treated waste storage room, is the room where wastes treated shall be stored, the wastes have to be stored in separate group as per the disposal options.
The liquid generated during handling of wastes and washing, shall be diverted on the inlet of Effluent Treatment Plant (ETP), as shown on figure(5.3) [3].

ETP

A wastewater treatment plant is a physical plant where various physical, biological or chemical processes are used to change the properties of the wastewater (e.g. by removing harmful substances) in order to turn it into a type of water (also called effluent) that can be safely discharged into the environment [14].

Figure (5.3) Effluent Treatment Plant

A suitable ETP should be installed to ensure that liquid effluent generated during the process of washing containers, vehicles, floors is disposed off after treatment. An administrative room must be located on assembly points for utilized of general administrative, record keeping, billing for records of waste; time and date receiving and transmitting of waste, Accident reporting; in any accident the authorized person shall report the accident with the medical action taken.

Every assembly point must have generator set as standby arrangements for power, with sufficient capacity to run the treatment equipment during the failure of power supply. From the point of view of security, the site walls must be high enough, fencing and guarded gates to prevent unauthorized access to the site by humans and livestock.

5.2.1 General Considerations

A telephone to be provided and maintained at the facility , A First Aid Box to be provided and maintained at the Assembly points. Proper lighting at the facility and care to keep the facility and surroundings odours free, Fire fighting facilities and emergency alarm to be installed.

Measures shall be implemented to control escape of litter, pests and insects at the site.

Necessary protective gear for the waste handlers shall be provided [3].

5.2.2 Treatment methods used in Assembly points

There are three treatment methods that are used in assembly points depending on medical waste type.

1- Chemical process.
2- Thermal process.
3- Mechanical process.

Mechanical process always used after chemical and thermal treatment to prevent operators and machine from medical waste hazard.

The blocks diagram below show the treatment and disposal techniques of medical waste according to different medical waste types and their last disposal technique.

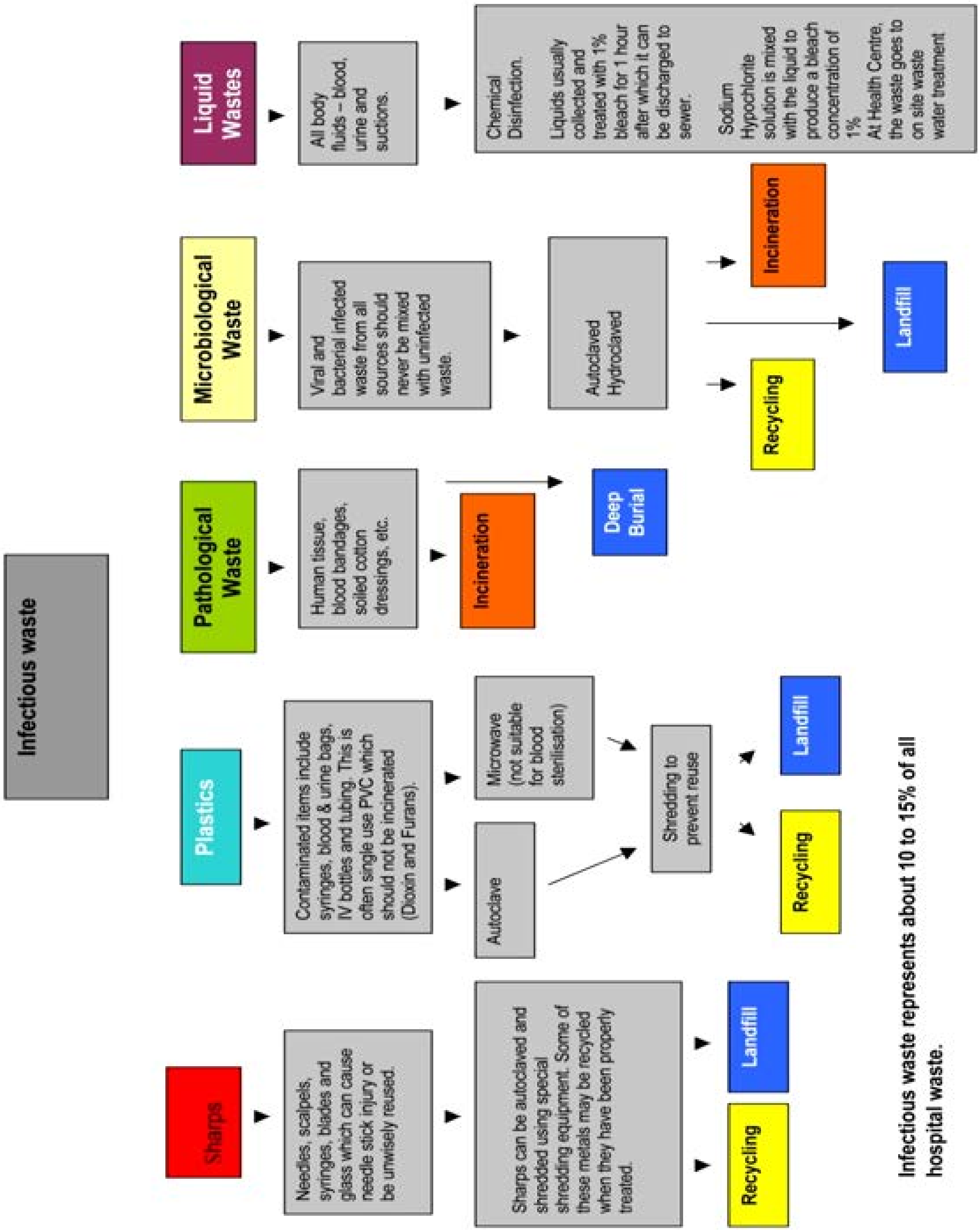


Figure (5.4) Block diagram for disinfection techniques used in Assembly point

1. Chemical processes

Chemical Disinfection

Chemicals are added to the wastes to kill or inhibit pathogens. However, the chemicals that are used themselves entail a health risk for the people who handle them and a risk of environmental pollution. This type of treatment is suitable mainly for treating liquid infectious wastes such as blood, urine, or hospital sewage.

Chemicals are 1% bleach (sodium hypochlorite NaClO), which is most active disinfectants against bacteria, viruses and other pathogens, [15] or a diluted active chlorine solution (0.5%) is used; the other disinfectants used are as follows: lime, ozone, ammonium salts. Formaldehyde and ethylene oxide must no longer be used because of their toxicity and they have more active against both bacteria and parasite eggs. Some types of chemical disinfectants have been shown on figure (5.5).

All strong disinfectants irritate the skin, eyes and respiratory system, they must be handled with caution – in particular, personal protective equipment must be used and they must be stored correctly.

Thermal disinfection for solid waste must be preferred over chemical disinfection for reasons of effectiveness and for ecological reasons [1].

Figure (5.5) Chemical disinfectants

2. Thermal processes

Thermal processes are those that rely on heat (thermal energy) to destroy pathogens in the waste. There are two types of thermal process; low temperature (autoclaves) and high temperature (incinerators).
Thermal disinfection (low temperature)

Autoclave

Autoclaving is a thermal process with low temperatures where waste is subjected to pressurized saturated steam for a sufficient length of time to be disinfected , (60 minutes at saturation temperature of 121°C and pressure of 1 bar) or a cycle of 45 minutes at 134°C (3bar) [1]. Autoclaves use for treatment of sharps, materials contaminated with blood and others [16].

Standards for waste autoclaving (vacuum autoclave)

I. A temperature of not less than 121°C and pressure of 1.03 bar (15psi) per an autoclave residence time of not less than 45 minutes.
II. Temperature of not less than 135°C and a pressure of 2.13bar (31psi) for an autoclave residence time of not less than 30 minutes [3].

An autoclave - shown below consists of a metal chamber sealed by charging door and surrounded by a steam jacket. Steam is introduced into both the outside jacket and the inside chamber which is designed to withstand elevated pressures. Heating the outside jacket reduces condensation in the inside chamber wall and allows the use of steam at lower temperatures.

Figure (5.6) Autoclave Machine

For ease and safety in operation, the system should be a horizontal steel cylinder, with capacity more than 8 m^3 connected to a steam generator, both of which can withstand a pressure of 6 bar (600kPa) and a temperature of 160°C. The system also includes a vacuum pump for sucking air from chamber before introducing steam; because air is an effective insulator, the removal of air from the chamber is essential to ensure penetration of heat into the waste, electricity supply and there must be sewer drainage. Waste is collected and put into autoclavable bags that may be placed in special carts or drawers [16]. The autoclavable bags waste must be hi density Polyethylene and/or high-strength Polypropylene [17], the figure below shows the autoclavable bags during handling of waste.

Figure (5.7) Autoclave handling process

Medical waste shall not be considered properly treated unless the time, temperature and pressure indicators indicate that the required time, temperature and pressure were reached during the autoclave process [3].

A. Properties of saturated steam

The table below shows the temperature and pressure properties of saturated steam

Table (5.1) Properties of saturated steam

ABSOLUTE PRESSURE		GAUGE PRESSURE	TEMPERATURE	
kPa	psia	psig	°F	°C
100	14.7	0	212	100
115	17	2.3	219	104
130	20	5.3	228	107
180	25	10	240	117
200	27	12	244	120
250	34	19	258	127
300	50	35	281	134
350	60	45	293	139
400	70	55	303	144
600	100	85	328	159

Kpa= kilopascal; psia = pounds per square inch (absolute); psig=pounds per square inch (gauge). Psig +14.7= psia

Note: some technical specifications list in psi without signifying if they are gauge or absolute pressure. Most of time, the values are gauge pressure.

Bar=100Kpa

B. Dimensions

For 2,727 kg per cycle and higher the approximate dimensions of autoclave in a range from a 1.8m diameter x 5m long vessel. A commercial system might have dimensions of 2.4m diameter x 9.7m long.

One of the major disadvantages of autoclave pointed out is that it doesn‘t reduce the size of waste fed in to the system.

C. Operation

The figure and steps below shows the operational cycle of the autoclave machine

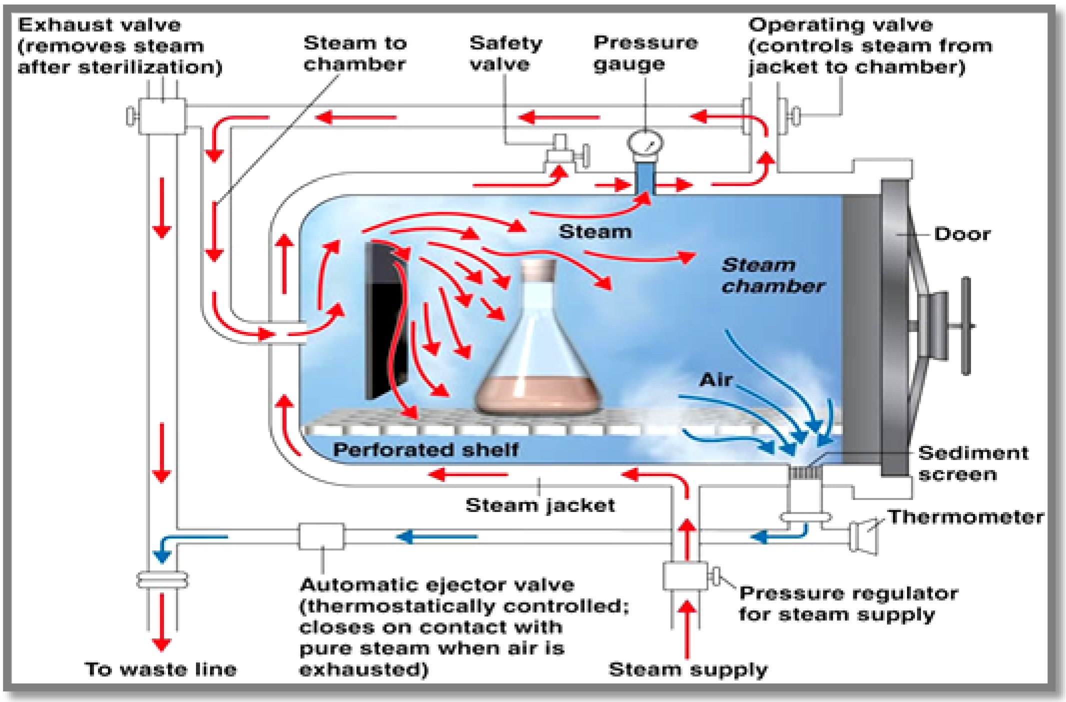


Figure (5.8) Operation cycle of an autoclave

A typical operating cycle for an autoclave involves the following

1. Waste collection: a cart or bin is lined with special plastic liners or large autoclavable bags to prevent waste from sticking to the container. Bags are then placed in the lined container.
2. Pre-heating (for autoclaves): steam is introduced into the outside jacket of the autoclave.
3. Waste loading: waste containers are loaded into the autoclave chamber. Periodically, chemical or biological indicators are placed in the middle of the waste load to monitor disinfection. The charging door is closed, sealing the chamber.
4. Air evacuation: air is removed through pre-vacuuming.
5. Steam treatment: steam is introduced into the chamber until the required temperature is reached. Additional steam is automatically fed into the chamber to maintain the temperature for a set time period.
6. Steam discharge: steam is vented from the chamber, usually through a condenser, to reduce the pressure and temperature.
7. Unloading: usually, additional time is provided to allow the waste to cool down.
8. Mechanical treatment: generally, the treated waste is fed into a shredder [16].

3. Mechanical processes

It is a mechanical destruction that can render the waste unrecognizable, it is consist of:

Shredder

Shredding is a process by which waste are de-shaped or cut into smaller pieces so as to make the waste unrecognizable. It helps in prevention of reuse of bio-medical waste and also acts as identifier that the waste has been disinfected and is safe to dispose off [3].
Shredders are designed with hardened steel cutting discs mounted on rotating shafts. These discs cut against other discs mounted on a counter-rotating shaft, as on figure below:

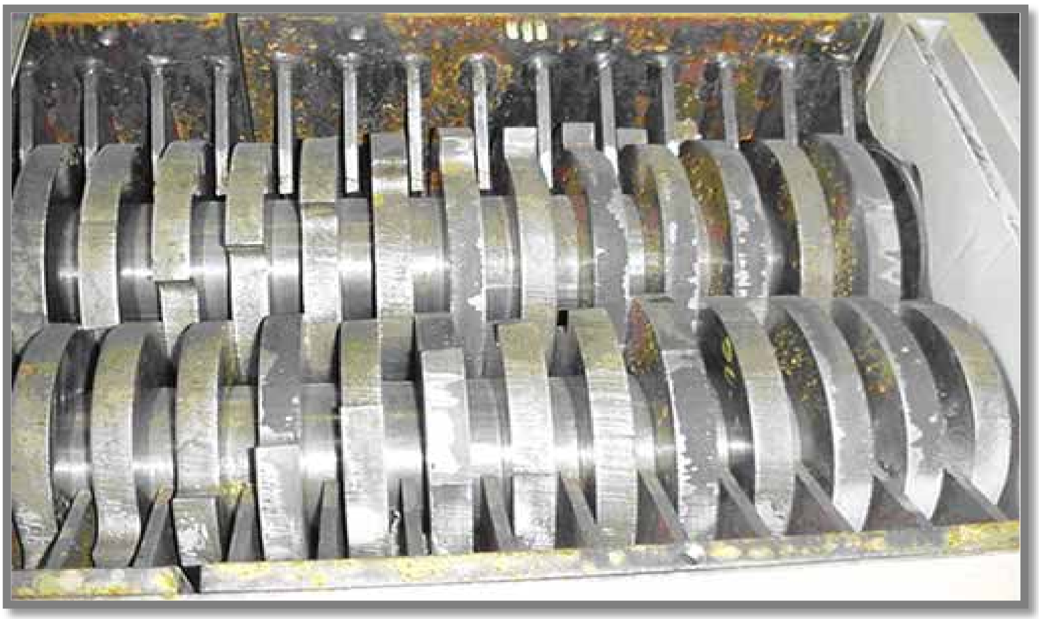


Figure (5.9) Parts of Shredder Machine

Because waste material can get lodged between the blades, the shredders used for medical waste are equipped with reverse action, e.g., when an overload occurs, the normal rotating motion is stopped and a reverse rotating motion is used to clear the obstruction. This action may be repeated several times automatically. If the blockage is still not removed, the shredder shut off and the operator is sent an audio-visual or electronic alert. Removing the blockage then requires manual operation. Shredders generally operate at low speed and high rotation force [16].
The shredding process is performed only after the waste has been treated by the Autoclave system or chemical treatment [18].

A shredder to be used for shredding bio-medical waste shall confirm to the following minimum requirements

1. The shredder should be properly designed such that it has minimum manual handling, and covered to avoid spillage and dust generation, the hopper and cutting chamber to accommodate the waste bag full of bio-medical waste.
2. The shredder blade should be highly resistant, non-corrosive, hardened steel and be able to shred waste sharps, syringes, scalpels, glass vial, blades, plastics, catheters, broken ampoules, intravenous sets/ bottles, blood bags, gloves, bandages etc. Also to handle/ shred wet waste, especially after autoclave.
3. The shredder should have low rotational speed (maximum 50 rpm), with minimum capacity of 5 kw for 100 kg/hr and 7.5 kw for 200 kg/ hr and three phase induction to ensure better gripping and cutting of the bio-medical waste. The motor shall be connected to the shredder shaft through a gear mechanism, for low movement- rpm and safety.
4. The discharge height (from discharge point to ground level) shall be sufficient (min 1m) to accommodate the containers for collection of shredder material, and to avoid spillage of shredder material [3].

Figure (5.10) Shredder Machine   Figure (5.11) Top view of Shredder

5.3 Design of Central Biomedical Waste Treatment Facility (CBWTF)

There are several concepts and specifications when designing a central medical waste treatment facility include the following:

A. Location

A CBWTF must be located at a place reasonably far away from the residential area and sensitive area so that it has minimal impact on these areas.

B. Land Requirements

Sufficient land is allotted for CBWTF to provide all requisite systems. It occupies an area of about one acre ($4000m^2$).

C. Infrastructure set up

The CBWTF must have enough space within it to install required treatment equipments (incinerator and air pollution control devices), disposal technique and incoming waste storage area, vehicle- parking and washing area, sewer drain, staff room.

D. Main waste Storage Rooms

Will be provided as near to the entry point of the CBWTF to unload and store all bio-medical wastes that have been transported to the facility from assembly points. The size of these rooms shall be adequate to store all the wastes transported to the CBWTF.

The front portion of the rooms will utilized for unloading the wastes from the vehicle, and back side utilized for shifting the wastes to the respective disposal technique. In the front of the room, where vehicle is parked for unloading, the floor shall be made impermeable; so that any liquid spilled during unloading does not percolate into the ground. The liquid generated during handling of wastes and washing, diverted to sewer drainage. Wastes must stack with clear distinction as per the color coding of the containers for specific disposal.

The main waste storage room must be adjacent to the incineration room with properly ventilation, and designed that waste can be stored in racks and washing can be done easily (easy to wash floors and walls). The floor and inner wall of the waste storage rooms shall have outer covering of impervious and glazed material so as to avoid retention of moisture and for easy cleaning. The room has to be washed and chemically disinfected daily.

E. Vehicle/container Washing Facility

Every time a vehicle is unloaded, the vehicle and empty waste containers washed properly and disinfected. It can be carried out in an open area with impermeable floor to avoid the spillage of washing liquids; the liquid effluent generated is disinfected to dispose on sewer drainage.

F. Incinerator Room

i. The incinerator structure shall be built in a room with proper roofing and cross ventilation. There shall be a minimum of 1.5 m clear distance in all the directions from the incinerator structure to the wall of the incinerator room.
ii. The floor and inner wall of the incinerator shall have outer covering of impervious and glazed material so as to avoid retention of moisture and for easy cleaning.
iii. The incineration ash shall be stored in a closed sturdy container in a masonry room to avoid any pilferage.
   Finally, the ash shall be disposed in a secured landfill.

G. Ash Pit Use for ash disposal after incinerator which is shown below

Figure (5.12) Incinerator ash disposal pit

H. Sharp pit

A sharp pit shall be provided for treated sharps after shredding [3].
The pit is lined with low permeability material such as clay to prevent the pollution of shallow groundwater and must be fenced to prevent the insect's access. Lime should be spread on the waste for added health protection or to eliminate odour. The pit should be sealed once it has been filled. The following are the essential factors that must be taken into consideration in the design and use of a sanitary landfill:

1. Access must be restricted and controlled.
2. Competent staff must be available.
3. The discarding areas must be planned and the bottom of the landfill must be waterproofed; dimension about 2.5 * 2.5 m, the bottom of the pit should be at least 4.5 meters higher than the groundwater level ; there must be no drinking water sources or wells in the vicinity of the site;
4. The waste must be covered daily and vectors (insects, rodents) must be controlled.
5. The landfill must be equipped with a final cover to prevent rainwater infiltration [1].

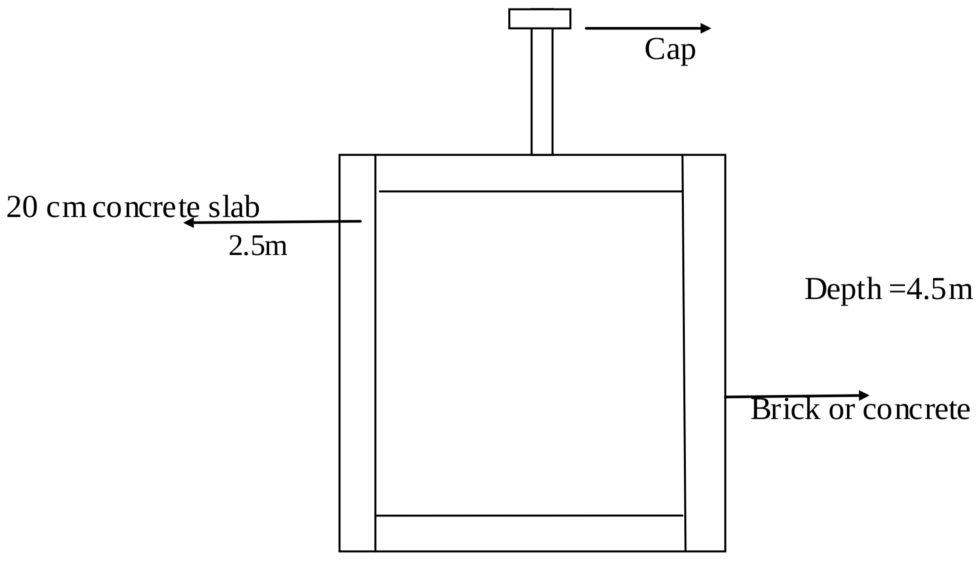


Figure (5.13) Sharp pit

I. Burial Pit

For disposing of anatomical waste

Standards for deep burial:

1. A pit of trench should be dug about 2 meters deep. It should be half filled with waste, and then covered with limit within 50 cm of the surface, before filling the rest of the pit with soil.
2. The pit must be covered with a meshed door to keep it protected from animals and birds.
3. On each occasion, when wastes are added to the pit, a layer of 10 cm. of soil shall be added to cover the wastes.
4. Burial must be performed under close and dedicated supervision.
5. The deep burial site should be relatively impermeable and no shallow well should be close to the site.
6. The pits should be sited so as to ensure that no contamination of any surface or ground water occurs. The area should not be prone to flooding or erosion.
7. The institution shall maintain a record of all pits for deep burial.

J. Generator Set

CBWTF shall have generator set as standby arrangements for power, with sufficient capacity to run the incinerator during the failure of power supply.

K. Site Security

High walls, fencing and guarded gates shall be provided at the facility to prevent unauthorized access to the site by humans and livestock.

L. Parking

Provision shall be made within the confines of the site for parking of required number of vehicles for unloading the waste and loading empty containers from the facility meant for transporting waste to and from the facility.

M. Washing Room

As shown on figures 5.14 (a, b), it is provided for eye washing/ hand washing/ bathing, and there should be labels for correct washing [3].
The purpose of this procedure is to minimize harm to workers from accidental exposures to chemicals and other hazardous materials [19].

Eye/Face Washing Procedures

1. Always wash from the outside edges of the eyes to the inside; this will help to avoid washing the chemicals back into the eyes or into an unaffected eye.
2. Water or eye solution should not be directly aimed onto the eyeball, but aimed at the base of the nose.
3. Velocity of the stream of water must be such that injury to the eye is avoided.
4. Flush eyes and eyelids or affected area with water or eye solution for a minimum of 15 minutes. "Roll" eyes around to ensure full rinsing.
5. Contact lenses must be removed as soon as possible to ensure that chemicals are not trapped behind the lenses and then the eyes can be completely rinsed of any harmful chemicals [20].

Figure (5.14a) Device use to irrigate and flush both the face and the eyes.

Figure (5.14b) Considerations of eye washing

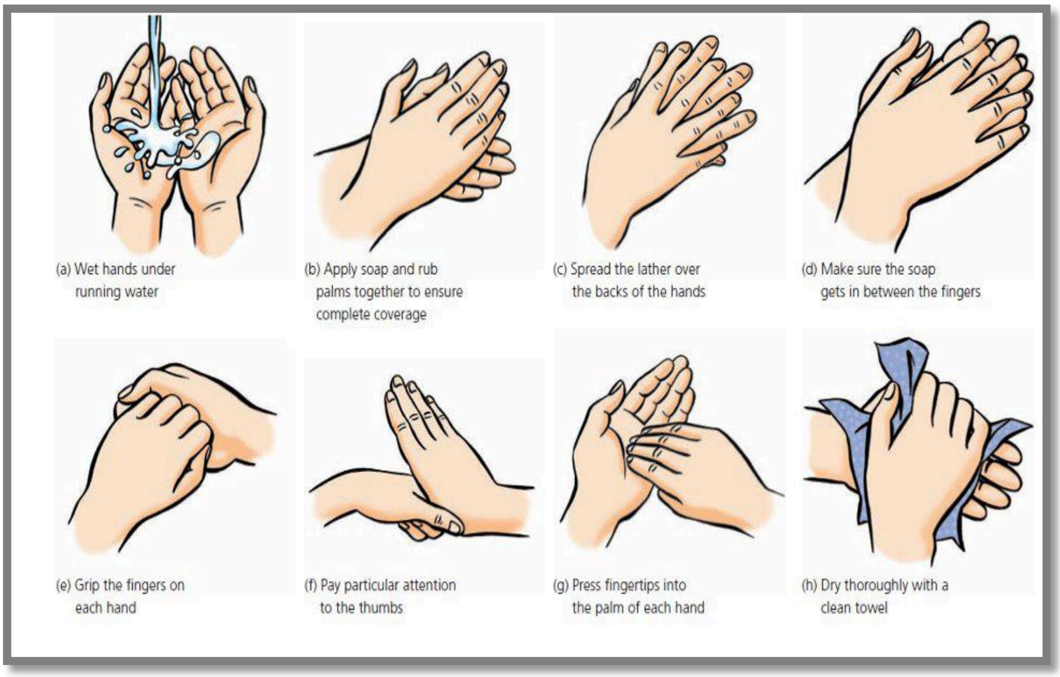


Figure (5.14c) the write way for hand washing

N. Administrative Room

This room shall be utilized for general administrative, record keeping, billing.

Records of waste movements

Daily records shall be maintained for the waste accepted and treated waste removed from the site. This record shall include the following minimum details:

i. Waste accepted: - waste collection date, name of the healthcare unit, waste category as per rules for quantity of waste, vehicle number and receiving date (at site).
ii. Treated waste removed: date, treated waste type, quantity, vehicle number and location of disposal.

Specifications should be considered in a CBWTF

1. A telephone to be provided and maintained at the facility.
2. A First Aid Box to be provided and maintained at the Assembly points.
3. Proper lighting at the facility and proper care to keep the facility and surroundings odours free.
4. Fire fighting facilities and emergency alarm to be installed.
5. Measures shall be implemented to control escape of litter, pests and insects at the site.
6. Necessary protective gear for the waste handlers shall be provided.

Every CBWTF operator shall submit a work plan to the prescribed authority. The work plan should include the details of facilities at the CBWTF, the collection, transportation and storage of the biomedical wastes, operational details [3].

5.4 Construction Guidelines of Biomedical Waste High Temperature Incinerators

The incineration is a type of thermal treatment with high temperature, use to burnout the health care waste.

5.4.1 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 very significant reduction of waste volume and weight. This process is usually selected to treat wastes that cannot be recycled or reused. The combustion of organic compounds produces mainly gaseous emissions, including steam, carbon dioxide, nitrogen oxides, certain toxic substances (e.g. metals), and particulate matter, plus solid residues in the form of ashes.

This design specified for rotary kilns which is operating at high temperature; that is capable of causing decomposition of genotoxic substances and heat-resistant chemicals [15].
Consumption of raw materials and energy by the installation of waste incineration plants consume the following

1. Electricity, for process plant operation.
2. Heat, for specific process needs.
3. Fuels, support fuels (e.g. gas, light oils, coal, and char).
4. Water, for flue-gas treatment, cooling and heat exchanger operation.
5. Flue-gas treatment reagents, e.g. caustic soda (NaOH), limestone($CaCO_3$), sodium bicarbonate, sodium sulphite (Na_2SO_3), hydrogen peroxide, activated carbon and ammonia.
6. Water treatment reagents, e.g. acids, alkalis, sodium sulphite, etc.
7. High pressure air, for compressors [21].

5.4.2 Main Types of Medical Incinerators

Different types of thermal treatments are applied to the different types of wastes, however not all thermal treatments are suited to all wastes. Three main types of incinerators are used: controlled air, excess air, and rotary kiln.

1- Controlled air, (double-chamber, pyrolytic incinerators)

Used at hospitals and similar medical facilities, also known as starved-air incineration or two-stage incineration. It consists of a pyrolytic chamber and a post combustion chamber as shown on figure. The combustion gas temperatures of primary pyrolytic chamber; where the wastes fed, are relatively low (760 to 980°C), on secondary chamber the combustion gas temperature are higher than primary chamber (980 to 1,095°C). Fuel consumption of pyrolytic incinerators is between 0.04 and 0.1m^3 of gas fuel per kg of waste. Waste feed capacities for controlled air incinerators range from about 200 kg/day to 10 tons/day.
These incinerators are not suitable for large amounts of medical waste. Beside, emission of toxic flue gas (including dioxins and furans) and sharps are not destroyed.

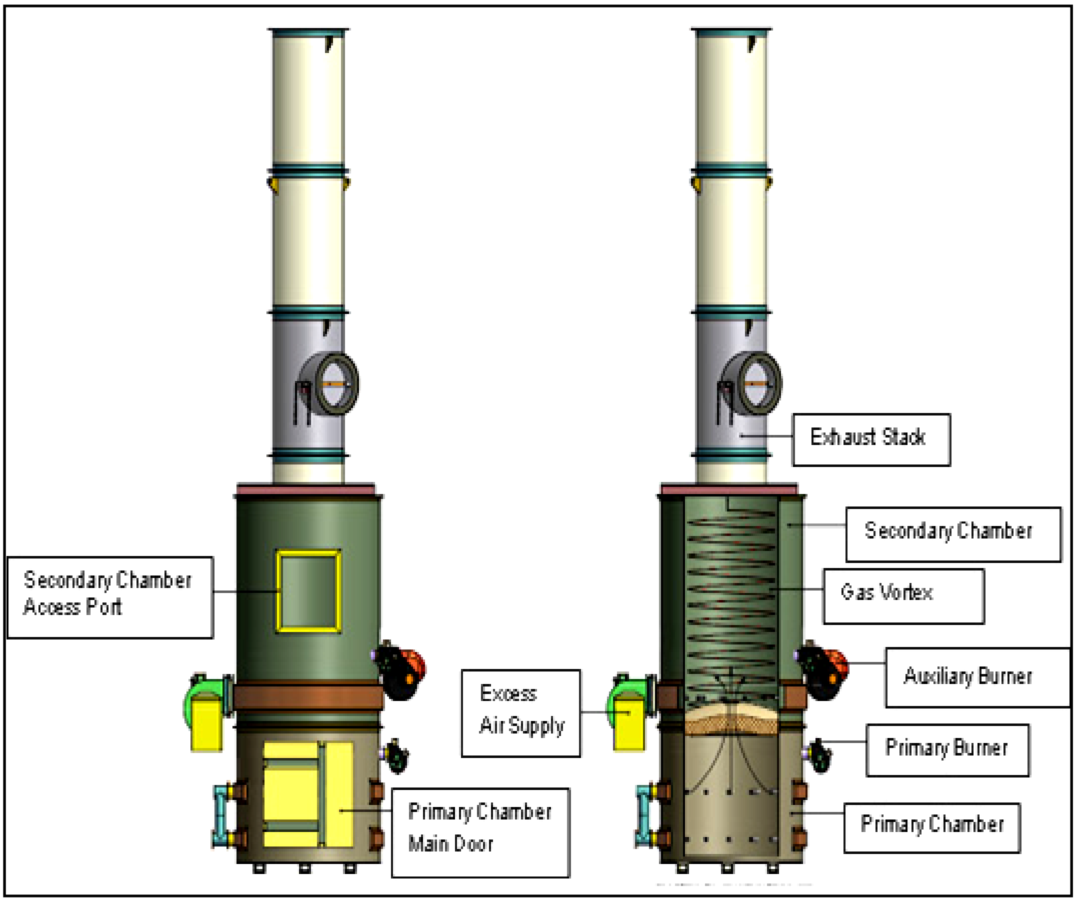


Figure (5.15) Controlled air incinerator

2- Excess air incinerators

Excess air incinerators are typically small modular units. They are also referred to as batch incinerators, multiple chambers or "retort" incinerators. Excess air incinerators are typically a compact cube with a series of internal chambers and baffles, shown on figure 5.16 (a, b). Waste is manually fed into the combustion chamber, the secondary chamber combustion gas typically 870 to 980°C. Waste feed capacities for excess air incinerators are usually 3.8 kg/min or less. They are usually operated in a batch mode.

Figure (5.16a) Excess air incinerator

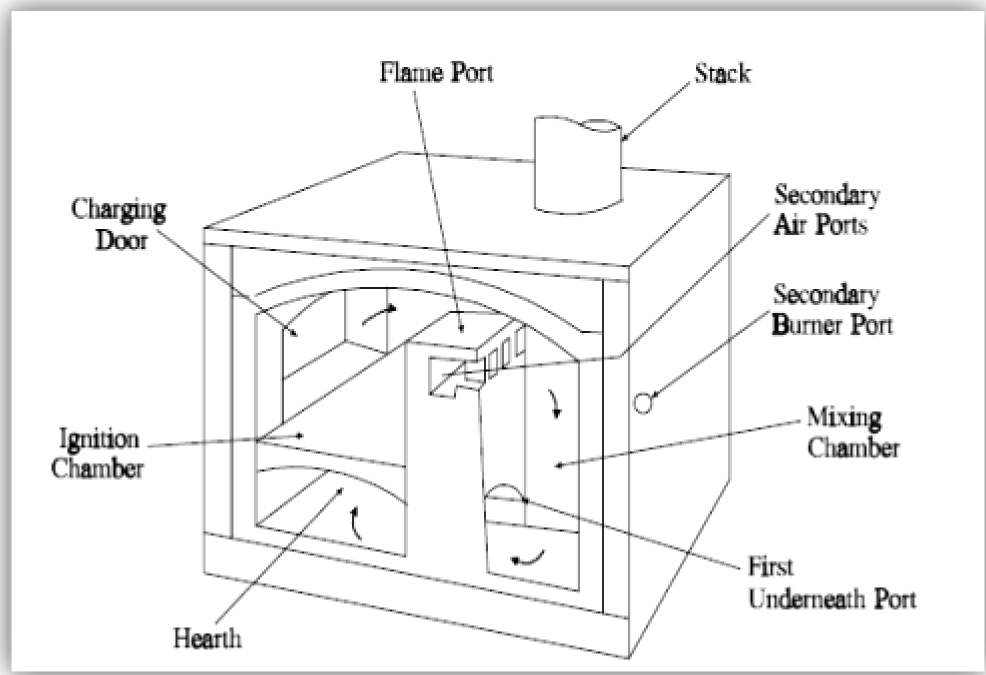


Figure (5.16b) inside view of Excess air incinerator parts

3- Rotary kiln incinerator (RKI)

It is designed with a primary chamber, where the waste is heated and volatilized, and a secondary chamber; where combustion of the volatile fraction is completed. Due to the turbulent motion of the waste in the primary chamber, solids burnout rates are higher for rotary kiln incinerators than for other incinerator designs. As a result, rotary kiln incinerators generally have add-on gas cleaning devices. The rotary kilns units tend to be larger than the others two types.

An auxiliary fuel and additional air are used to increase the reaction temperature, [22] the natural gas consumption between 4.5 and 20 m^3 per ton of waste. Operating temperatures range from ($800^{\circ}C$-$1000^{\circ}C$) and ($1000^{\circ}C$- $1400^{\circ}C$) in the primary chamber and afterburner [23], medical waste feeding capacity about (3-5) tons/hr [24].The waste shall be fed into the other incinerators in small batched after the mixed interval of time but a continuous charging using appropriate feeding mechanism in case of rotary kiln incinerator. The rotary kiln incinerator for medical and hazardous waste is operating 24h per day.

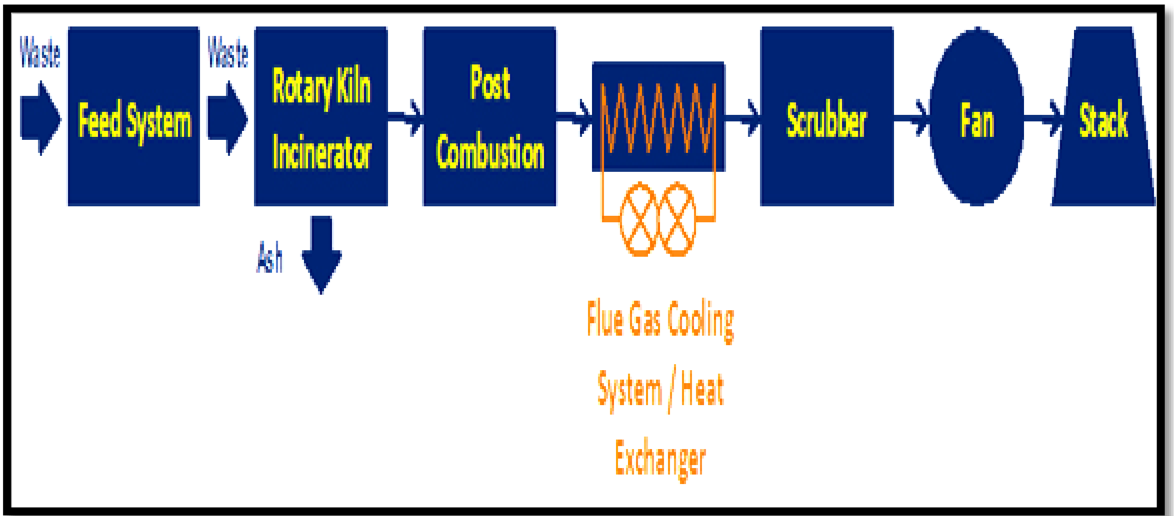


Figure (5.17) Block diagram of Rotary Kiln plant Steps

The table below shows the differences between different types of incinerator

Table (5.2) Comparison between different types of incinerator

	Controlled air incinerator	Excess air incinerator	Rotary kiln incinerator
Operating Temperature	760-1095 C	870-980°C	800-1400°C
Waste Capacity	200kg-10 ton /day	3.8 kg/min	3-5 ton/hr
Fuel Consumption	0.04-0.1m[3] natural gas per kg of waste	More than 0.1 natural gas per kg of waste	4.5-20m[3] natural gas per ton of waste
	Sharps, plastics are not destroyed	Sharps, plastics are not destroyed	Most type of waste
	Batch feeding	Manual Batch feeding	Continuous feeding

Rotary kiln almost treat all types of medical waste

1. Hazardous medical waste.
2. Infectious waste, surgical waste, injection needles, rubber gloves and tubing, tissues and bandage, drop-bags, medical remains, scalpels, infectious and pathological waste, blood plasma remains, cloths, laboratory waste, medicine remains, glass pipette, plastic samples, steel tools, etc.
3. Chemical waste and pesticides and pharmaceutical waste.

Wastes that should not be incinerated

4. Pressurized containers (may explode during incineration and cause damage to the equipment).
5. Wastes with high heavy-metal content incineration will cause emission of toxic metals (e.g. lead, cadmium, mercury) into the atmosphere [15].

Main advantages of rotary kiln

1. Universal application.
2. Minimum requirements with respect to sorting and preparation of waste.
3. Wide range of waste which can be incinerated simultaneously (Can handle liquid, sludge, solid, gas) waste in large quantities.
4. Genuinely continuous incineration.
5. High combustion temperatures, up to 1,400°C.
6. Easily controlled dwell time of waste in combustion chamber.
7. Rotate wastes in rotary kiln, enabling through mixing with air.
8. Has great resistance to high temperatures.

5.4.3 The Components of the Rotary Kiln System

Rotary kiln system consists of several components, which are described below.

I. The screw feeder

Used to convey and feed the waste to the rotary kiln, with a 3.5m length and 0.5 m diameter. The injection screw conveyors extend 0.9m into the rotary kiln and withstand elevated kiln temperatures. The conveyors manufactured using 310, 316, and 304 stainless steel components to withstand the high temperature as well as the corrosive environment of the process.

The design incorporated a screw to stop short to the housing discharge to create a natural plug condition at the end of the screw conveyor. This plug prevents heat, gases and fumes from flowing back into the preceding equipment and processes, high-torque drive units used to push the material plug into the rotary kilns. A 316 stainless steel hanger bearing with stellite (cobalt chromium alloy) bearing inserts and coupling shaft with stellite sleeve. These two components were able to add excellence wear resistance and withstand the extreme environment [25].

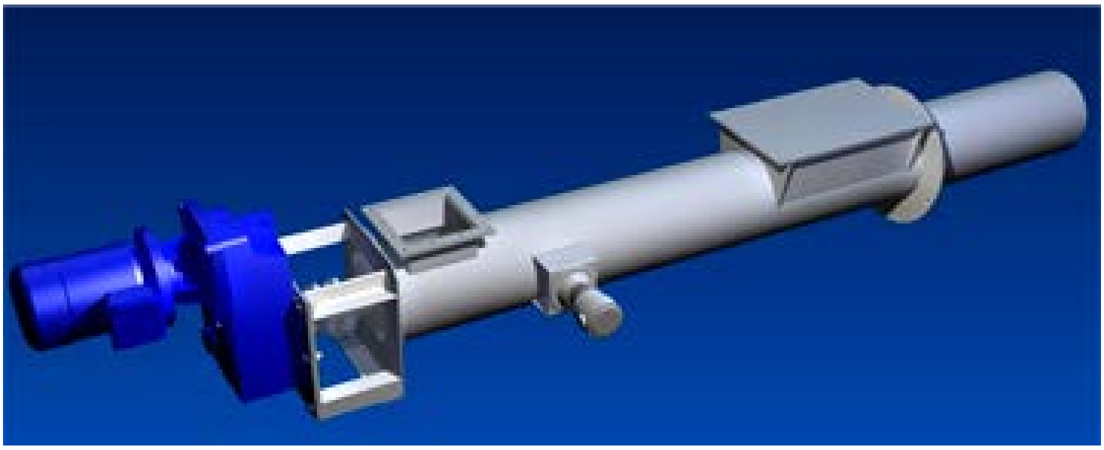


Figure (5.18a) High temperature injection screw conveyor

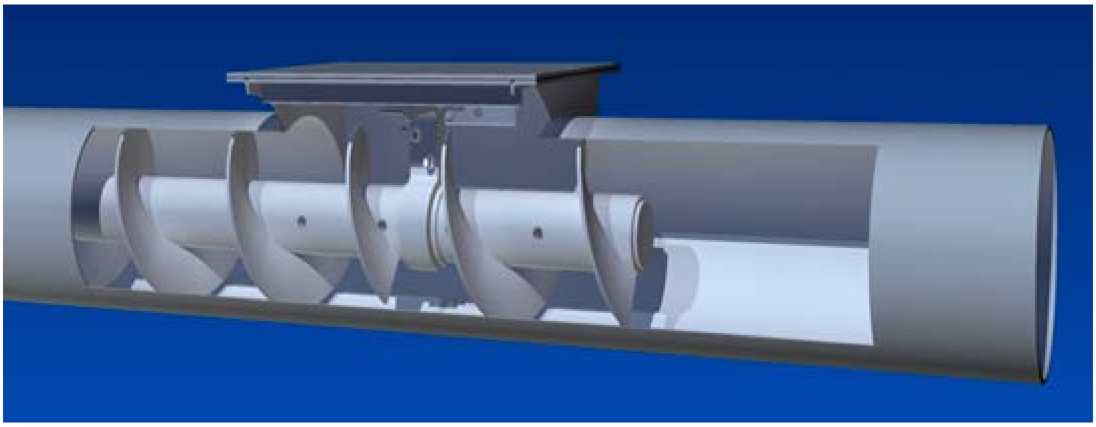


Figure (5.17b) Feeder cross section view

Figure (5.18c) High temperature injection screw conveyor

The solid waste bags/containers are picked up with a gripper or automatic crane which is shown below; the gripper is moving by lifting gear automatically or manually, two steel clapboards are installed in the chute (hopper) to maintain good seal. The chute can not only prevent air flowing into the primary chamber, but also prevent fire from the combustion chamber entering the feeding system [26].

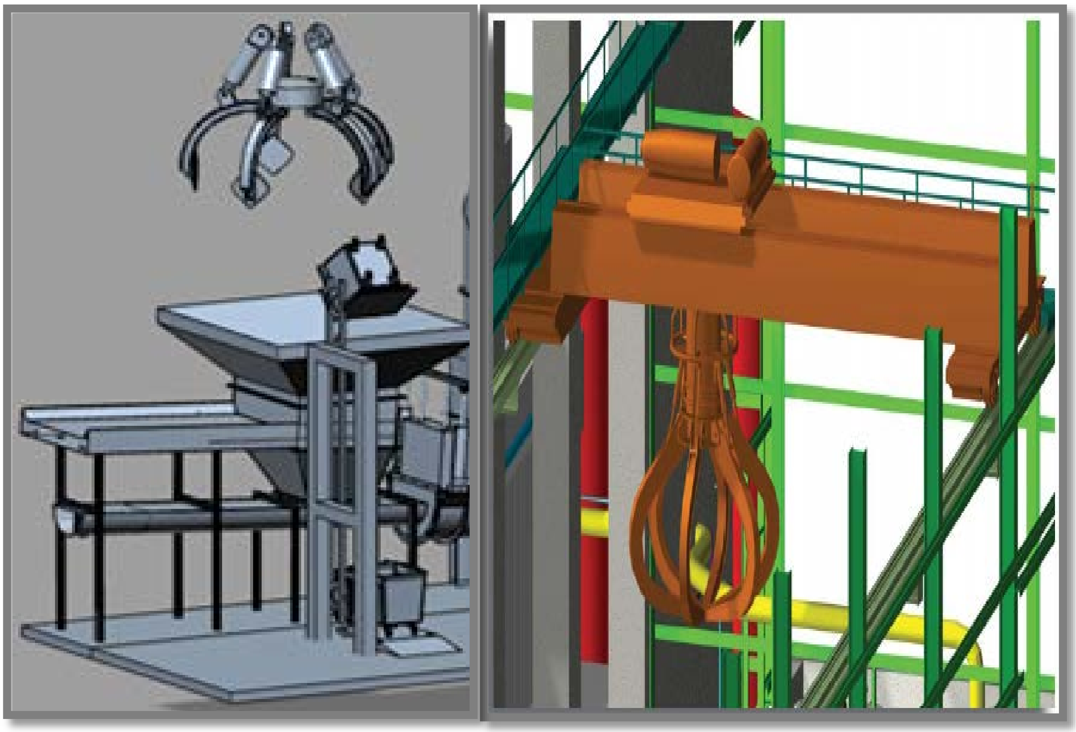


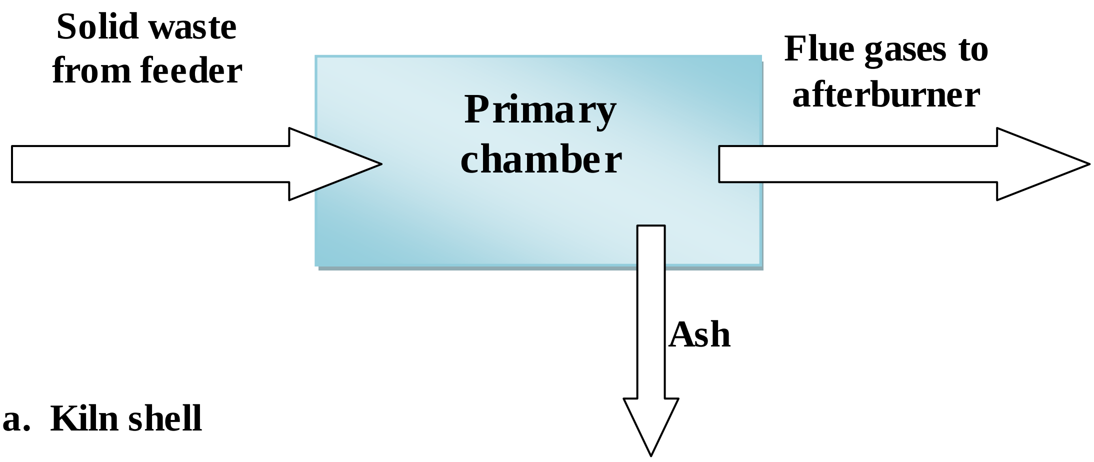
Figure (5.19a) Gripper system

Figure (5.19b) Waste feeding system using Grip crane

The liquid waste materials are stored in tanks and injected into the combustion chamber with an air assisted atomizing nozzles directly into the kiln through the main burner. These nozzles spray the liquid waste and mix it with combustion air [27].

II. Primary chamber “Primary Combustion Chamber PCC”

PCC is the chamber where the medical waste fed into, temperature is controlled by the under-fire air supply which maintain high enough to destroy hazardous organics in the waste, it is consists of number of parts:



a. Kiln shell

Is a horizontal inclined cylinder made of steel shown on figure(5.20a), usually (carbon steel), the shell thickness typically in the range from 18-25 mm, [28] the dimensions of the shell is 2.5 meters diameter and 6 meters length. Rotary kiln incinerators usually have a length-to-diameter ratio (L/D) between 2 and 8 [23].

Figure (5.20a) Kiln shell

b. Refractory lining

The refractory material is consist of acid-resistance refractory brick that line the shell from inside, such as ceramic material or high alumina (Al_2O_3) material with minimum binders; which is strong enough to sustain maximum temperature up to1000^{o}C in primary chamber, [29]to insulate the steel shell from the high temperatures inside the kiln. Beside, insulation and protection against slag attacks, and protection of the shell against corrosive properties of the process material; this assures maximum operating life for kiln, even when processing materials with a high acid content are used [30]. The average thickness of refractory lining and insulated bricks is 250 mm.

c. Tyres and rollers

Tyres, sometimes called (riding rings), and rollers is use to support the kiln and allow it to rotate with minimal friction, shown on figure (5.20b). Tyres consist of a single annular steel casting, machined to a smooth cylindrical surface, which attach loosely to the kiln shell through a variety of "chair" arrangements. The kiln shell is supported by two steel tyres that ride on rollers, which allow the kiln to rotate around its horizontal axis. The tyre rides on pairs of steel rollers, which is machined to a smooth cylindrical surface, and set about half a kiln-diameter apart.

The rollers must support the kiln, and allow rotation that is as nearly frictionless as possible [31]. The rollers are mounted on a steel base plate which provides the inward horizontal forces on the rollers and distributes the weight of the kiln over the pier. Rollers are designed to subtend 60° at the tyre centre to sustain horizontal forces and for more stability of kiln, shown on figure (5.20c) [28].

Figure (5.20b) Rotary shell with Tyres and rollers

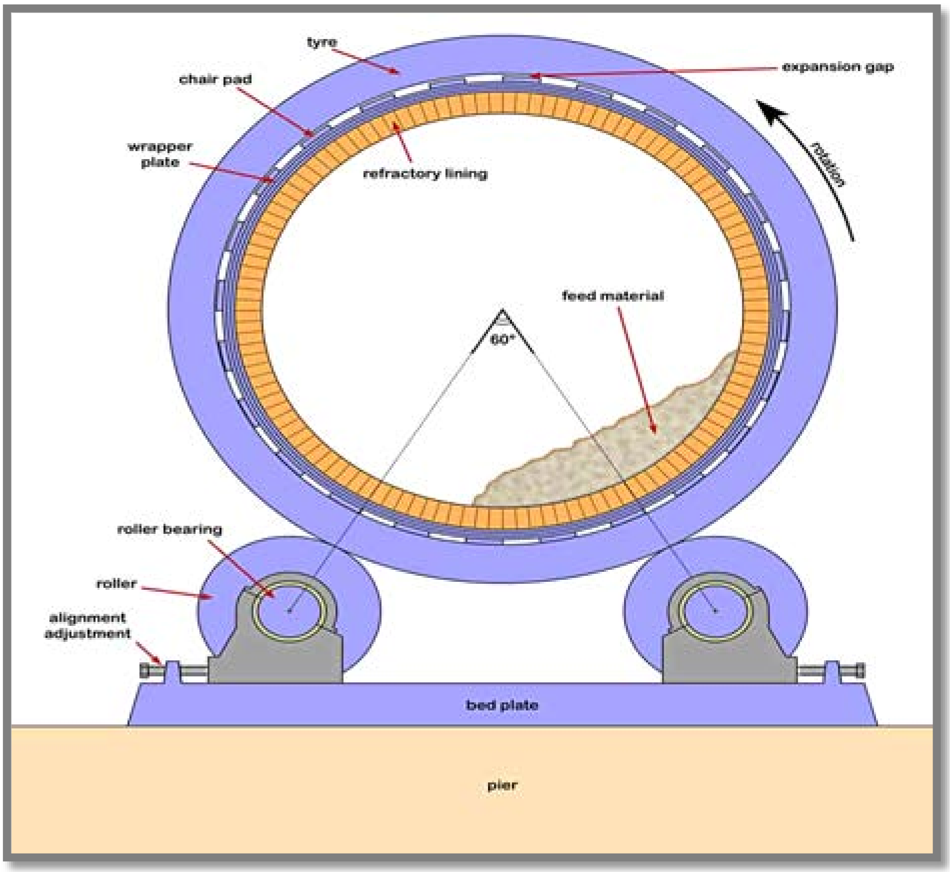


Figure (5.20c) Tyres and rollers position on rotary kiln

The kiln rotates at a horizontal angle of 4^o degrees at a speed of 2 to 5 times per minute, by the torque being supplied through the rollers. This relies upon the friction between roller and tyre, and the critical requirement is that the friction should be sufficient to start a heavily-loaded kiln from the stalled condition. This rotation keeps fed medical waste moving; to prevent the heap formation of waste on the hearth and to uniform spreading of waste on the hearth to facilitate the heat transfer between the waste and hot flames, this is leading to vaporize for easier burning, [9] and minimization of fuel energy requirements[27].

Figure (5.20d) Rotary shell with feeder and burner

The rotating drum is positioned between an auxiliary gas/oil burner at the end of PCC and the afterburner on the feeding side, both of which are stationary.

The auxiliary burner is used to start combustion and maintain desired combustion temperatures heat of about A 300.000 kcal/hr [9] before feeding waste.

At the chamber there is an air nozzles below the burner connected to a high-pressure blower with actuated damper. As the combustion rate of the material increases, the damper is opened thus maintaining a proper air ratio (primary air) for complete combustion of the smoke and particulate [30]. Flow meter/ suitable flow measurement device will be provided on the air ducting [3]. The solid and liquid wastes that fed into the rotating kiln are partially burned into inorganic ash and gases. The ash is discarded in an ash bin, and the gaseous products in which uncombusted organic materials still reside, are sent to the secondary combustion chamber for complete destruction [32]. Solids retention time in the kiln is 0.5 to 1.5 hours [27]. When the waste is consumed, the primary burner shuts off. Typically, the afterburner shuts off after a set time.

Rotary kilns in which combustion gases flow opposite to waste flow and against the inclination of the kiln incinerator called (countercurrent rotary kilns), shown on figure (5.20e), are preferred to those in which gases flow in the same direction (co-current); they have lower potential for overheating because the auxiliary heat burners are located opposite the incinerator [22]. The counter current rotary kiln is shorter and has a larger diameter than co-current type.

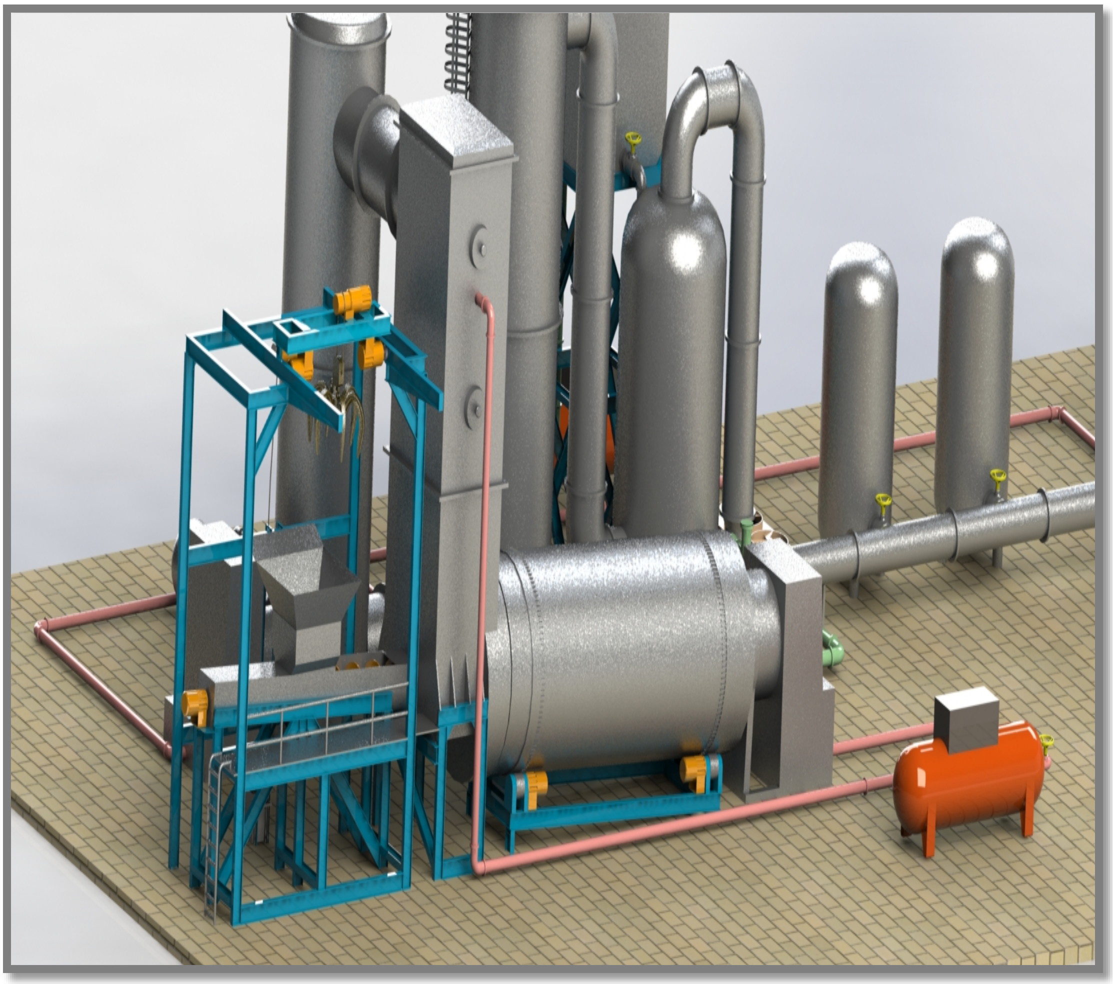


Figure (5.20e) Counter-current rotary kiln

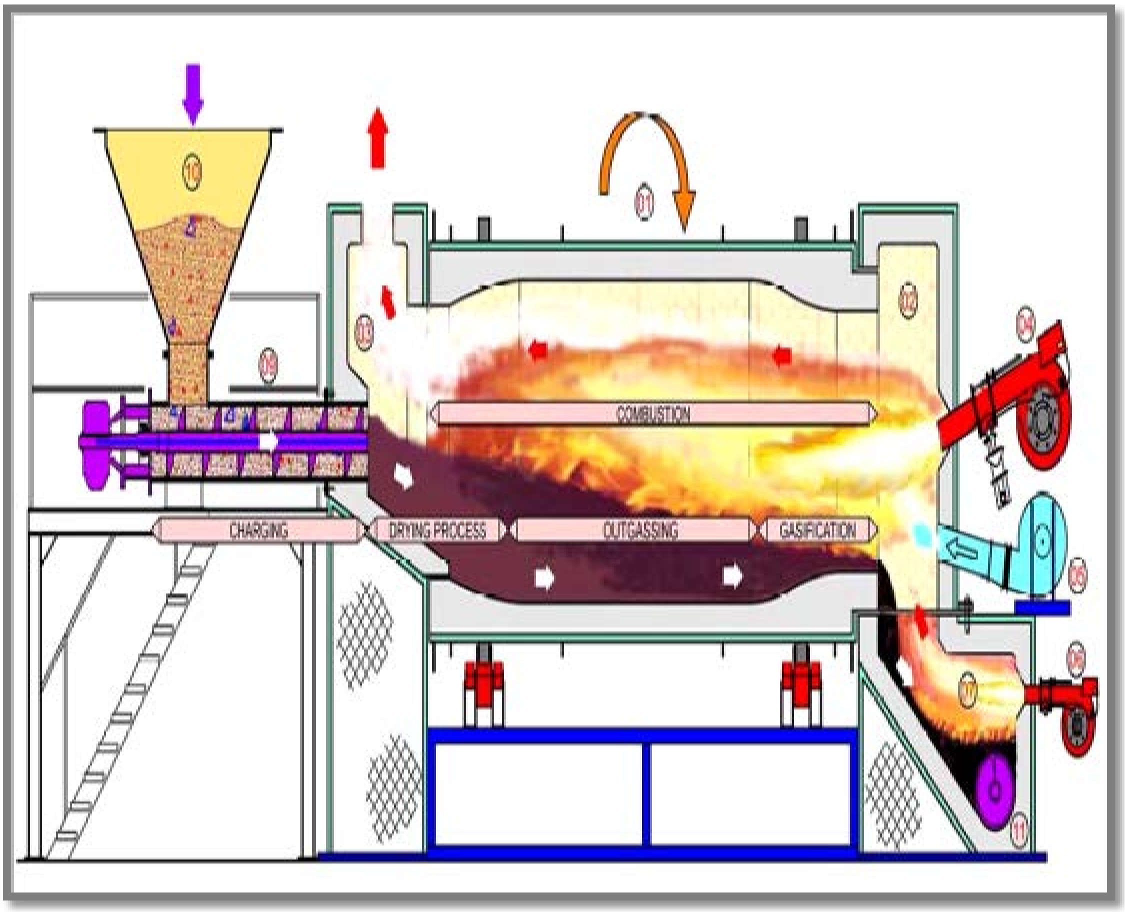


Figure (5.20f) Burning operation inside Rotary kiln

1. Rotative combustion chamber
2 .Front head
3. Rear head
4 .Start and supporting burner
5. Primary air fan
6. Automatic ashes chamber burner
7. Ashes chamber
8. Flue gases
9. Waste feeder
10. Solid, Liquid, Pasty and Sludge hazardous waste
11. Unloading ashes cochlea
12. Gases to post combustion chamber

III. The afterburner": a secondary oxidation/combustion chamber" SCC

It is a refractory-brick-lined cylinder, made of steel (carbon plate), attached to stationary furnace and supporting the rotating kiln as shown below [9]. SCC must be vertical; no pipeline is needed for connection between the PCC and the SCC; so the heat loss in pipeline occurring in traditional multi-chamber incinerator is eliminated [26]. Combustion of the volatiles is completed in the secondary chamber [32].

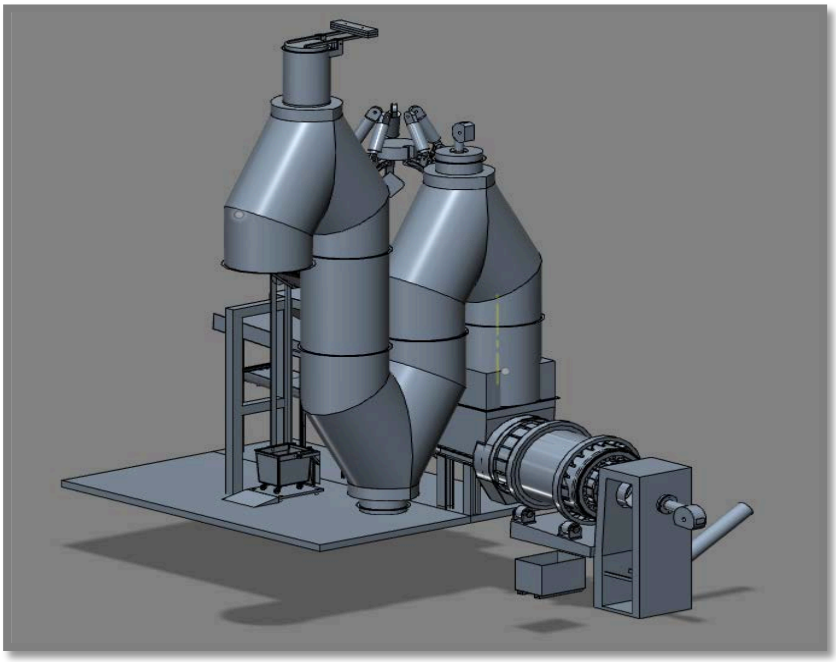


Figure (5.21a) Afterburner

The secondary combustion chamber operates at a higher temperature than the primary chamber, its burner capacity about 1000.000kcal/hr for secondary chamber [29]. A 304 stainless steel stack mounted to the discharge connection of the secondary chamber between afterburner and air pollution control system, figure (5.21b) [30]. The stack (emergency chimney**)** is used in case of failure on after burner and when over pressurizations occurs; this goes open and heat will escape [27]. The secondary chamber operates at excess air (secondary air) supplied at the top of the secondary combustion chamber. The secondary air injector is fixed in tangential direction to achieve well gases mixed effect [26] shown on figure (5.21c).

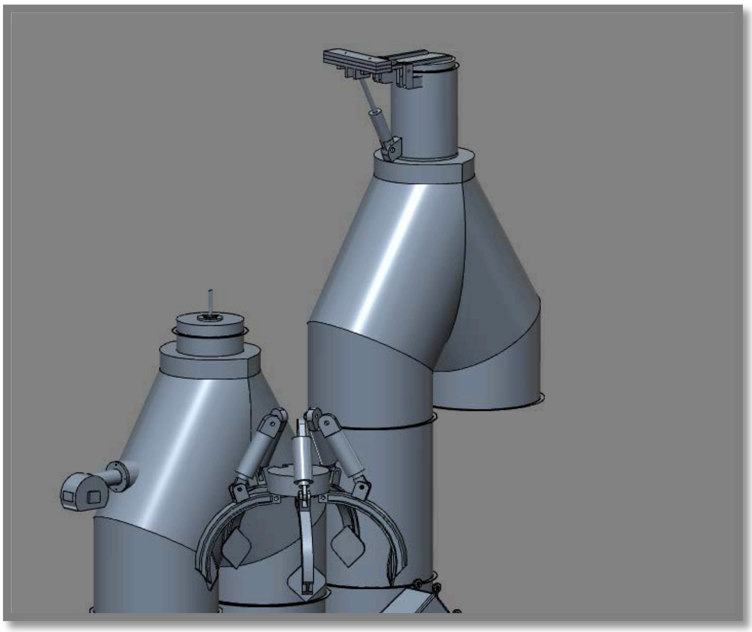
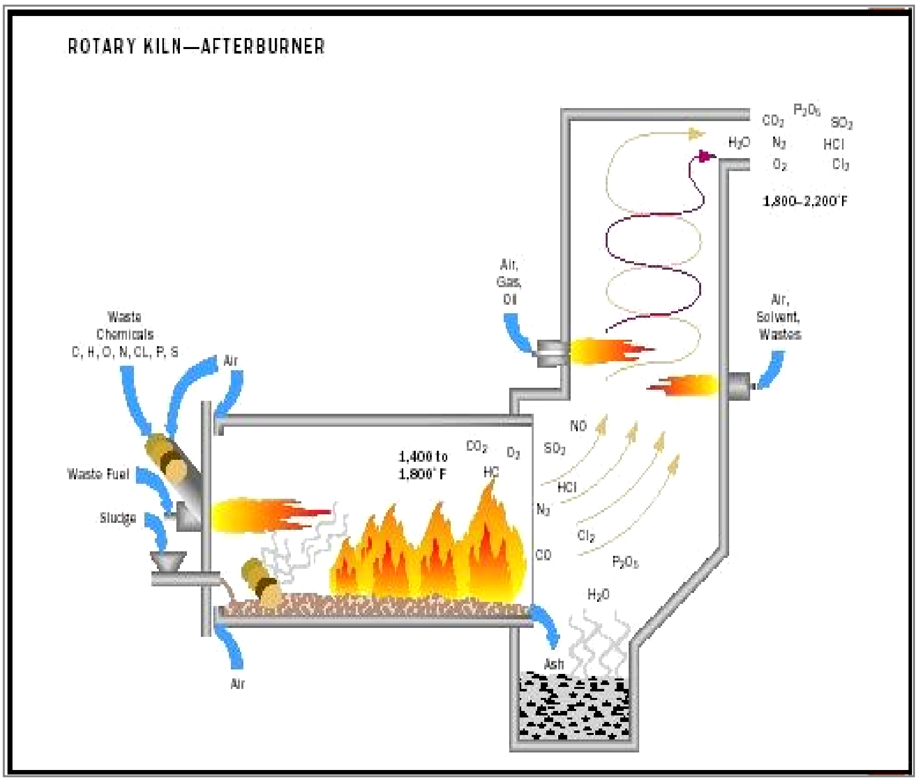


Figure (5.21b) Afterburner Emergency vent



Figure(5.21c) Combusition operation on afterburner

If sufficient air is not being supplied by the burner; high CO or hydrocarbon levels in the effluent gases will be measured in the stack gas monitoring system, this is indications for additional combustion air is required.
The sides and the top portion of the primary and secondary chambers shall preferably have rounder corner from inside to avoid possibility of formation of black pockets on dead zones [3], burn off gaseous organic compounds in the post-combustion chamber typically has a residence time of 2 seconds. [15]Liquid wastes may also be injected, with steam or air assisted atomizing nozzles, directly into the SCC.

IV. The heat exchanger

It is a piece of equipment built for efficient heat transfer from one medium to another. It is used for energy utilization and cooling of flue gases. Tubular water heat exchangers are generally used for steam and hot water generation from the energy potential of hot flue-gases [33].

Heat exchangers consist of series of tubes, as shown on figures below; set of these tubes contains the fluid (water) that will be heated. The second fluid (gases) runs over the tubes that are being cooled, so that it can provide the heat or absorb the heat required [34].

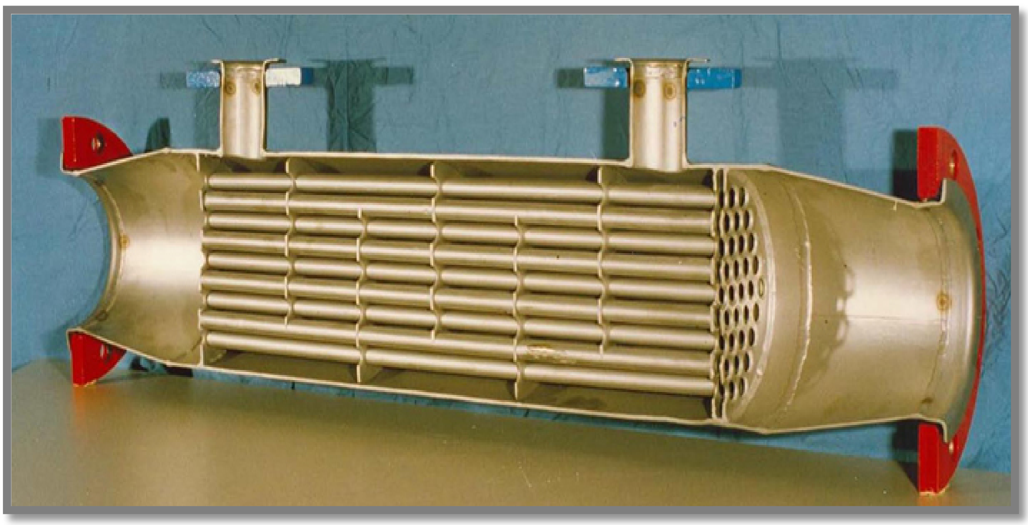


Figure (5.22a) Heat exchanger cross section view

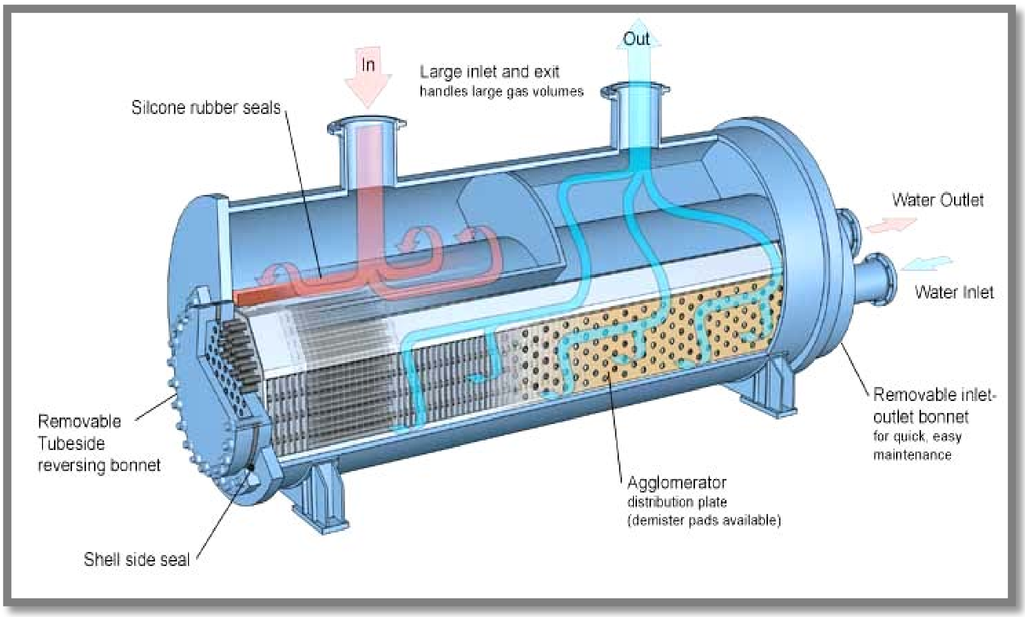


Figure (5.22b): Heat exchanger operation

The cooling of the flue gases is necessary to prevent damage to the filter bags in the next stage, the flue gases directly enter the heat exchanger in which they are cooled to a temperature of approximately 200^{o}C. The water steam generated in the heat exchanger is discharged to the atmosphere. On the other way the steam can be used to drive a steam turbine incase of using boiler with heater. The medical waste is thus effectively converted into useful energy (electricity) [35].

In the ductwork between the boiler and the baghouse there is a damper and an air inlet. The damper is operated automatically, in response to afterburner outlet temperature. The air inlet is opened when the gases exiting in the boiler approach the design limits for the filter bags. This allows inflow of cool air, diluting and cooling the combustion gas stream [9]. There are limit switches for high steam pressure and low water level to protect the heat exchanger in the event of miss operation.

V. Air pollution control devices (APCDs)

Bio-medical waste incinerators shall always be equipped with APCDs. The most frequently used control devices are scrubbers and fabric filters (FFs) Incineration has a number of outputs such as, ash and the emission to the atmosphere of flue gas [22]. Before the installation of the flue gas cleaning system, flue gases may contain significant amounts of:

1. Particulate matter: various sizes.

2. Heavy metals: as mercury Hg, lead Pb and others.
3. Carbon compounds: including dioxins (PCDD), furans (PCDF), carbon monoxide (CO) amongst others.
4. Acid gases and other gases: including hydrochloric acid (HCl), Hydrogen fluoride (HF), sulfur dioxide (SO_2), Oxides of nitrogen (NO_x), and others.
5. Dust: from dry reagent handling and waste storage areas.
6. Green house gases (GHGs):–from decomposition of stored wastes e.g. carbon dioxide CO_2, Methane CH4.

Reduction of organic carbon compounds –PCDD/F

Activated carbon is injected into the gas stream after heat exchanger stage, where it mixes with flue-gases. It may be injected on its own or combined with alkaline reagent, usually lime ($Ca(OH)_2$) or sodium bicarbonate ($NaHCO_3$). The injected alkaline reagent, their reaction products and the carbon adsorbent are then collected and filtered from gas flow in a bag filters, the adsorbed PCDD/F is discharged with other solid wastes from the bag filters.

Reduction of emissions of oxides of nitrogen NO_x

The formation of NO_x is either thermal during combustion, a part of the air nitrogen is oxidized to nitrogen oxides; this reaction only takes place significantly at temperatures above 1300 °C, depends exponentially on the temperature and is directly proportional to the oxygen content. Or fuel NO_X during combustion, a part of the nitrogen contained in the fuel is oxidized to nitrogen oxides.
NO_x is treated by using ammonia (NH_3) as reduction agent; is injected in the form of aqueous solutions into the furnace to reduce NO_X emissions. The nitrogen oxides in the flue-gas basically consist of NO and NO_2 which are reduced to nitrogen N_2 and water vapour by the reduction agent.

Reduction of mercury emissions Hg

By activated carbon and alkaline reagent.

Reduction of heavy metals (other than Hg)

Heavy metals in incineration are converted mainly into non-volatile oxides and deposited with flue ash, thus using the baghouse filters as for dust removal, or by injection of activated carbon [21].

Reduction of particulate emissions, using the baghouse (fabric filters)

a) Definition

It is a dust removal device use for dry removal of solid particles and dust from polluted air or gas [36]. Fabric filters provide mainly particulate matter control which is a result of incomplete combustion of organics (soot).

Figure (5.23a) Baghouse system

b) Components

It is consists of a number of cylindrical filtering elements (bags) with a bag cleaning system contained in a main shell structure with dust hoppers, shown below on figure (5.23b) [22]. Filter bags in the baghouse compartment are supported internally by rings or metal cages, shown on figures 5.23(c, d); to prevent collapse of the bag due to entering and flowing of gases from outside to inside of the bags [37].

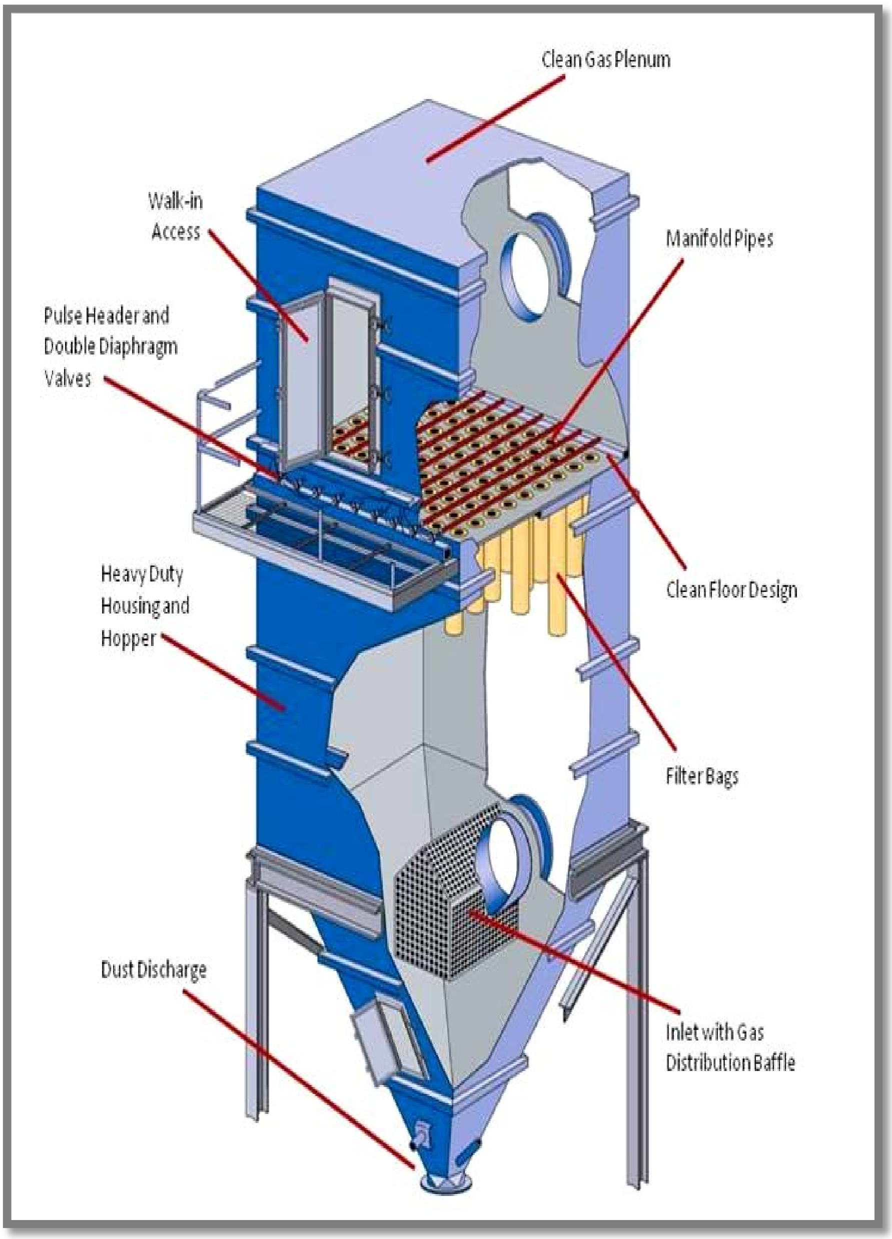


Figure (5.23b) inside view of Baghouse

Figure (5.23c) Filters bag shell

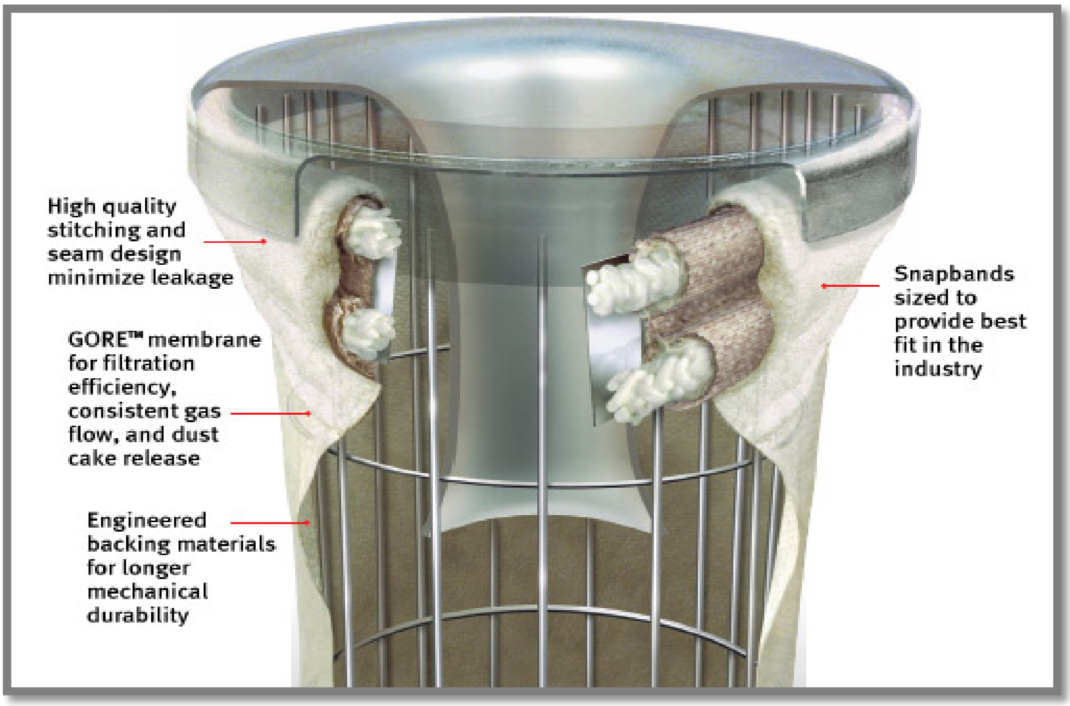


Figure (5.23d) Filter bag metal cage

The diameter of bags about 117 mm and length of bags 2.4m depend on manufactures. Filters are made of fiber (synthetic textiles, cotton or fiber glass) in tube shape that is relatively resistant to chemical aggression [15]. Filter bag must coat with calcium carbonate to maximize the efficiency of dust collection and for long usage life [38].

Table (5.3) Characteristics of filter textiles

Bag Type	Temp Limits (F/C)	Resistance To Acid	Resistance To Alkalis	Resistance To Hydrolysis	Resistance To Oxidation
Cotton	180/85	Poor	Good	Good	Good
PVC	160/65	Excellent	Excellent	Excellent	Excellent
Polypropylene	190/90	Excellent	Excellent	Excellent	Poor
Nylon	230/110	Poor	Excellent	Good	Good
Polyester	300/150	Good	Poor	Poor	Good
PPS	375/190	Excellent	Excellent	Excellent	Fair
Aramid(Nomex)	400/205	Poor	Excellent	Poor	Fair
Polyamide	450/235	Fair	Fair	Good	Good
PTFE	500/260	Excellent	Excellent	Excellent	Excellent
Fiberglass	550/285	Good	Fair	Excellent	Excellent

The beghouse may contain filters of about 25 Nomex (aramid fiber) bags with a total area of 23.2 square meters or more [9]. Functioning bag houses typically have a particulate collection efficiency of 99% or better, even when particle size is very small.

c) Modes of operation

There are two modes of operation

1. Filtration mode

After cooling down, the polluted flue gases (Particulate-laden gas) and air stream enters the baghouse from side part of the hoppers (large funnel-shaped containers used for storing and dispensing particulate), as on figure (5.24), [37] due to the slowdown and the change of direction of the gas flow the primary separation of rough dust particles takes place. The residual polluted gas then rises up to the vertically hung filtration bags, [36] where particles become trapped in the fiber mesh of the fabric bags, and will be separated on the outer surface of filtration bags thus cleaning the gas [22]

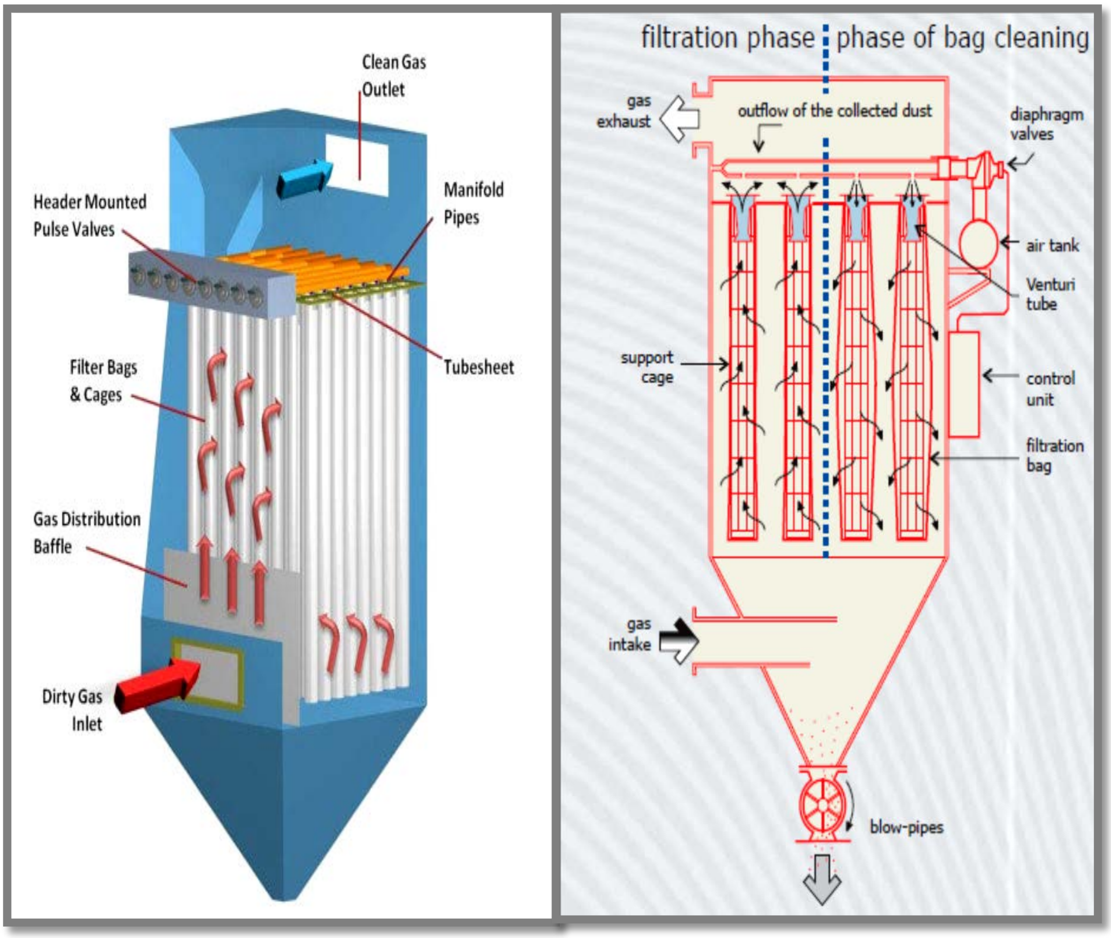


Figure (5.24) Baghouse filtration and cleaning phase

Both the collection efficiency and the pressure, drop across the bags surface increase as the dust layer on the bag builds up. Dust particles form a continuous layer of dust on the outer surface of the filtration bags, since the system cannot continue to operate with an increasing pressure drop, the bags are cleaned periodically [22] by using pulse/pressure - jet technique [36].

2. Cleaning mode

The pulse-jet cleaning mechanism uses a high pressure jet of air (compressed air-induced pulse) to remove the dust from the bags, on figure (5.25) [37]. The basic action of the pulse jet cleaning system is to direct a burst of compressed air into each bag at its open top, shown on figures 5.26(a, b); this air burst or pulse, is admitted by the timed opening and closing of a solenoid valve, the solenoid admits air into the blowpipes from air tank, one of which is positioned above each row of bags.

The blowpipes have in them small holes positioned over and directed towards each bag top. A venture is built into the top of each cage, shown on figures 5.27(a, b). The venture is used to encourage the entrainment of air by the pulsed air so that a larger volume of air is used in cleaning than can be supplied by the compressed air system alone [39].

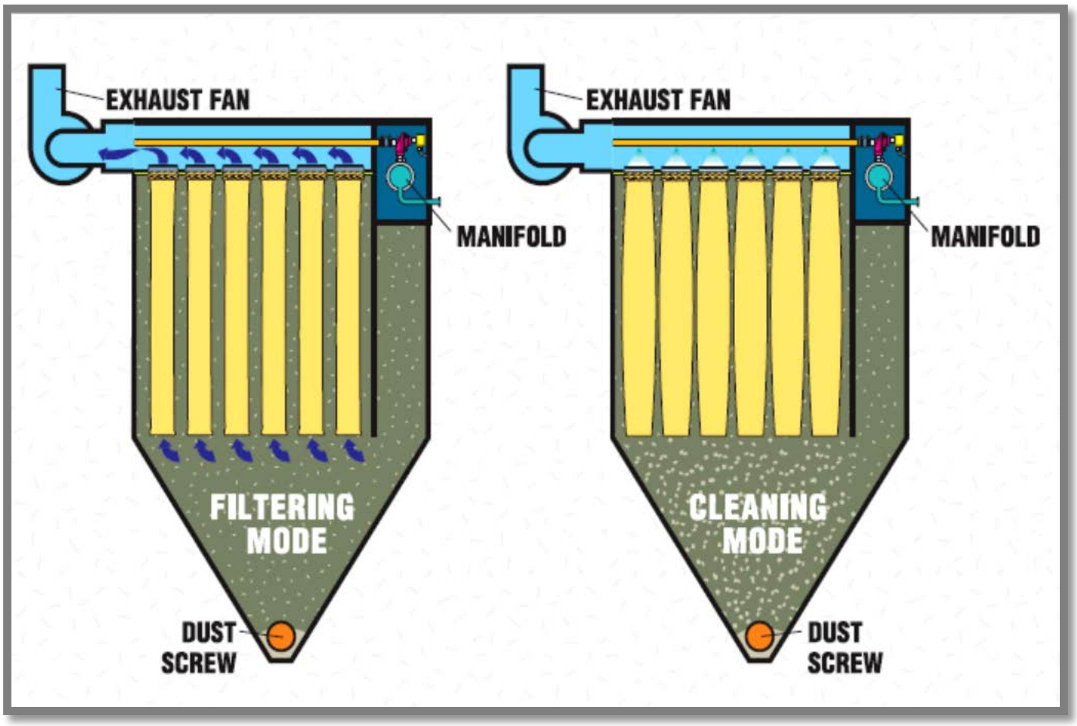


Figure (5.25) Pulse jet baghouse mode

Figure (5.26a) Bag cleaning technique   Figure (5.26b) blowpipes shape

Figure (5.27a) Venture

Figure (5.27b) Venture handling

If a baghouse is not overloaded, the compressed air pressure of 5.1 to 5.8 bars will be adequate. Pressures in the 7.2 to7.9 bars range will cause more problems than they solve (damage of bags) as shown below on figure (5.28).

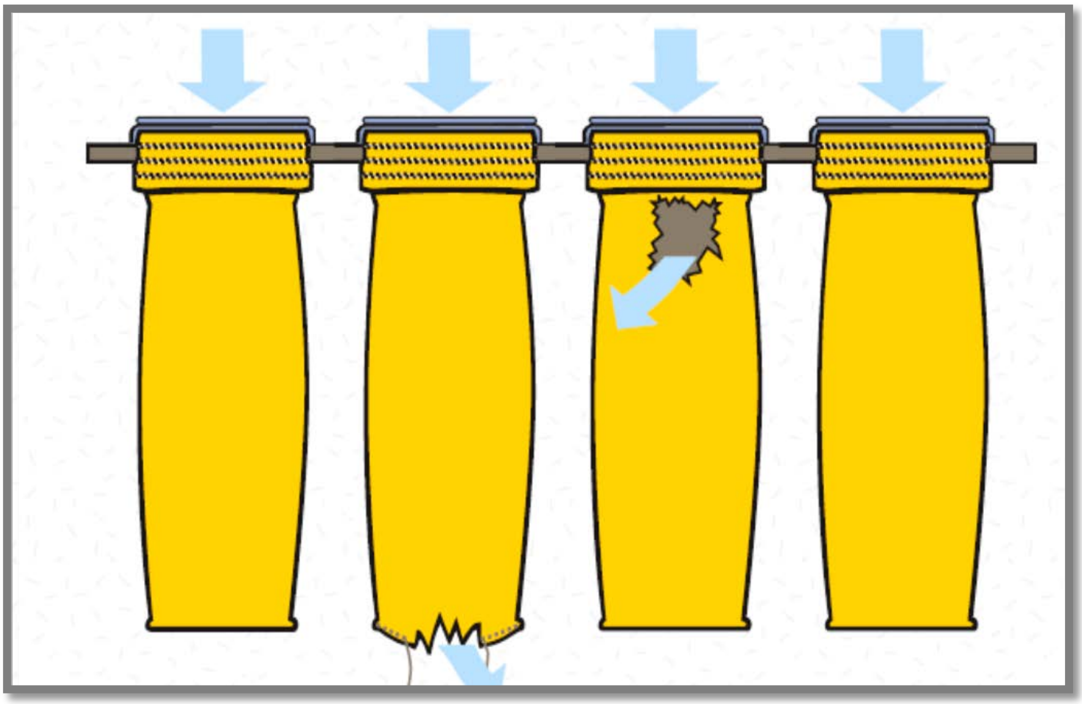


Figure (5.28) High pressure air pulsing

*Pulsing with high air pressure damages bags

Because the bags are not taken out of service for cleaning, discharged dust must fall counter to the rising gas stream. Gentle pulsing allows dust to remain agglomerated and fall into the hopper as shown below on figure (5.29a).

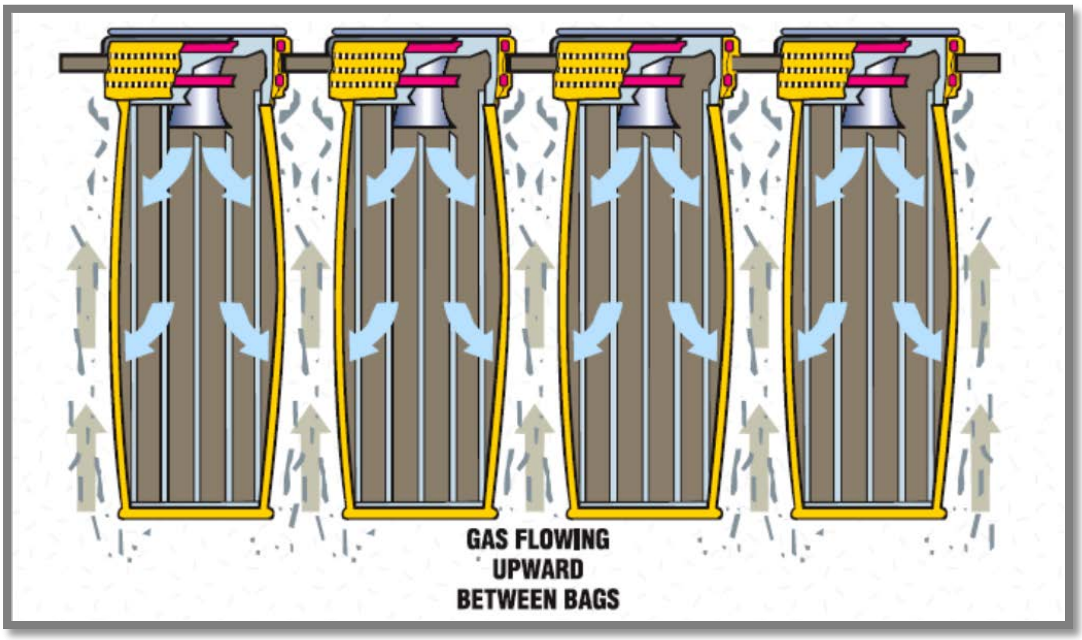


Figure (5.29a) Bag cleaning with gentle pulsing

Severe pulsing breaks the agglomerated dust cake into individual particles which are unable to fall against the rising gas, as shown on figure below:

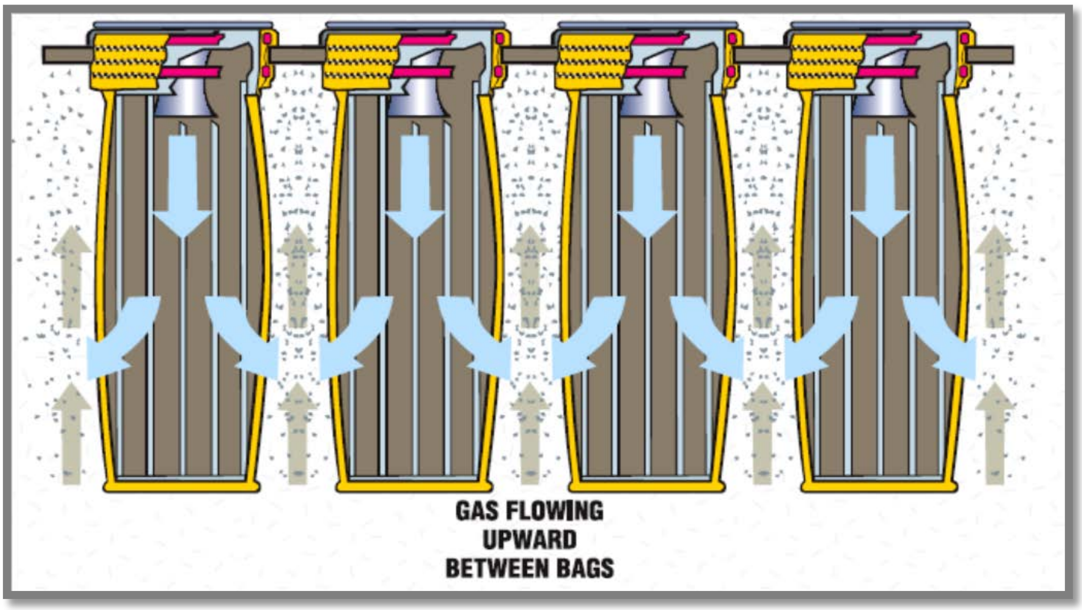


Figure (5.29b) Bag cleaning with severe pulsing

A rotary air lock, shown below, is used for controlling air leakage to baghouse during dust discharge; because the air leakage reduces the production capacity and increases baghouse temperature.

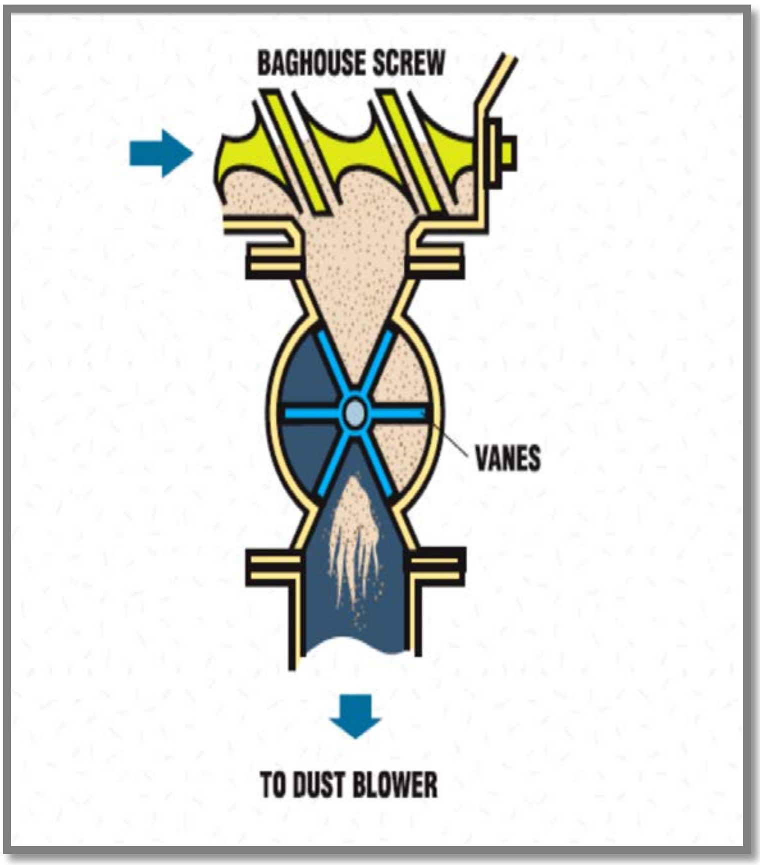


Figure (5.30) Rotary air lock

The control systems designed to allow the operator to keep the cleaning system in operation at all times when the plant is running (turning the cleaning system on and off is to be avoided); to avoid bag cleaning reset operation.

Pulse-jet dust collectors can be operated continuously and cleaned without interruption of flow; because the burst of compressed air is very small compared with the total volume of dusty air through the collector. Cleaning can take place while the baghouse is online (filtering) or is offline (in isolation) [38].
Figure and table below show the dimensions and characteristics of baghouse unit.

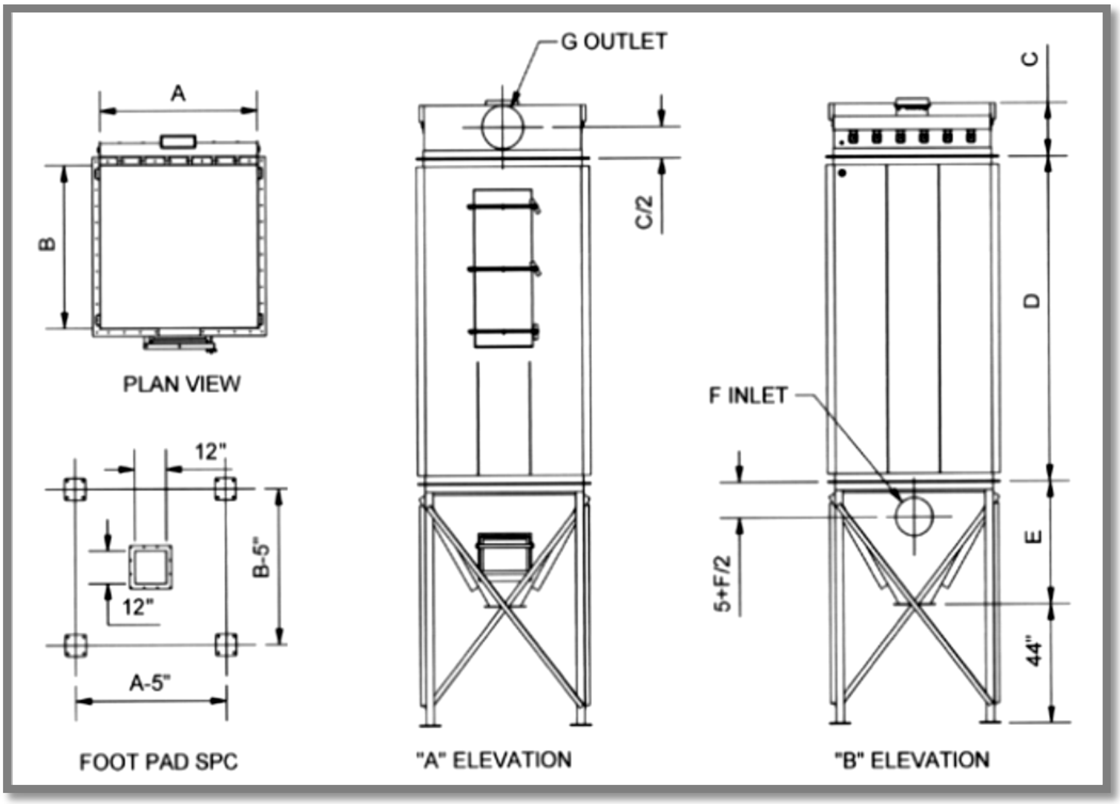


Figure (5.31) Baghouse dimensions

Table (5.4) Baghouse dimension specifications

FILTER MODEL	FT² OF CLOTH			DIMENSIONS									
BOTTOM ENTRY INLET	96" BAGS	120" BAGS	144' BAGS	A	B	C	D(8')	D(10')	D(12')	E	F	G	H
25 BR (8) (10) (12) BEI	314	393	471	48	48	25	96	120	144	28	12	10	
36 BR (8) (10) (12) BEI	452	565	678	57	57	25	96	120	144	36	14	12	
49 BR (8) (10) (12) BEI	615	769	923	66	66	25	96	120	144	43	18	16	
64 BR (8) (10) (12) BEI	804	1005	1206	75	75	25	96	120	144	51	20	18	
81 BR (8) (10) (12) BEI	1017	1272	1526	84	84	25	96	120	144	59	22	22	18
100 BR (8) (10) (12) BEI	1256	1570	1884	93	93	25	96	120	144	67	24	24	18
121 BR (8) (10) (12) BEI	1520	1900	2280	102	102	25	96	120	144	74	26	26	18
144 BR (8) (10) (12) BEI	1809	2261	2713	111	111	25	96	120	144	82	30	30	18

Reduction of acid gases emissions (the Scrubber - Wet scrubbers)

a) Definition

Wet scrubber used for high controlling acid gases (HCl, SO_{2}...) and particulate emissions. It is a dust collector that uses liquid (water/ alkaline reagent). Scrubber design and the type of liquid solution used largely determine contaminant removal efficiencies. With plain water, removal efficiencies for acid gases (HCl, HF…etc) will be high, but addition of an alkaline reagent to the scrubber liquor will have of higher removal efficiencies for SO_x (acid neutralization) [22].

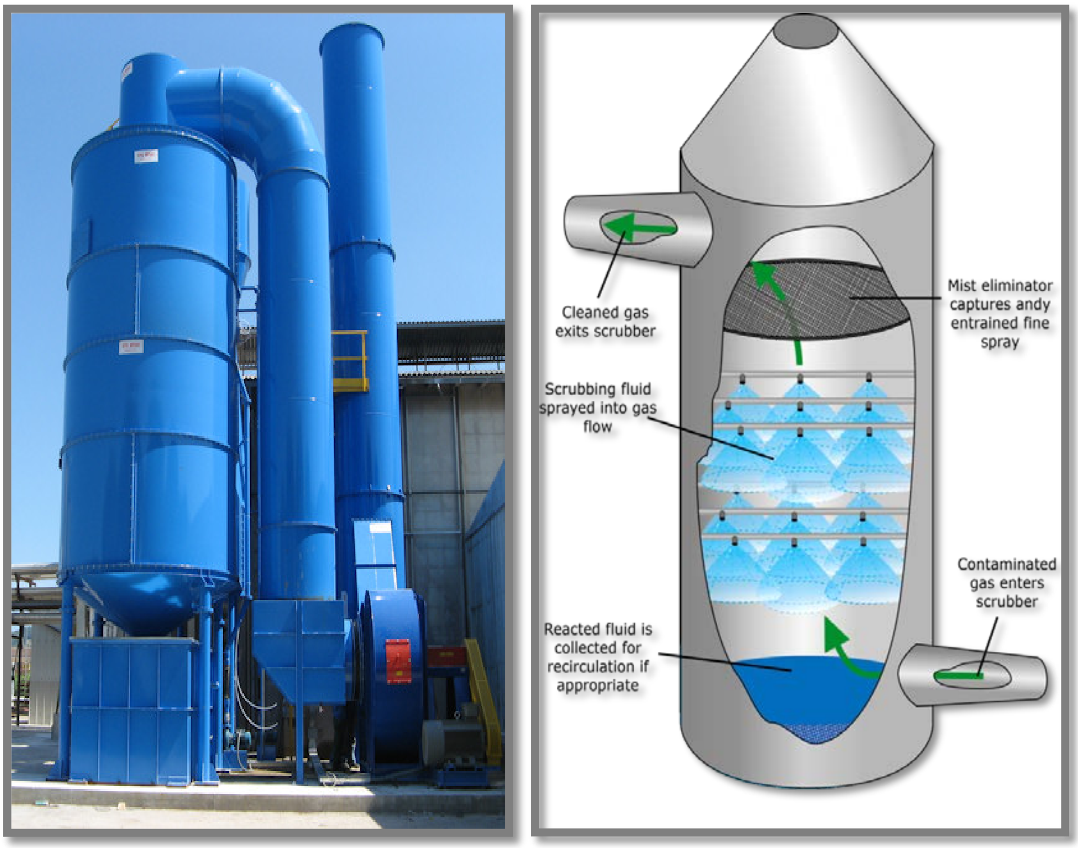


Figure (5.32) Scrubber system

b) Function

The scrubbing liquid/sorbent solution comes into contact with a gas stream containing dust particles and it will remove dust particles by capturing them in the liquid droplets. Wet scrubbers remove pollutant gases by dissolving or absorbing them into the liquid [38]. Greater contact of the gas and liquid streams yields higher dust removal efficiency [40].

c) Operation

Scrubbing liquid is introduced into the scrubber by nozzles “shown below”, as a spray directed down over a circular “scrubbing vane” arrangement, the liquid drains through the vanes, it creates curtains of scrubbing liquid, shown on figure (5.34). Dust laden gas enters the scrubber tangentially and collides with the curtains initiating particle agglomeration. The coarser particles produced are washed down to the slurry outlet.

Figure (5.33a) Spray nozzle

A restriction disc shown on figure (5.33b), is located in the scrubbing vane assembly, accelerates the spin velocity of the gas. This action combined with the flood of atomized liquid from the spray causes the formation of fine liquid droplets which encapsulate the fine particulates, again enhancing agglomeration.

Figure (5.33b) Rotative Disc

The cyclonic action of the saturated gas stream as it spins upward, forces the agglomerated particles to fall out of suspension. The coarser droplets impinge on the mist eliminator vanes, which are located at the exit to scrubber, and the finer droplets are forced to drop out of suspension by gravitational and centrifugal forces acting on the gas stream as it exit through the top [40].

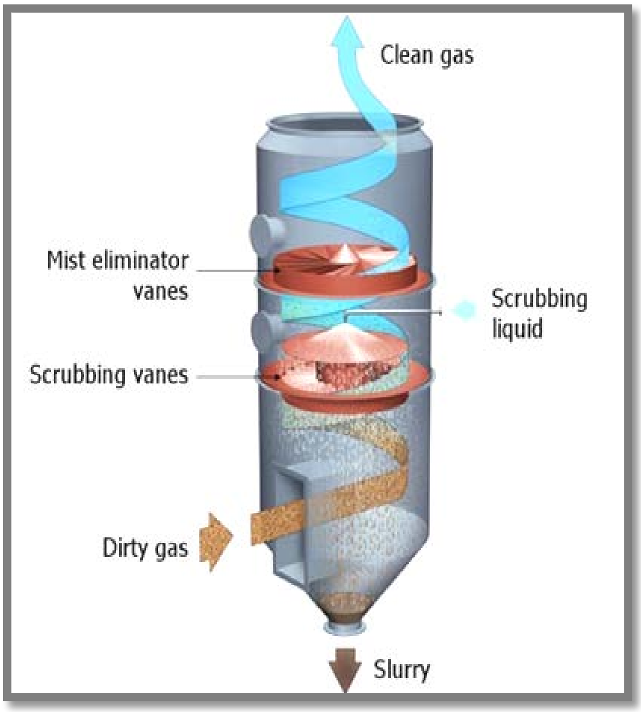
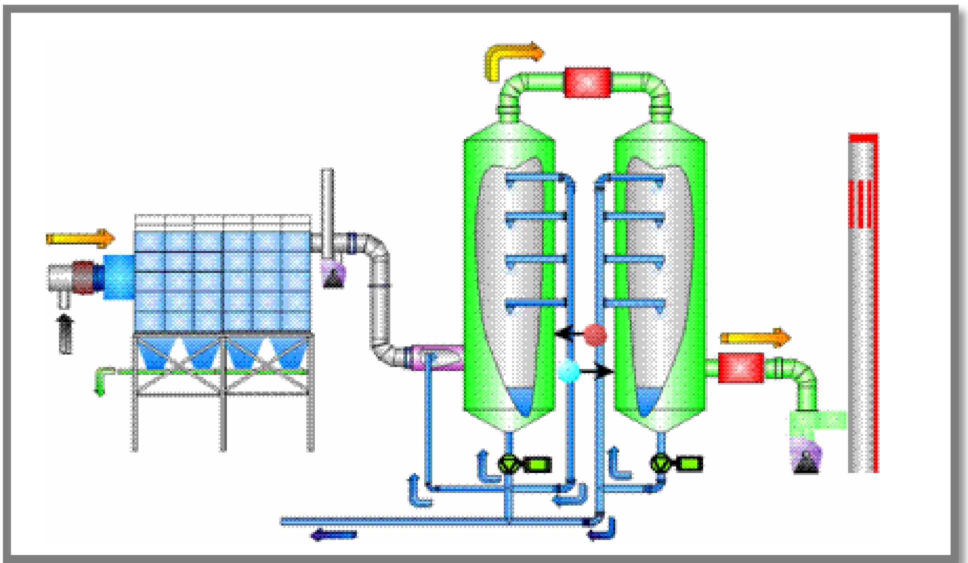


Figure (5.34) Wet scrubber operation technique

The acidity of the contact liquid is monitored by a pH probe in the scrubber bottom. Typically, wet scrubbers have two stages arrangement for more purification of flue gases, as shown in figure (5.35). Acid gases (HCl and HF…) and some of SO_2 are mainly removed on the first stage of the wet scrubber; which is strongly acidic in case of only water injection (low PH from 0-1); water also used to quench the gas to saturation conditions. If the first stage is kept at a pH of below 1, the removal efficiency of ionic Hg as $HgCl_2$, which is generally the main compound of mercury after waste combustion, is over 95 %.
Removal of sulphur dioxide (SO_2) is achieved on a second washing stage, controlled at a pH close to neutral or alkaline (generally pH 6 - 7) , in which caustic soda (NaOH) solution , sodium bicarbonate($NaHCO_3$), lime slurry ($Ca(OH)_2$) or limestone($CaCO_3$) is added. There also will be further removal of HCl and HF. These stages are done to avoid the build-up of chlorides in the scrubber liquor, which can be highly corrosive.

If lime or limestone is used, the sulfate (gypsum $CaSO_4$), carbonates and fluorides will accumulate as water-insoluble residues. These substances may be removed to reduce the salt load in the waste water and hence reduce the risk of encrustation within the scrubbing system. They removed by clarifying, thickening, or vacuum filtering of the scrubber blow down [21], shown on figure (5.35). The lime/limestone removal efficiency is about 95% for SO_2 and about 99% for HCl, HF [27]. When using a caustic soda solution there is no such risk because the reaction products are water-soluble.



Typical wet process (2 stages) with upstream de-duster

The waste water from the scrubber system is either cleaned by special treatment (neutralization) and discharged or recycled to the scrubber by evaporated it and spraying it back into the flue-gas as a quench in combination with a dust filter [21].

Figure (5.36a) Wet scrubber layout

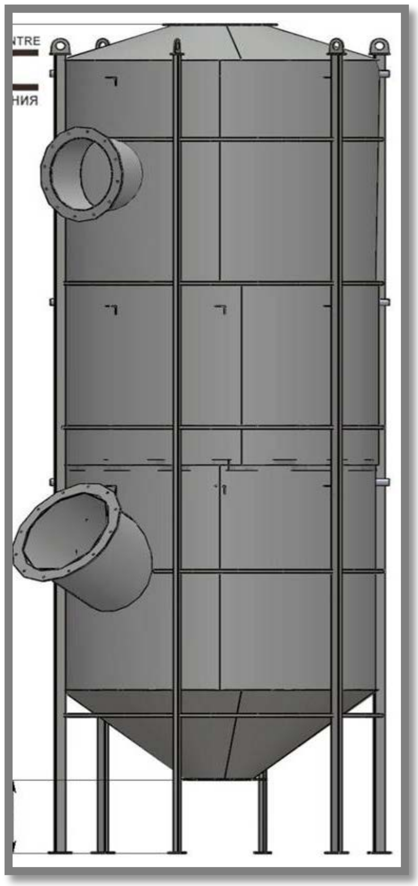
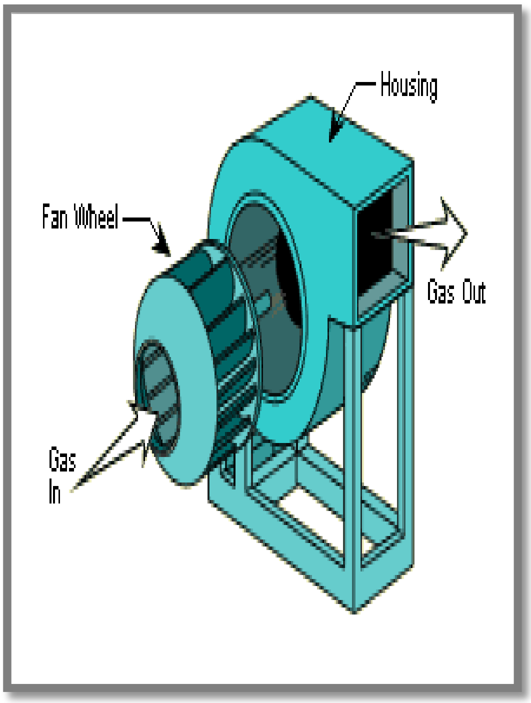


Figure (5.36b) Lateral view

VI. The induced draft fan (ID fan)

ID fan is used to pull combustion gases from the scrubber and all of the upstream equipment to draw it up through the kiln stack and to maintain a negative kiln pressure with respect to the atmosphere; to prevent fugitive gas emissions from leaking through the rotary kiln seals [27]. It is located adjacent to stack.

Fan driven by motor, drive the impeller rotation, the gas along the air inlet get into the impeller, as a result of the action of the impeller, the gas gain pressure and kinetic energy increased to overcome the resistance of pipelines then the gas transported to higher distance, as on figure below.



Figure(5.37a) ID fan Flow process

Figure (5.37b) Induced draft fan

VII. Exhaust stack

The exhaust stack, shown on figure below, must be vertical to ensure gas flue smoothly, has an internal diameter of 500 mm, and 10m tall and is lined with refractory gunite (mixture of cement, sand, and water). The chimney / stack shall be lined from inside with minimum of 3 mm thick natural hard rubber suitable for their duty conditions [3].

The stack is equipped with gas monitoring system and a damper that in normal operation directs the combustion gases from the afterburner so that they are pulled through the boiler, baghouse and scrubber [9]. If there is a process fault, such as an electrical failure or low boiler water level, the damper is operated automatically to change the flow from the afterburner directly to the stack.

Figure (5.38) Exhaust Stack

After using flue-gas cleaning system, the stack emission levels shown below are achieved [21]:

Table (5.5) Stack gases emissions

Parameter	Emission ($mg\ Nm^{-3}$) [a]	Total mass ($kg\ yr^{-1}$) [b, d]	Specific emissions ($g\ t^{-1}$) [c,d]
Dust *	<0.05	35.54	0.395
HCl *	0.42	298.5	3.318
HF	<0.05	35.54	0.395
SO_2 *	1.2	852.86	9.48
CO *	33	23453.61	260.7
NO_X as NO_2 *	104	73914.42	821.6
Cr	0.0005	0.35	0.004
As	<0.0001	0.071	0.00079
Ni	0.0003	0.21	0.0024
Cd	0.0003	0.21	0.0024
Hg	0.0014	0.995	0.011
Cu	0.0005	0.35	0.004
C_{org} *	2.2	1563.58	17.38
NH_3	1.9	1350.36	15.01
PCDD+PCDF	0.00154 $ng\ Nm^{-3}$	1.1 $mg\ yr^{-1}$	0.012 $\mu g\ t^{-1}$
PAH	0.0133	9.45	0.11

* Continuous measurement
a Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O2; dry flue-gas; standard conditions)
b In kg yr^{-1}, dioxin loads in mg yr^{-1}
c Emissions related to one ton used waste in g t^{-1}; dioxin emissions in ɱg t^{-1}
d Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (7900 Nm^3 t^{-1}waste) and the waste quantity (89964 t yr^{-1}).

The emissions of stack gases after purification are 11% oxygen per ton, 1.4% propane, 8% water, 4% methane, 75% nitrogen , 3% carbon dioxide , Organic matter content in bottom ash after incineration is typically less than 1 %

Burner

The Rotary kiln system will be equipped with modulating natural gas, auxiliary burners with flame safety; to bring the kiln to operating temperature before feeding waste. The burners will be mounted to the outer shells of both chambers [30].

Figure (5.39) Burner

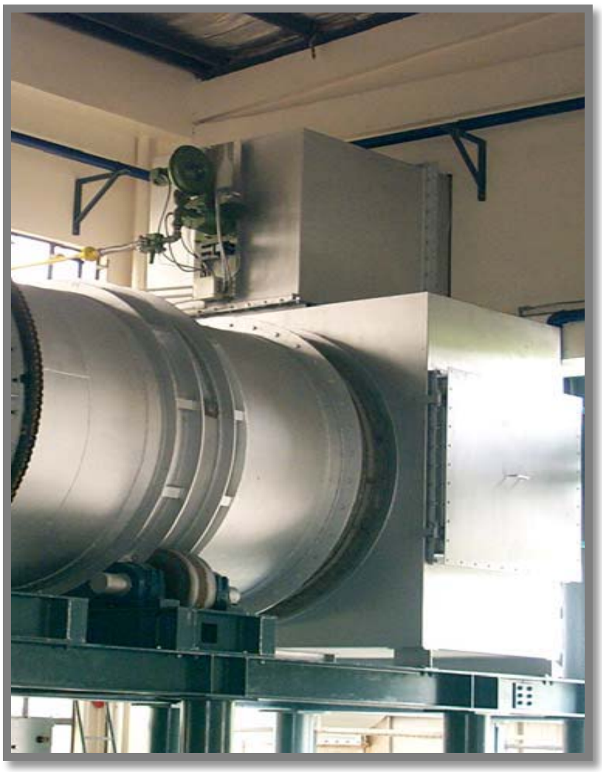


Figure (5.40) Rotary kiln burner attachment

Air Supply

The air supply in the PCC is only about 40% of the stoichiometric requirement, equal to 1/3-1/4 of the recommended air levels. In the lower part of the PCC, this air is ensured to burn out the solid char. Primary air shall be admitted near/ at the hearth for better contact. The air supply in the SCC is 100% of the stoichiometric requirement; for complete waste combustion, so the volatiles from PCC can be decomposed completely [26].

The PLC (Program Logic Control)

The controls, shown on figure 5.41 (a, b), are designed to permit the proper and safe operation of the unit and to provide the operator with various options to broaden the versatility of the unit; by means of limit switches, energizes or de-energizes pumps as required, and also operates alarms or shuts down equipment at the onset of unsafe or undesirable conditions [9]. The system shall monitor and record temperatures, feed rates and cycles, external equipment conditions, and safeties by control system. The control panel includes the various electrical controls to assure a safe start-up and pre-heat of the chambers and operation of the Kiln.

The most important of these functions is to shut down the entire process if the afterburner temperature is excessive or if the boiler water level is low. In such cases, the stack damper opens and the combustion gases are discharged directly to the stack without cooling in the boiler, filtration in the baghouse, or neutralization in the scrubber.

The rotary kiln incinerator (RKI) must equip with a temperature controller, which will shut off the feed when present operating temperature conditions are not met. Feeding will not resume until conditions have been corrected. Operating temperatures controlled by adjusting the fuel-to-air ratio according to temperature monitors in the designated flue gas flow areas. Temperature is sensed by thermocouples, which are connected to the system temperature controls [30].
Thermocouples were installed in primary combustion chamber before admission of secondary air and secondary combustion chamber outlet as measurement equipment of temperature [26].

Figure (5.41a) Control system box

Figure (5.41b) Control room

5.5 Design Layout

By combining all above mentioned parts, a final layout for a complete waste treatment facility with air pollution control devices is obtained figure (5.42), to achieve the purpose of treatment and reduction of medical waste mass.

Each part of the total facility was selected among different options to achieve the best result of its functions. Beginning with the feeding system, the screw feeder has been choosing for its safe operation and design which blocks heat and fumes from leaking outside the primary chamber. Then for the primary combustion chamber, the counter current rotary kiln was used for its low operation cost and high performance in reducing waste, while insuring an opposite flow of gases that travels smoothly to the secondary combustion chamber. For this part “U” shape combustion channels were choose, this type can significantly increase gas turbulence in the high temperature region so the residence time of flue gas at high temperatures is ensured for at least 2 seconds, thus the required combustion of the volatiles is completed.

Upon the completion of waste treatment, more units were added for output gases treatment, prior this treatment a heat exchanger was placed for cooling those gases to prevent damaging baghouse filters inner parts, this type of heat exchanger was chosen for its long life and low operation cost, besides heat transfer between cold water and hot gases produces steam that can be used in turbine systems for power generation. The Air pollution control devices were chosen among variety of systems to fulfill the gas cleaning requirements. Activated carbon and alkaline reagent injections were used for absorbing carbon compounds and heavy metals in a row. Then baghouse filters for reduction of particulate emissions and two stage wet scrubber for acid gases treatment.

In the final stage an induced draft fan is used to draw gases to the atmosphere through the exhaust stack.

Figure (5.42) Three Dimension Rotary kiln system with air pollution control devices

5.6 Cost Analysis

The economic bottom line will always be an important consideration from the outset of a building project. However, the capital costs do not tell the whole story and the whole life costs must be evaluated and used in comparisons.

It should also be noted that in some circumstances high-quality design linked with effective stakeholder engagement can reduce planning risk, which in turn can reduce lead-in times. How design impinges (effect) on the initial planning stages of a project might have significant implications for setting the budget of particular relevance is the balance between the cost of providing a purely functional facility and the added value that good design can bring. Sustainable design measures should not simply be viewed as an added capital cost. Consideration of the whole life costs and benefits when specifying desired design outcomes [13].

Total capital cost should include all direct and indirect costs related to sitting and installation as well as the equipment purchase cost. Some technologies require little site preparation and installation, while others involve significant installation requirements. Capital costs may be accounted for by assuming a fixed interest rate and amortizing the capital cost for the lifetime of the technology.

1. Capital cost- US$ 22 – 25 million.
2. Maintenance cost: typically 3 – 5% of capital investment cost.

Table (1.5) Cost analysis [41]

Capacity of RK incinerator	**Capital cost**	**Maintenance cost**
3.5 ton/hr	22-25 Million dollars	3-5% Of capital cost

CHAPTER SIX

DISCUSSION

6.1 Biomedical Waste Management Process

A waste management process; handling, segregation, mutilation, disinfection, storage, transportation and final disposal are vital steps for safe and scientific management of biomedical waste in any establishment. The key to minimization and effective management of biomedical waste is segregation (separation) and identification of the waste.

6.2 Quantities

The quantity of waste generated in health care settings, have to be known while making a good waste management system. Hence, the quantities of different categories of waste have to be estimated by discussions interviews and by physical checks.

The quantities generated vary from hospital to hospital and depend on the type of health-care facility and local economic conditions. The waste quantities were physically weighed in different hospitals having specialized units.

6.3 Current Scenario

Most of the hospital biomedical waste is being disposed along with municipal solid waste. The untreated liquid waste from the health institutions is let into drainage. Normally the waste is collected in open containers without disinfection. Bandages, cotton and other items used to absorb body fluids are collected in plastic bags or other non-specified containers. Waste is collected in mixed form, waste sharps are discarded without disinfection and mutilation; which may result in their being re-used thus spreading an infection.

Disposable plastic items may be segregated by the waste pickers, from where the waste is deposited either inside the hospital grounds, or outside in the community bin for further transportation and disposal along with municipal solid waste for selling again without disinfection.

Since the infectious waste gets mixed with municipal solid waste, it has potential to make the whole lot infectious in adverse environmental conditions.

Interviews and observations showed that most workers on biomedical waste are collecting medical and nonmedical waste without safety precautions, no segregation into infectious and non-infectious categories and are disposed in municipal bins located either inside or outside the facility premises. Wastes from operation theatres, wards and pathological laboratories are disposed of without any disinfection/sterilization. Amputated body parts and anatomical wastes, are buried.

My surveys showed that there has been a weak implementation of rules and guidelines by Khartoum Ministry of health about medical waste treatment and disposal. Beside the poor awareness about medical waste risks and safe handling procedures, most hospitals did not differentiate between domestic and medical waste disposal.
It was concerning that to realize most of health care establishment administrators neither adopted training programs regarding identification of medical waste types for workers dealing with medical waste, nor declared the necessity of having specialized waste-workers within the hospital. As observed no dedicated budget for waste management, none of health care establishment had user manuals or proper guidelines for collecting medical waste; which meant waste-worker had to improve their own way of doing things; that maximized the risks they are exposed to.

Another serious problem prevailing in hospitals was the improper internal transportation of medical wastes, as some hospitals were doing it manually while others were doing it by overloading trolleys and without disinfection for trolleys.

Another dangerous practice followed by some studied hospitals was the disposal of liquid medical wastes directly into the city sewage system without sterilization or dilution.

All governmental hospitals and 80 % of private hospitals were depending on the city cleaning authorities for transporting and disposing of medical wastes outside hospitals. There is no proper treatment facility in state of Khartoum, so most of HCEs dispose of their waste without segregation with municipal waste. As a result of all above, the establishment of a governmental owned CBWTF and setting of necessary concise guidance was found to be an ideal solution for proper medical waste treatment to ensure the contribution of hospitals and medical centers located in Khartoum State with minimum overhead cost on HCE budgets and less hazardous impacts on environment.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

There has been a poor awareness about medical waste risks and safe handling procedures among health care establishments; administrators and workers. Poor waste management can jeopardize care staff, employees who handle medical waste, patients and their families and the neighbouring population. In addition, the inappropriate treatment or disposal of that waste can lead to an environmental contamination or pollution and most hospitals were not differentiating between domestic and medical waste. Budgets were not allocated for waste management, which caused shortages in waste facilities handling equipment and supplies and absence of training programs for staff, resulting in poor knowledge and practices of waste-workers, a high rate of injuries and possible exposure of staff and visitors to hazardous waste.

The management of the waste from health services is complex and to be successful it must be understood and addressed by everyone working in health services. The health care establishments is severely lacking in actions to dispose of its waste and uphold its statutory responsibilities. This is due to the lack of education, awareness and trained personnel to manage the waste in the hospital, as well as the paucity of the funds available to proper waste management system.

Health care establishment facilities would suffer a very high cost of ownership in case local waste treatment facilities were built, beside the high operational cost and allocated staff to the process.

The study concludes that the need of designing central common medical waste facility is the ideal method for waste treatment and disposal of all HCEs.

7.2 Recommendations

The recommendations of this project are

1. This project is the ideal solution for medical waste treatment in Khartoum state and it's strongly recommended to be applied.
2. To gain the maximum benefits of this project, strict enforcement of guidelines and legal provisions, better environmental management system for the disposal of biomedical waste in HCEs is needed.
3. A skilled staff with adequate qualifications and training to be designated for incinerator operation and maintenance.
4. Energy utilization system can be added to this system.

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