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Handbook

Operation and Maintenance of Hospital Medical Waste Incinerators

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Disclaimer

This document generally describes the proper operation of a hospital waste incinerator. It is based on EPA's review and assessment of various scientific and technical sources. The EPA does not represent that this document comprehensively sets forth procedures for incinerator operation or that it describes applicable legal requirements, which vary according to an incinerator's location. Proper operation of an incinerator is the responsibility of the owner and operator.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Preface

The hospital medical waste incinerator program was funded as a project of EPA's Control Technology Center (CTC). The CTC was established by EPA's Office of Research and Development (ORD) and Office of Air Quality Planning and Standards (OAQPS) to provide technical assistance to State and local air pollution control agencies. Three levels of assistance can be accessed through the CTC. First, a CTC HOTLINE has been established to provide telephone assistance on matters related to air pollution control technology. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical guidance through publication of technical guidance documents, development of personal computer software, and presentation of workshops on control technology matters.

The technical guidance projects, such as this one, focus on topics of national or regional interest that are identified through contact wth State and local agencies. In this case, the CTC became interested in developing a training course for operators of hospital waste incinerators through a request by the State of Maryland. This document was prepared to be used as the basis for development of the training materials. The document also is intended as a technical guide for use by Federal, State, and local agency personnel, hospital waste management personnel, and hospital incinerator operators.

This document provides information on the operation and maintenance (O&M) procedures that should be practiced on hospital waste incinerators and associated air pollution control equipment to minimize air emissions. This document provides only a general overview of proper O&M procedures with the intention of identifying good operating practices. Operators of hospital waste incinerators should have O&M manuals from the manufacturer which provide specific O&M instructions for their equipment. This document should be viewed as a supplement to the manufacturer's O&M recommendations.

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Acknowledgments

This document was prepared by Midwest Research Institute located in Cary, North Carolina. Principal authors were Roy Neulicht, Mark Turner, Dennis Wallace, and Stacy Smith. Participating on the project team for EPA were Ken Durkee and James Eddinger of the Office of Air Quality Planning and Standards, Charles Masser of the Air and Energy Engineering Research Laboratory, James Topsale of Region III, Charles Pratt of the Air Pollution Training Institute, and Justice Manning of the Center for Environmental Research Information. Also participating on the project team were Carl York and William Paul of the Maryland Air Management Administration.

The review of this document by representatives of the National Solid Waste Management Association Waste Combustion Equipment Council (NSWMA - WCEC) and the Ontario Ministry of the Environment is acknowledged and appreciated.

Chapter 1
Introduction

The main objective of this document is to identify the operation and maintenance (O&M) procedures that should be practiced on hospital waste incinerators and associated air pollution control equipment to minimize air emissions. Proper O&M, in addition to reducing air emissions, improves equipment reliability and performance, prolongs equipment life, and helps to ensure proper ash burnout. This document provides only general guidance on proper O&M procedures with the intention of identifying good operating practices. The operator of a hospital waste incinerator should have O&M manuals from the manufacturer which provide specific O&M instructions for their equipment. This document does not provide such specific instructions, and is not intended to do so. The document is intended as a technical guide for use by Federal, State, and local agency personnel, hospital waste management personnel, and hospital incinerator operators.

The concern about disposal of infectious wastes generated by hospitals is increasing rapidly due to the fear of the spread of viruses such as acquired immune deficiency syndrome (AIDS) and hepatitis B, as well as the concern about exposure to toxic metals and organics. Incineration continues to be an attractive infectious waste disposal option for hospitals encountering high disposal costs, refusal of their waste at treatment and disposal facilities, and tighter regulation. Proper incineration sterilizes pathogenic waste, reduces waste volumes by over 90 percent, and, in some cases, may provide economic benefits through waste heat recovery. Onsite incineration is an attractive option because it reduces handling and transportation of the wastes and because waste heat recovery can have economic advantages for the facility. The need for disposal of infectious wastes and problems associated with such disposal also has spurred the interest in special commercial incineration facilities. In either case, the operating facility must address the problems of air emissions and ash disposal from the incinerator.

Hospital waste incinerators may emit a number of pollutants depending on the waste being incinerated. These pollutants include: particulate matter, acid gases, toxic metals, toxic organic compounds, carbon monoxide, sulfur oxides, nitrogen oxides, and pathogens and viruses. Proper operation of the incinerator will reduce the emissions of most of these pollutants. Air pollution control devices are available to further control these pollutants.

In response to public concern about hospital incineration, several States recently have enacted or are in the process of enacting regulations which govern the incineration of general hospital wastes and infectious wastes, specifically. These regulations specify emission limits for hospital incinerators, and frequently they also address operating practices related to waste handling and charging, combustor operations, ash characteristics, and ash handling practices. Some of the operating practices that have been specified in these regulations include:

1. Limits on characteristics of wastes charged to the incinerator;
2. Specific requirements for waste packaging and waste charging practices;
3. Combustor temperature limits;
4. Ash burnout levels; and
5. Ash handling and disposal practices.

The combustion efficiency of a hospital waste incinerator and the pollutant removal efficiency of its associated air pollution control equipment ultimately is affected by equipment O&M. Regardless of how well the equipment is designed, poor O&M practices will lead to the deterioration of components and a resultant decrease in both combustion quality and pollutant removal efficiency. In addition, O&M practices affect equipment reliability, on-line availability, continuous compliance with emission limits and operating practice standards, and regulatory agency/source relations. Lack of timely and proper O&M leads to a gradual deterioration in the equipment, which in turn increases the probability of equipment failure and decreases both the reliability and on-line availability of the equipment. Frequent violations of emission limits or operating the facility outside the limits of operating practices established by regulations can result in public complaints, increased frequency of inspection, potential fines for noncompliance, and in some cases, mandatory shutdown until emission problems are solved. Good O&M practices are essential to safe, reliable operation of the facility.

This document summarizes technical information related to the proper operation and maintenance of hospital waste incinerators and associated air pollution control systems. Chapter 2 presents background information on hospital waste incineration systems including a summary of combustion principles and descriptions of the types of incinerators typically used for hospital waste. Chapter 3 presents background information on add-on air pollution control systems for hospital waste incinerators. Chapter 4 identifies key operating parameters and good operating practices for hospital waste incineration and air pollution control systems. Operating parameters which can be monitored and/or automatically controlled also are discussed in Chapter 4. Chapter 5 provides general guidance on the maintenance of incinerators and air pollution control systems. Chapter 6 describes instrumentation which can be used for the control and monitoring of the key operating parameters. Chapter 7 identifies some common operational problems associated with hospital waste incinerators and air pollution control systems; the possible causes and solutions to the problems are discussed. Chapter 8 discusses recordkeeping procedures which can assist in operating and maintaining an incineration system. Chapter 9 provides general safety guidelines, and Chapter 10 presents a glossary of terms.

Chapter 2

Hospital Incineration Systems

2.1 Introduction

Incineration is the process by which combustible materials are burned, producing combustion gases and noncombustible residue and ash. The product combustion gases are vented directly to the atmosphere or to the atmosphere after treatment in an air pollution control device. The noncombustible ash residue is removed from the incinerator system and is disposed of in a landfill. Incineration provides the advantage of greatly reducing the mass and volume of the waste. This reduction substantially reduces transportation and disposal costs. For infectious hospital wastes, another major objective of the incineration process is the destruction of infectious organisms (pathogens) that may exist in the waste. The destruction of the pathogens is caused by their exposure to the high temperatures which exist within the incinerator. Incineration of hospital wastes also is attractive aesthetically because it destroys organic components of the waste that the community often finds objectionable when wastes are disposed of in landfills.

Two additional objectives achievable through proper operation of hospital waste incinerators are minimizing organic content in the solid residue and controlling atmospheric emissions to acceptable levels. Generally, tight control on organics in the ash, i.e., good burnout, promotes waste reduction and pathogen destruction. Reduction of atmospheric emissions of constituents that are potentially harmful to human health and the environment is a prerequisite to acceptance of hospital incineration as a feasible disposal alternative by the community.

The overall purpose of this technical document is to present information on the operation of hospital waste incineration systems that can contribute to achieving these objectives. This chapter provides background information on the incineration process that will enhance the usefulness of the remainder of the document. It presents information on basic incineration principles and processes and integrates this information to promote an understanding of hospital waste incineration as an overall system.

The hospital waste incineration process can be separated into the following steps:

1. Waste preparation;
2. Waste charging;
3. Waste combustion;
4. Treatment of the combustion gases, (i.e., add-on air pollution control); and
5. Residue ash handling.

Waste heat recovery also may be included as a part of the incinerator system. The incineration process and the major subsystems of an incineration system are depicted in Figure 2-1. An incinerator operates as a system in which all of the process steps mentioned above are interrelated. For example, the charging procedures implemented by the operator will affect how well the wastes burn in the combustion chamber and, consequently, the ash quality Proper operation of a system requires an understanding of the principles of operation of each of the components and of the interrelationship of those components for a particular system configuration.

The remainder of this chapter presents background information on hospital incineration processes in three parts. Section 2.2 presents fundamental concepts on pathogen destruction and combustion principles. Section 2.3 describes hospital waste characteristics and briefly addresses how these characteristics affect incineration. Section 2.4 describes incineration system components and the different incinerator systems that are used to treat hospital wastes.

2.2 Fundamental Concepts Related to Hospital Waste Incineration

An understanding of how an incinerator operates as a system requires familiarity with some basic scientific and engineering principles. This section provides a brief discussion of the key principles related to two basic areas – pathogen destruction and combustion chemistry/physics. The discussions are quite abbreviated and are designed to provide the reader with the basic information needed to understand the

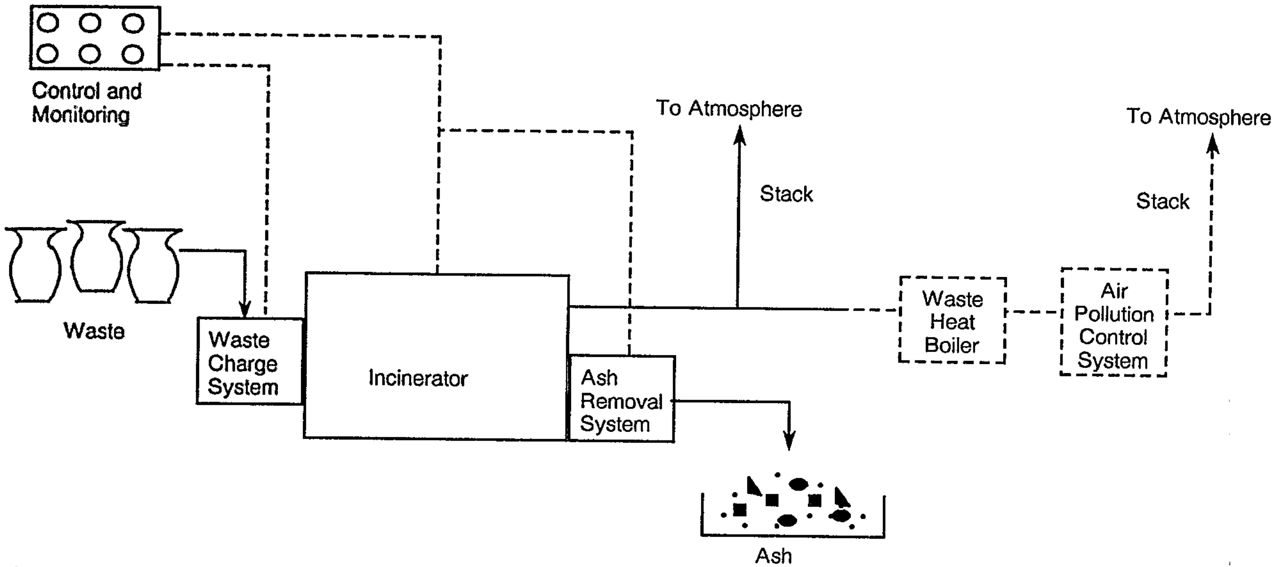

Figure 2-1. Major components of an incineration system.

remainder of this document; they do not provide complete coverage of the subject areas.

Those readers desiring more information on these subjects should consult References 1 through 3 on pathogen destruction and References 4 through 8 on combustion.

2.2.1 Pathogen Destruction

The primary objective of hospital waste incineration is the destruction of pathogens in infectious wastes. The U. S. Environmental Protection Agency (EPA) has defined infectious waste as "waste capable of producing an infectious disease .... For a waste to be infectious, it must contain pathogens with sufficient virulence and quantity so that exposure to the waste by a susceptible host could result in an infectious disease."[1] Some examples of hospital wastes which may be considered to be infectious are:[1]

1. Microbiological laboratory wastes including cultures and equipment which has come in contact with cultures of infectious agents;
2. Blood and blood products (such as serum, plasma);
3. Sharps, including needles, laboratory glass wastes, and glass pipets;
4. Surgical, autopsy, and obstetrical wastes which have had contact with patient blood or body fluids;
5. Wastes which have had contact with communicable disease isolation wastes;
6. Human and animal tissue containing pathogens with sufficient virulence and quantity so that exposure to the waste by a susceptible human host could result in an infectious disease; and
7. Dialysis unit wastes; i.e., wastes that were in contact with the blood of patients undergoing hemodialysis.

The pathogens in infectious waste can be destroyed by the high temperatures achieved in hospital incinerators. Data on the incinerator conditions required to destroy the universe of pathogens that are present in infectious waste are quite limited, but they do indicate that temperature and time of exposure are important. Emissions of microorganisms from the incinerator could be attributed to insufficient retention time and temperature as a result of the following conditions:

1. Initial charging of the incinerator before operating temperatures are achieved;
2. Failure to preheat the refractory lining;
3. Temperature fluctuations caused by intermittent use;
4. Exceeding design airflow rates, thereby reducing the retention time;
5. Charging beyond incinerator capacity; and
6. Excessive moisture content of the waste.

Other factors such as the type of refractory lining, the positioning and number of burners, and the precision of temperature controlling devices also can have a significant bearing on the effectiveness of sterilization.[2,3] The destruction of microorganisms in the incinerator ash also depends on temperature and time exposure.

2.2.2 Principles of Combustion[4-9]

In principle, combustion of hospital waste is a chemical process that is equivalent to combustion of fossil fuels for energy recovery. It is a chemical reaction that involves rapid oxidation of the organic substances in the waste and auxiliary fuels. This violent reaction releases energy in the form of heat and light and converts the organic materials to an oxidized form. Some of the basic principles related to the combustion process are discussed in the following subsections. Specifically, the basic chemical reactions, stoichiometric air requirements, thermochemical relations, and volumetric flows are discussed in the first four subsections. In the last subsection, the combustion process is discussed in general terms, and the role of waste characteristics in that process is outlined.

2.2.2.1 *Chemical Reactions.*

The organic portion of hospital waste consists primarily of carbon (C), hydrogen (H), and oxygen (O). These elements are involved in the reactions that generate most of the energy and the bulk of the combustion gas products that are released during incineration. Other elements found to a lesser degree are metals, sulfur (S), nitrogen (N), and chlorine (Cl). Although these elements are of lesser importance to the main "combustion reaction," they play an important role in potential air pollution problems.

The reaction chemistry in the combustion zone is quite complex and involves a wide variety of organic compounds and free radical species. However, a general understanding of combustion can be achieved by treating these reactions simply as a combination of carbon and hydrogen in the organic material with the oxygen in the combustion air and organic material. These simplified reactions can be represented by the chemical equations:

$$C + O_2 \rightarrow CO_2 + \text{Heat} \tag{2-1}$$

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Heat} \tag{2-2}$$

When complete combustion occurs, carbon and hydrogen combine with the oxygen of the combustion air to form carbon dioxide (CO_2) and water vapor (H_2O), respectively, as shown above. If incomplete combustion occurs, carbon monoxide (CO) also will be formed.

Available thermodynamic equilibrium data and bench-scale test data indicate that organic chlorine which enters the combustion chamber reacts almost completely to form hydrogen chloride (HCl) and elemental chlorine (Cl_2). Unless the system has very low H:Cl ratios in the feed, almost no Cl_2 is formed.[8] The HCl and any Cl_2 that is formed leave the combustion chamber in vapor phase.

Sulfur that is chemically bound in organic materials making up the hospital waste is oxidized during the combustion process to form sulfur dioxide (SO_2) at a rate directly proportional to the sulfur content of the waste. Some SO_2 may react with alkaline reagents also present in the waste or ash. However, the amount of SO_2 involved in such reactions is expected to be negligible due to the high HCl content of the flue gas. Because it is a stronger acid than SO_2, HCl will react more quickly with available alkaline compounds than SO_2 and will tie up the alkaline compounds before they have a chance to react with SO_2. Consequently, essentially all organic sulfur present in the waste will leave the combustion chamber as vapor phase SO_2.

Nitrogen enters the combustion chamber as a component of the waste and in the combustion air. It can react in the combustion chamber to produce nitrogen oxides (NO_x). The NO_x is formed by one of two general mechanisms. "Thermal NO_x" is the result of the reaction between molecular nitrogen and molecular oxygen, both of which enter the combustion zone in the combustion air. "Fuel NO_x" results from the oxidation of nitrogen which enters the combustion zone chemically bound within the fuel structure. The rate of thermal NO_x formation is sensitive to the flame temperature. The detailed mechanisms of fuel NO_x formation are not well understood, but the formation is not extremely sensitive to temperature.[9]

2.2.2.2 *Stoichiometric Combustion Air.*

The theoretical amount of oxygen required for complete combustion is known as the stoichiometric or theoretical oxygen and is determined by the nature and the quantity of the combustible material to be burned. Combustion oxygen is usually obtained from atmospheric air. The additional oxygen (or air) over and above the stoichiometric amount is called "excess air."

The overall chemical composition (ultimate analysis) of the waste/fuel mixture can be used to calculate the mass-based stoichiometric oxygen requirements with the factors in Table 2-1. Volumetric oxygen requirements can be estimated with the following equation:

$$\dot{Q}_o = \dot{M}_o \times K \tag{2-3}$$

where:

$\dot{Q}_o$ = volumetric flow of O_2 (scm/h)

$\dot{M}_o$ = Mass flow of O_2 (kg/h)

K = 0.2404 scm O_2/kg O_2 at 20°C and 1 atm.

Total volumetric air requirements can be estimated by multiplying volumetric oxygen requirements by 5.

2.2.2.3 *Thermochemical Relations.*

Thermochemical calculations are used to estimate heat release and heat transfer associated with combustion. These calculations permit determination

Table 2-1. Stoichiometric Oxygen Requirements and Combustion Product Yields[10]

Elemental Waste Component	Stoichiometric Oxygen Requirement	Combustion Product Yield
C	2.67 lb/lb C	3.67 lb CO_2/lb C
H_2	8.0 lb/lb H_2	9.0 lb H_2O/lb H_2
O_2	-1.0 lb/lb O_2	
N_2	–	1.0 lb N_2/lb N_2
H_2O	–	1.0 lb H_2O/lb H_2O
Cl_2	-0.23 lb/lb Cl_2	1.03 lb HCl/lb Cl_2 -0.25 lb H_2O/lb Cl_2
F_2	-0.42 lb/lb F_2	1.05 lb HF/lb F_2 -0.47 lb H_2O/lb F_2
Br_2	–	1.0 lb Br_2/lb Br_2
I_2	–	1.0 lb I_2/lb I_2
S	1.0 lb/ lb S	2.0 lb SO_2/lb S
P	1.29 lb/lb P	2.29 lb P_2O_5/lb P
Air N_2	–	3.31 lb N_2/lb $(O_2)_{stoich}$

Stoichiometric air requirement = $4.31 \times (O_2)_{stoich}$.

of the energy released by the combustion process and assessment of the transfer of the energy to the environment. Thermochemical calculations involve determination of fuel (or waste) heating values, heat contents of entering and leaving streams, and any other heat losses. A definition of terms that will be helpful for understanding these calculations is presented below.

Heat of combustion. Heat energy evolved from the union of a combustible substance with oxygen to form CO_2 and H_2O (and SO_2) as the end products, with both the reactants starting and the products ending at the same conditions, usually 20°C (68°F) and 1 atm (29.92 in Hg).

Gross or higher heating value – HV_G or HHV. The quantity of heat evolved as determined by a calorimeter where the combustion products are cooled to 16°C (60°F) and all water vapor is condensed to liquid. Usually expressed in terms of kcal/g or kcal/m^3 (Btu/lb or Btu/scf).

Net or lower heating value – HV_N or LHV. Similar to the higher heating value except that the water produced by the combustion is not condensed but is retained as vapor at 18°C (60°F). Expressed in the same units as the gross heating value.

Enthalpy or heat content. Total heat content, expressed in kcal/g (Btu/lb), above a standard reference condition.

Sensible heat. Heat, the addition or removal of which results in a change of temperature.

Latent heat. Heat associated with a change of phase, e.g., from liquid to vapor (vaporization) or from liquid to solid (fusion), without a change in temperature. Usually expressed as kcal/g (Btu/lb).

Available heat. The quantity of heat available for intended (useful) purposes. The difference between the gross heat input to a combustion chamber and all the losses.

For steady-state operations:

$$\text{Heat in (sensible + HHV)} = \text{Heat out (sensible + latent + available)} \qquad (2\text{-}4)$$

Heat is liberated in the combustion process at the rate of 7.8 kcal/g of carbon burned and 34 kcal/g of hydrogen burned (14,100 Btu per pound of carbon burned and 61,000 Btu per pound of hydrogen burned). Alternatively, heat is liberated from the combustion process at a rate that is equal to the product of the mass flow rate of the waste (and auxiliary fuel) and the higher heating value of waste (and fuel). A major latent "heat loss" is the energy required to evaporate moisture in the waste and vaporize organic constituents. The energy required to raise the temperature of the evaporated moisture and any excess air to combustion chamber temperatures is a part of the sensible "heat loss."

Maximum combustion temperatures are attained at stoichiometric conditions. As the amount of excess air is increased above the stoichiometric point, the combustion temperature is lowered because energy is used to heat the combustion air from ambient temperature to the combustion chamber temperature. The greater the volume of the excess air, the greater the "heat loss" due to raising the air temperature. As the amount of excess air is decreased, the combustion temperature increases until it becomes maximum at the stoichiometric point. Below the stoichiometric point, the temperature decreases because complete combustion has not occurred. Since the complete combustion reaction (which is exothermic) has not occurred, the maximum heat is not generated. A graphical representation of the relationship between combustion temperature and excess air level is shown in Figure 2-2.

As the excess-air level increases, the volume of oxygen supplied to the incinerator that is not reacted increases, resulting in a higher oxygen concentration in the effluent gas stream. Since the total amount by weight (kg) of carbon dioxide generated during combustion is based on stoichiometric ratios, it remains constant for a specific quantity of carbon in the waste. However, as the excess-air level increases, the concentration of carbon dioxide in the total combustion gas stream decreases due to dilution from the excess air (oxygen and nitrogen). The oxygen concentration and carbon dioxide concentration of the effluent gas stream are useful indicators of the

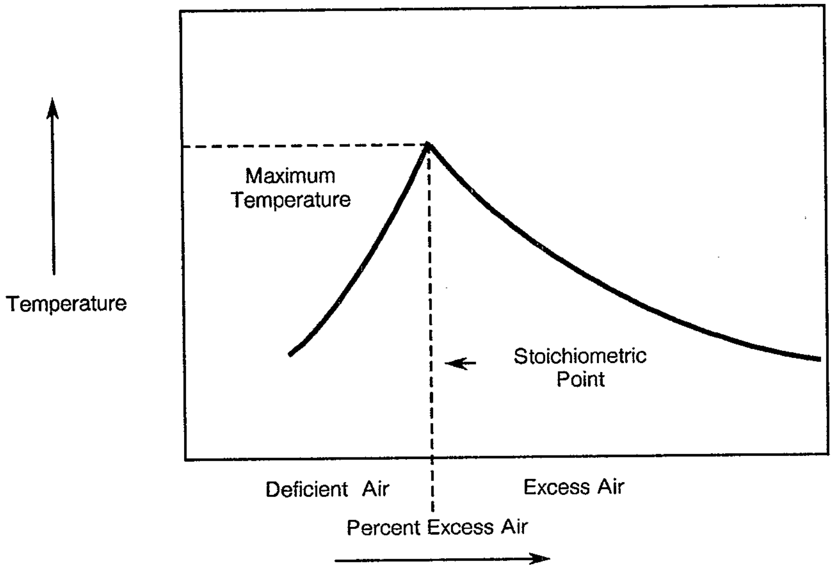

Figure 2-2. **Relationship of temperature to excess air.**[7]

combustion excess air levels and are useful for monitoring the combustion process.

2.2.2.4 *Volumetric Gas Flows.*

Gas flows through a combustion system and air pollution control system are a major consideration in the design and operation of those systems. Three key principles that are important to understanding the operation of those systems are the relationship of volumetric flow to gas residence time, the volume occupied by compounds (either organic constituents or water) vaporized in the combustion chamber, and the relationship of gas volume to temperature and pressure.

Complete destruction of pathogens and complete combustion of organic constituents require exposure of the materials to high temperatures for minimum residence times. Some State regulations now require a minimum residence time in the secondary combustion chambers, and operators must comply with these requirements. The residence time is a function of chamber volume and volumetric flow rate and can be estimated (plug flow assumed) with the following equations:

$$t = \frac{60\,V}{Q_{gas}} \qquad (2\text{-}5)$$

$$Q_{gas} \doteq Q_{air} + Q_{H_2O} \qquad (2\text{-}6)$$

where:

t = residence time, s

V = combustion chamber volume, m^3

Q_{gas} = combustion gas flow rate at combustion chamber conditions, m^3/min

Q_{air} = combustion airflow rate at combustion chamber conditions, m^3/min

Q_{H_2O} = release rate of free moisture from the waste at combustion chamber conditions, m^3/min

These equations assume complete turbulent flow in the combustion chamber and that the volume of combustion gas is approximately equal to the volume of combustion air.

As waste is exposed to high temperatures in the combustion chamber, some materials in that waste are volatilized into the vapor or gas phase. Two issues of particular concern are the volume of water vapor produced by the moisture in the waste and the volume of gas produced by highly volatile organic materials such as solvents that evaporate almost instantly as they are exposed to high temperatures. The volume of gas produced from a given mass of material can be calculated from the equation:

$$V_i = 24.04 \frac{M_i}{MW_i} \qquad (2\text{-}7)$$

where:

V_i = volume of compound i at standard conditions, scm

M_i = mass of compound i, kg

MW_i = molecular weight of compound i, g/g mole

This equation estimates volumes at standard conditions, which are defined to be 20°C (68°F) and 1 atm (29.92 in. Hg). The paragraphs below describe how volumes can be estimated for different temperatures and pressures.

The volume that a gas occupies, or the volumetric flow rate of a gas, is dependent on the temperature and pressure of the gas. Estimates of gas volume or gas volumetric flow can be modified to reflect different temperatures or pressures with the equations:

$$V_2 = V_1 \frac{T_2 P_1}{T_1 P_2} \qquad (2\text{-}8)$$

$$Q_2 = Q_1 \frac{T_2 P_1}{T_1 P_2} \qquad (2\text{-}9)$$

where:

V_i = volume at condition i, m^3

T_i = temperature at condition i, K (where K = 273 + °C)

P_i = absolute pressure at condition i, atm

Q_i = volumetric flow at condition i, m^3/min

2.2.2.5 The Combustion Process.

The goal of the combustion process is complete combustion of the organic constituents in the waste feed. Complete combustion requires sufficient air in the combustion chamber, sufficient temperatures in the combustion bed and combustion gas, sufficient time over which materials are exposed to a temperature profile, and mixing that assures good contact of the waste/fuel with the combustion air.

Each organic substance in hospital waste has a characteristic minimum ignition temperature that must be attained or exceeded, in the presence of oxygen, for combustion to occur. Above the ignition temperature, heat is generated at a higher rate than it is lost to the surroundings, and the elevated temperatures necessary for sustained combustion are maintained.

The residence time of a constituent in the high-temperature region should exceed the time required for the combustion of that constituent to take place. Residence time requirements establish constraints on the size and shape of the furnace for a desired firing rate. Because the reaction rate increases with increasing temperature, a shorter residence time will be required for combustion at higher temperatures if good combustion conditions are present.

Adequate oxygen supplies and turbulence and the resultant mixing of organic materials and oxygen are also essential for efficient combustion. Inadequate mixing of combustible gases and air in the furnace can lead to emissions of incomplete combustion products, even from an otherwise properly sized unit with sufficient oxygen. Turbulence will speed up the evaporation of liquid fuels for combustion in the vapor phase. In the combustion of waste solids, turbulence will help to break up the layer of combustion products formed around a burning particle of waste. Under nonturbulent conditions, the combustion rate is slowed because this layer of combustion products decreases the amount of oxygen that contacts the surface of the particle.

For hospital waste incinerators, the distribution of combustion air between the primary and secondary chambers and the methods used to inject that air to the chamber are key operating considerations. The distribution of air between the two chambers affects the amount of oxygen that is available for reaction in each chamber. (See the discussion of stoichiometry above.) The method of injection of the air to the two chambers is one of the factors that controls turbulence and mixing.

The chemical and physical characteristics of the waste stream also have significant effects on the combustion process and on the composition of the effluents from the process. Generally, wastes can be characterized by a "proximate analysis," which is a laboratory determination of four waste characteristics – volatile matter, fixed carbon, moisture, and ash or noncombustibles. The paragraphs below define these four parameters and describe their effects on the combustion process.

Volatile matter is that portion of the waste which can be liberated (i.e., vaporized) with the application of heat only (i.e., no chemical reaction occurs). Actual combustion of volatile matter is a gas-phase reaction (i.e., the combustion occurs after the material has been vaporized). Key factors that must be considered when volatile matter is introduced to the combustor are the rate at which the material is vaporized and the ability of the combustor to provide adequate volume and airflow for that release.

Fixed carbon is the nonvolatile carbon portion of the waste and must be burned at higher temperatures and at increased duration of exposure to the combustion air. The combustion of fixed carbon is a solid-phase reaction. An incinerator should be operated with a solids residence time that is sufficient for fixed carbon combustion.

Moisture, which is evaporated from the waste as temperatures of the waste are raised in the combustion chamber, passes through the incinerator, unchanged, as water vapor. Two major impacts that this moisture has on the combustion system are increasing volumetric flow and reducing residence time of the combustion gases. It also absorbs energy and reduces the temperature in the combustor.

Unlike organic constituents, inorganic constituents, specifically metals, are not "destroyed" during the combustion process. Rather, they are distributed or partitioned among the incinerator effluent streams. Metals constituents can leave the combustion chamber as bottom ash or in the combustion gas. The relative distribution of the metals between these streams is based on such factors as the chemical form of the metals charged to the combustor, the localized reaction atmosphere in the combustion chamber, localized chamber temperatures, and localized chamber airflows. Metals that leave the chamber as bottom ash ultimately can reach a land disposal site or can be lost to the atmosphere as fugitive emissions. Metals can leave the combustion chamber in the gas stream either as entrained particulate matter or as a metal vapor. If the metals emissions from an incinerator are of concern, they can be reduced by using an add-on air pollution control system. The efficiency of such a control system will depend on the control system design and operating characteristics and the physical characteristics of the metals, particularly the solid/vapor distribution and the size distribution of the metals that are entrained as particles.

2.3 Hospital Waste Characteristics

Hospital wastes are heterogeneous mixtures of general refuse, laboratory and pharmaceutical chemicals and containers, and pathological wastes. All of these wastes may contain potentially infectious wastes. In some cases, the wastes fired to hospital incinerators also may contain wastes classified as hazardous under the Resource Conservation and Recovery Act (RCRA) or low-level radioactive waste.

General refuse from hospitals is similar to generic wastes from residences and institutions and includes artificial linens, paper, flowers, food, cans, diapers, and plastic cups. Laboratory and pharmaceutical chemicals can include alcohols; disinfectants; antineoplastic agents; and heavy metals, such as mercury. Infectious wastes include isolation wastes (refuse associated with isolation patients); cultures and stocks of infectious agents and associated biologicals; human blood and blood products; pathological wastes; contaminated sharps; and contaminated animal carcasses, body parts, and bedding.[1] Examples of wastes defined as infectious are presented in Table 2-2.[1] In the U.S., infectious wastes are required to be discarded in orange or red plastic bags or containers. Often these "red bag" wastes may contain noncontaminated general refuse discarded along with the infectious waste.

Table 2-2. Examples of Infectious Waste[1]

Waste category	Examples[a]
Isolation wastes	• Wastes from patients with diseases considered communicable and requiring isolation • Refer to Centers for Disease Control, Guidelines for Isolation Precautions in Hospitals, July 1983
Cultures and stocks of infectious agents and associated biologicals	• Specimens from medical and pathology laboratories • Cultures and stocks of infectious agents from clinical, research, and industrial laboratories; disposable culture dishes, and devices used to transfer, inoculate and mix cultures • Wastes from production of biologicals • Discarded live and attenuated vaccines
Human blood and blood products	• Waste blood, serum, plasma, and blood products
Pathological waste	• Tissues, organs, body parts, blood, and body fluids removed during surgery, autopsy, and biopsy
Contaminated sharps	• Contaminated hypodermic needles, syringes, scalpel blades, pasteur pipettes, and broken glass
Contaminated animal carcasses, body parts, and bedding	• Contaminated animal carcasses, body parts, and bedding of animals that were intentionally exposed to pathogens

[a] These materials are examples of wastes covered by each category. The categories are not limited to these materials.

Incinerators are thermal systems; they are designed to operate at a certain heat input (kcal/h or Btu/h). Under the most efficient operating conditions, the heat input rate would be constant at or near the maximum design rate. Furthermore, all of the heat input would come from the waste, with little or no need for auxiliary fuel. The waste characteristics, i.e., heat content and moisture content of the waste being charged to the incinerator, will affect the operator's ability to maintain good combustion conditions in the incinerator without the use of auxiliary fuel.

The chemical and physical characteristics of the different waste materials that are fired to hospital waste incinerators vary widely. A study of hospitals in Ontario provided information on the heating value, bulk density, and moisture content of different waste materials. The results from this study are presented in Table 2-3 (SI units) and Table 2-4 (English units).[2]

Hospital waste can vary considerably in composition and consequently in heat content, moisture content, and bulk density. Hospital waste can vary in Btu content from a low value of about 3,400 kJ/kg (1,500 Btu/lb) (primarily low-Btu, high-moisture anatomical waste) to 45,000 kJ/kg (20,000 Btu/lb) (low-moisture, high-heat content plastics such as polyethylene). Because of the potential for a wide range in waste characteristics and the impact of varying waste characteristics on incinerator performance, large volumes of wastes with unusually high or low Btu or moisture contents should be identified so that charging procedures and rates to the incinerator can be adjusted accordingly as described in Chapter 4.

The chemical composition of the waste materials also may affect pollutant emissions. Wastes containing metals and plastics are of particular concern. Metals which vaporize at the primary combustion chamber temperature (e.g., mercury) may become metal oxides with particle size distributions primarily in the size range of 1 µm or less. These small particles may become easily entrained and exhausted with the combustion gases with limited capture by conventional air pollution control equipment. Halogenated plastics, such as polyvinyl chloride, will produce acid gases such as HCl. The presence of the chlorinated waste also may contribute to the formation of toxic polycyclic organic material such as dioxins and furans under poor operating conditions.

Some plastics such as polyethylene and polystyrene do not contain significant amounts of halogens and can be incinerated efficiently without major concern for acid gas or toxic pollutant formation. However, the high heating value of these and other plastic materials can cause excessively high temperatures in the primary combustion chamber. The potential for refractory damage, slagging, and clinker formation increases unless charging rates are adjusted or the plastics are mixed with other wastes of lower heat content.

2.4 Types of Hospital Waste Incinerator Systems

2.4.1 Introduction[7,11,12]

The terminology used to describe hospital waste incinerators that has evolved over the years is quite varied. Multiple names have been used for the same basic types of incinerators, and much of the terminology does not enhance precise definitions that can be used to define good O&M practices. However, most incinerators have been grouped historically into one of three types – "multiple-chamber," "controlled-air," and "rotary kiln."

Most incineration systems installed before the early 1960's were "multiple-chamber" systems designed and constructed according to Incinerator Institute of America (IIA) standards. The multiple-chamber incinerator has two or more combustion chambers. These "multiple-chamber" systems are designed to operate at high excess-air levels and, hence, are often referred to as "excess-air" incinerators. Multiple-chamber, excess-air incinerators are still found at many hospitals. Many of the multiple-chamber incinerators were designed specifically for pathological wastes and are still being used for that purpose. Note that although the term "multiple-chamber" incinerator typically is used to describe this type of excess-air incinerator, the typical controlled-air and rotary kiln units also contain multiple chambers.

The incineration technology that has been installed most extensively for hospital wastes over the last 15 years generally has been "controlled-air" incineration. This technology is also called "starved-air" combustion, "modular" combustion, and "pyrolytic" combustion. The systems are called "controlled-air" or "starved-air" because they operate with two chambers in series and the first chamber operates at substoichiometric conditions. Similar modular "controlled-air" units which operate with excess-air levels in the primary chamber are also manufactured and sold for combustion of municipal solid waste (MSW); however, these units apparently are not widely used for hospital waste incineration.

Rotary kiln-type incineration systems have been widely used for hazardous waste incineration in the U.S. The rotary kiln has two combustion chambers. The primary chamber is a horizontal rotating kiln that typically operates with excess air. However, some manufacturers now have rotary kilns designed to operate with a substoichiometric atmosphere in the kiln; these kilns use special seals and air injection schemes.[13] The exhaust gases exit the kiln to a fixed secondary chamber. Rotary kiln incineration technology is being applied to hospital waste incineration at a few locations in the U.S. and Canada.[11]

This historical grouping of incineration types is of some assistance in characterizing how hospital waste incinerators operate, but it is limited because it does not address the complete combustion "system" and how the incinerator is operated. Three important factors which help to characterize the hospital waste incinerator system and its operation are (1) the air distribution to the combustion chambers, (2) the mode of operation and method of moving waste through the system, and (3) the method of ash removal. For hospital waste incinerators, air distribution can be classified based on whether the primary chamber operates under substoichiometric (starved) or excess-air conditions. The mode of

Table 2-3. Characterization of Hospital Waste[2] (Metric)

Component description	HHV dry basis, kJ/kg	Bulk density as fired, kg/m^3	Moisture content of component, weight %	Heat value as fired, kJ/g
Human anatomical	18,600-27,900	800-1,200	70-90	1,860-8,370
Plastics	32,500-46,500	80-2,300	0-1	32,300-46,500
Swabs, absorbants	18,600-27,900	80-1,000	0-30	13,000-27,900
Alcohol, disinfectants	25,500-32,500	800-1,000	0-0.2	25,500-32,500
Animal infected anatomical	20,900-37,100	500-1,300	60-90	2,090-14,900
Glass	0	2,800-3,600	0	0
Beddings, shavings, paper, fecal matter	18,600-20,900	320-730	10-50	9,300-18,800
Gauze, pads, swabs, garments, paper, cellulose	18,600-27,900	80-1,000	0-30	13,000-27,900
Plastics, PVC, syringes	22,500-46,500	80-2,300	0-1	22,300-46,500
Sharps, needles	140	7,200-8,000	0-1	140
Fluids, residuals	0-23,200	990-1,010	80-100	0-4,640

Table 2-4. Characterization of Hospital Waste[2] (English)

Component description	HHV dry basis, Btu/lb	Bulk density as fired, lb/ft^3	Moisture content of component, weight %	Heat value as fired, Btu/lb
Human anatomical	8,000-12,000	50-75	70-90	800-3,600
Plastics	14,000-20,000	5-144	0-1	13,900-20,000
Swabs, absorbants	8,000-12,000	5-62	0-30	5,600-12,000
Alcohol, disinfectants	11,000-14,000	48-62	0-0.2	11,000-14,000
Animal infected anatomical	9,000-16,000	30-80	60-90	900-6,400
Glass	0	175-225	0	0
Beddings, shavings, paper, fecal matter	8,000-9,000	20-45	10-50	4,000-8,100
Gauze, pads, swabs, garments, paper, cellulose	8,000-12,000	5-62	0-30	5,600-12,000
Plastics, PVC, syringes	9,700-20,000	5-144	0-1	9,600-20,000
Sharps, needles	60	450-500	0-1	60
Fluids, residuals	0-10,000	62-63	80-100	0-2,000

operation can be single batch, intermittent duty, or continuous duty. Ash is removed on a batch or a semicontinuous basis. Characteristics of the major types of incinerators that are likely to be found at U.S. hospitals with respect to these three factors described above are listed in Table 2-5. The remainder of this section describes the types of incinerators as classified in Table 2-5.

2.4.2 Multiple-Chamber Incinerators[14]

Two traditional designs that are used for multiple chamber incinerators are the "in-line hearth" and "retort" hearth. The in-line hearth design is depicted in Figure 2-3. For in-line hearth incinerators, combustion gases flow straight through the incinerator, with turns in the vertical direction only (as depicted by the arrows in Figure 2-3). Depicted in Figure 2-4 is the retort hearth multiple-chamber incinerator. In the retort hearth design, the combustion gases turn in the vertical direction (upward and downward) as in the in-line incinerator, but also turn sideways as they flow through the incinerator. Because the secondary chamber is adjacent to the primary chamber (they share a wall) and the gases turn in the shape of a U, the design of the incinerator is more compact. In-line incinerators perform better at capacities greater than 750 lb/h. The retort design performs more efficiently than the in-line design at capacities less than 750 lb/h. The retort design is the most common design used in hospital waste applications.

Multiple-chamber incinerators may have fixed hearths or grates or a combination of the two in the primary chamber. The use of grates for a system incinerating infectious waste is not recommended because liquids, sharps, and small, partially

Table 2-5. Classification of Hospital Incinerators

Type of incinerator	Air supply[a]	Waste feed	Ash removal
Multiple chamber	Excess	Manual or mechanical batch feed; single or multiple batches per burn	Batch at end of burn
Batch/controlled air	Starved	Batch (manual or mechanical); 1 batch per burn	Batch at end of burn
Intermittent duty controlled air	Starved	Manual or mechanical batch feed; multiple batches per burn	Batch at end of burn
Continuous duty controlled air	Starved	Mechanical continuous or multiple batch feed	Intermittently or continuously during burn
Rotary kiln	Excess	Mechanical semicontinuous or continuous feed	Continuous

[a] Indicates whether primary chamber operates at below (starved) or above (excess) stoichiometric air levels.

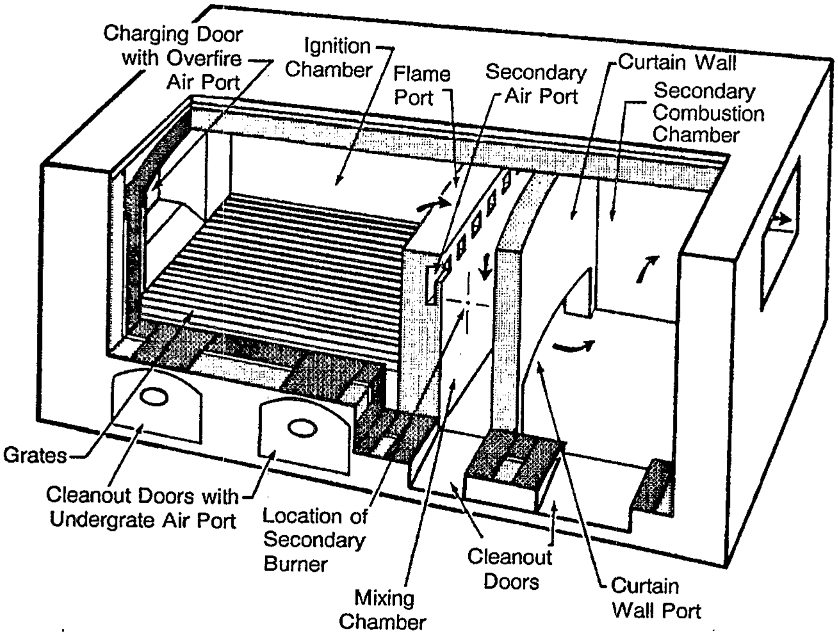

Figure 2-3. In-line multiple-chamber incinerator with grate.[14]

combusted items can fall through the grates prior to complete combustion or sterilization.

Multiple-chamber incinerators frequently are designed and used specifically for incinerating pathological ("Type 4" anatomical) wastes. Pathological waste has a high moisture content and may contain liquids; consequently, a pathological incinerator always will be designed with a fixed hearth. A raised "lip" at the door often is designed into the hearth to prevent liquids from spilling out the door during charging. Because the heating value of pathological waste is low and is not sufficient to sustain combustion, the auxiliary burner(s) provided in the primary chamber of pathological incinerators are designed for continuous operation and with sufficient capacity to provide the total heat input required.

2.4.2.1 *Principle of Combustion and Air Distribution*

Combustion in the multiple-chamber incinerator occurs in two (or more) combustion chambers. Both chambers are operated with excess air (thus these units often are referred to as "excess-air" incinerators). Ignition of the waste, volatilization of moisture, vaporization of volatile matter, and combustion of the fixed carbon (solid-phase combustion) occur in the primary chamber. The combustion gases containing the volatiles exit the primary chamber through a flame port into a mixing

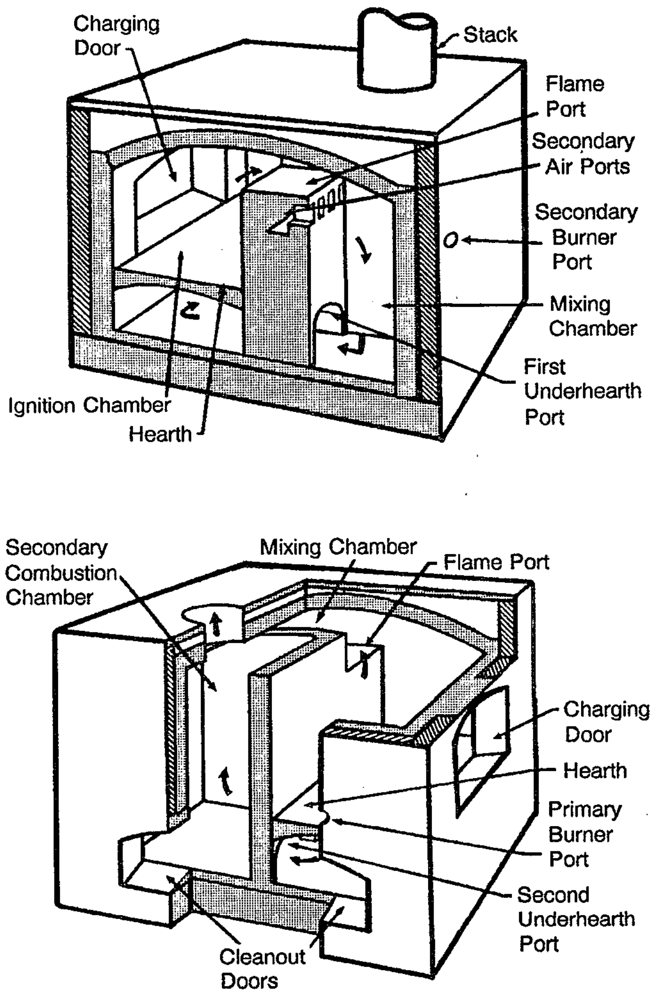

Figure 2-4. Retort multiple-chamber incinerator for pathological wastes.[14]

chamber and then pass into the secondary combustion chamber. Secondary air is added into the flame port and is mixed with the combustion gas in the mixing chamber. A secondary burner is provided in the mixing chamber to maintain adequate temperatures for complete combustion as the gases pass into and through the secondary combustion chamber.

The incinerator is designed for surface combustion of the waste which is achieved by predominant use of overfire combustion air and limiting the amount of underfire air in the primary chamber. Multiple-chamber, excess-air incinerators operate with an overall excess-air range of 300 to 600 percent.[14] In older units, combustion air typically was provided by natural draft via manually adjusted dampers and air in-leakage through doors. Newer multiple-chamber incinerators often use forced-draft combustion air blowers to provide the combustion air to the combustion chambers.[15]

2.4.2.2 *Mode of Operation*

Multiple-chamber incinerators typically are designed for single batch or intermittent-duty operation. That is, this type of incinerator typically does not have an automatic, continuous ash removal system which would make continuous operation possible. Consequently, the incinerator must be shut down at routine intervals (for example, daily) for ash removal, and the incinerator is operated "intermittently."

2.4.2.3 *Waste Feed Charging Systems*

Waste feed charging to multiple-chamber units is typically done manually. The waste is loaded into the primary chamber through the open charging door. Mechanical charging systems, such as hopper/ram-feed systems also may be used.[15] (Hopper/ram-feed systems are discussed in the next section.)

2.4.2.4 *Ash Removal Systems*

For the typical multiple-chamber incinerator, ash is removed manually after the incinerator is shut down. The charging and/or ash cleanout doors are opened, and either a rake or shovel is used to remove the ash.

2.4.2.5 *Use of Multiple-Chamber Incinerators for Incinerating Hospital Wastes*

The use of multiple-chamber, excess-air incinerators for incineration of redbag wastes has several drawbacks. First, operating in the surface-combustion excess-air mode in the primary chamber results in entrainment of flyash which can cause excessive particulate matter emissions. Second, since the incinerator is designed to operate with the primary chamber in an excess-air mode, the combustion air levels and the combustion rate within the primary chamber are not easily controlled. Consequently, the incinerator control system may not provide a sufficient level of control to assure complete combustion when waste composition and volatile content of the waste fluctuates over a wide range. Red bag wastes are not homogeneous and may vary widely in volatile content and moisture content. Third, operating with high levels of excess air is less energy efficient because it requires auxiliary fuel usage to maintain secondary combustion chamber temperatures.

Multiple-chamber, excess-air incinerators are better suited to incineration of pathological wastes than red bag wastes because the consequences of the above-mentioned drawbacks are not as severe for pathological wastes.[2] The volatile content of pathological waste is low, and in general, the waste composition is not highly variable. The primary burner provides most of the heat input and the incinerator operates in a steady, constant mode with a steady, consistent combustion air input and excess-air level.

In some cases, older multiple-chamber incinerators may be upgraded to include more modern technology. Recently, some older multiple-chamber units have been retrofitted so that the incinerator operates with substoichiometric air levels in the primary chamber; in essence, these units have been converted into the controlled-air units discussed in the next section.[15]

2.4.3 Controlled-Air Incinerators

2.4.3.1 Principle of Controlled-Air Incineration[16]

The principle of controlled-air incineration involves sequential combustion operations carried out in two separate chambers. Figure 2-5 is a simplified schematic of an incinerator that operates on the controlled-air principle. The primary chamber (sometimes referred to as the ignition chamber) accepts the waste, and the combustion process is begun in a below stoichiometric oxygen atmosphere. The amount of combustion air to the primary chamber is strictly regulated (controlled). The combustion air usually is fed to the system as underfire air. Three processes occur in the primary chamber. First, the moisture in the waste is volatilized. Second, the volatile fraction of the waste is vaporized, and the volatile gases are directed to the secondary chamber. Third, the fixed carbon remaining in the waste is combusted. The combustion gases containing the volatile combustible materials from the primary chamber are directed to the secondary chamber (sometimes referred to as the "combustion chamber"). There, the combustion air is regulated to provide an excess-air combustion condition and is introduced to the chamber in such a manner as to produce turbulence and promote good mixing of the combustion gases and combustion air. This gas/air mixture is burned, usually at high temperatures. The burning of the combustion gases under conditions of high temperature, excess oxygen, and turbulence promotes complete combustion.

Combustion control for a controlled-air incinerator is usually based on the temperature of the primary (ignition) and secondary (combustion) chambers. Thermocouples within each chamber are used to monitor temperatures continuously; the combustion air rate to each chamber is adjusted to maintain the desired temperatures. Systems operating under controlled-air principles have varied degrees of combustion air control. In many systems, the primary and secondary combustion air systems are automatically and continuously regulated or "modulated" to maintain the desired combustion chamber temperatures despite varying waste composition and characteristics (e.g., moisture content, volatile content, Btu value).[11] In other systems (particularly batch or intermittent-duty systems), the combustion air level control is simplified and consists of switching the combustion air rate from a "high" to a "low" level setting when temperature setpoints are reached or at preset time intervals.

The controlled-air technique has several advantages. Limiting air in the primary chamber to below stoichiometric conditions prevents rapid combustion and allows a quiescent condition to exist within the chamber. This quiescent condition minimizes the entrainment of particulate matter in the combustion gases, which ultimately are emitted to the atmosphere. High temperatures can be maintained in a turbulent condition with excess oxygen in the secondary chamber to assure complete combustion of the volatilized gases emitted from the primary chamber. The temperature of the secondary chamber can be maintained in the desired range (hot enough for complete combustion but not hot enough to cause refractory damage) by separately controlling the excess-air level in the secondary chamber; as the excess-air level is increased, the temperature decreases. Second, control of the primary chamber combustion air to below stoichiometric levels maintains primary chamber temperatures below the melting and fusion temperatures of most metals, glass, and other noncombustibles, thereby minimizing slagging and clinker formation.

For the controlled-air incinerator, the capacity of the secondary combustion chamber dictates (i.e., limits) the burning rate; the combustion chamber must have adequate volume to accept and completely oxidize all the volatile gases generated in the primary chamber and to maintain sufficient combustion air so that excess oxygen is available.

2.4.3.2 Batch/Controlled-Air Incinerators[11]

In this type of unit, the incinerator is charged with a single "batch" of waste, the waste is incinerated, the incinerator is cooled, and the ash residue is removed; the cycle is then repeated. Incinerators designed for this type of operation range in capacity from about 50 to 500 lb/h. In the smaller sizes, the combustion chambers are often vertically oriented with the primary and secondary chambers combined within a single casing. Figure 2-6 is a schematic of a controlled-air incinerator intended for batch operation.[17] This unit's combustion chambers are rectangular in design and are contained within the same casing.

Batch/controlled-air units can be loaded manually or mechanically. For the smaller units up to about 300 lb/h, manual waste feed charging typically is used.

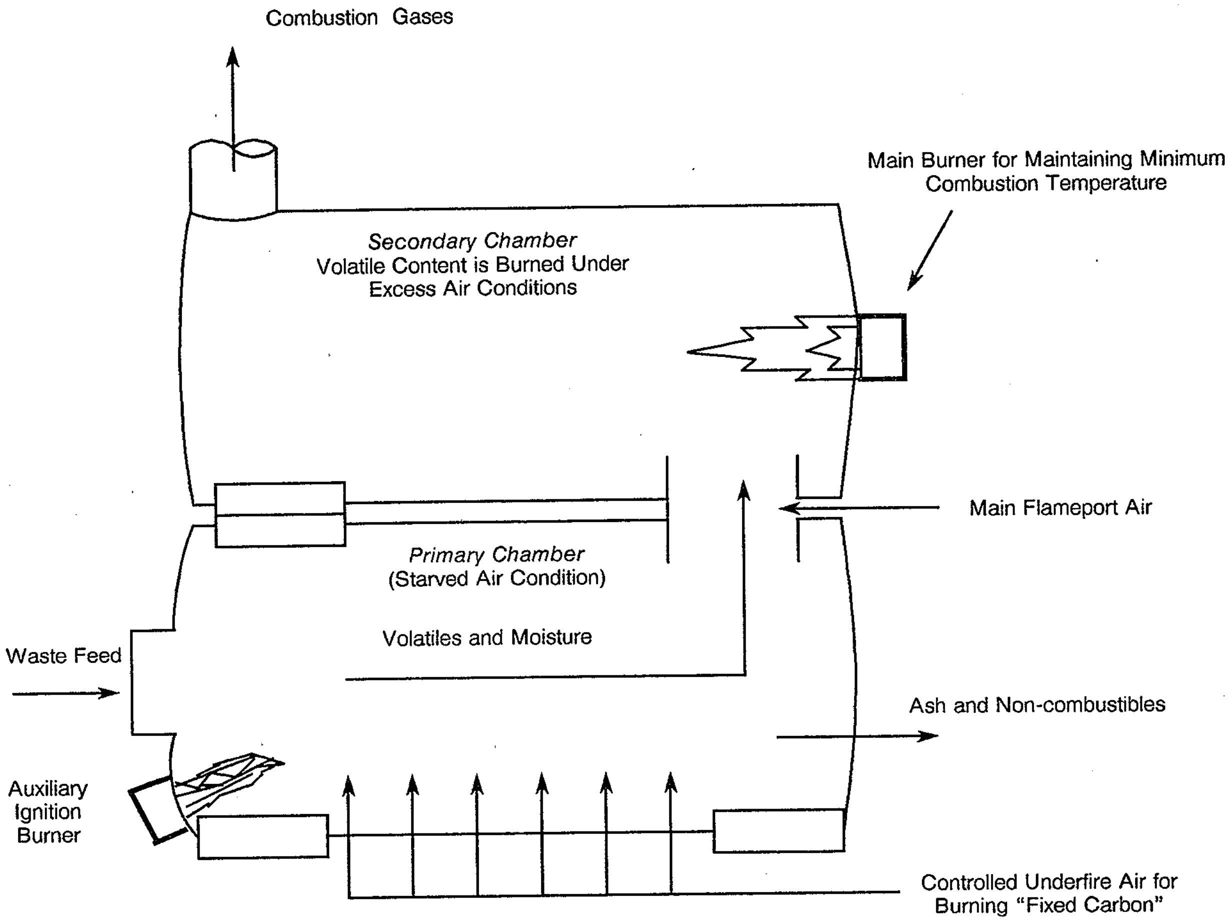

Figure 2-5. **Schematic of a controlled-air incinerator.**[16]

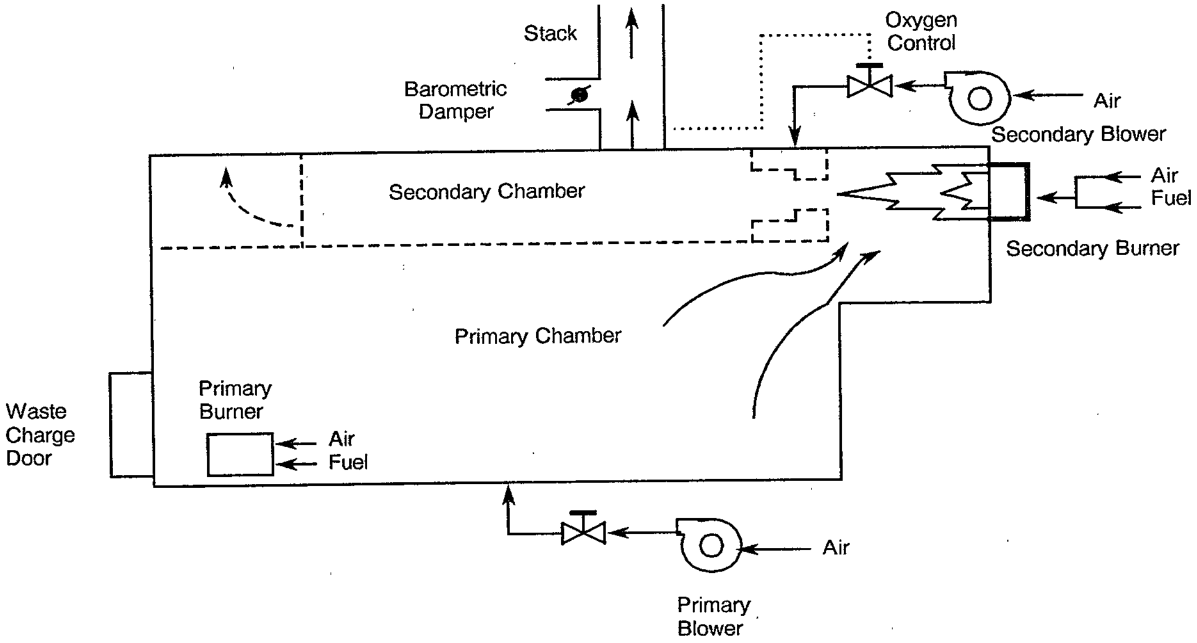

Figure 2-6. **Schematic of a single batch controlled-air incinerator.**[17]

Manual loading involves having the operator load the waste directly to the primary chamber without any mechanical assistance. For a batch-type unit, one loading cycle per day is used. The incinerator is manually loaded; the incinerator is sealed; and the incineration cycle is then continued through burndown, cooldown, and ash removal without any additional charging. Ash is removed manually at the end of the cycle by raking or shoveling the ash from the primary chamber.

2.4.3.3 *Intermittent-Duty, Controlled-Air Incinerators*

The charging procedures of an incinerator that could operate in single batch mode often are varied to include multiple charges (batches) during the 12- to 14-hour operating period before final burndown is initiated. These intermittent-duty units typically operate in the 50 to 1,000 lb/h range. The intermittent charging procedure allows the daily charge to the incinerator to be divided into a number of smaller charges that can be introduced over the combustion cycle. Consequently, a more uniform gas stream is fed to the secondary chamber. Figure 2-7 is a schematic of a controlled-air incinerator which is intended for intermittent-duty operation. This unit has a vertically oriented primary chamber followed by a horizontal combustion chamber. This unit, although not shown with a mechanical feeder, can be fitted with a hopper/ram assembly.

A typical daily operating cycle for a controlled-air, intermittent- duty-type incinerator is as follows:

	Operating step	Typical duration
1.	Cleanout of ash from previous day 15 to 30 minutes	15 to 30 minutes
2.	Preheat of incinerator 15 to 60 minutes	15 to 60 minutes
3.	Burndown	2 to 4 hours
4.	Cooldown	5 to 8 hours

For intermittent-duty operation, the daily waste loading cycle of the incinerator is limited to about an 8- to 14-hour period. The waste loading period is limited by the amount of ash the primary chamber can physically hold prior to shutting down the unit for ash removal. The remainder of the 24-hour period is required for burndown of the ash, cooldown, ash cleanout, and preheat.

For smaller units, the waste often is fed manually. For units in the 300 to 500 lb/h range, mechanical waste feed systems often are employed, and for units above 500 lb/h, mechanical waste feed systems typically are employed. The typical mechanical waste feed system is a hopper ram assembly. Figure 2-8 is a schematic of a typical hopper ram assembly.[20] In a mechanical hopper/ram feed system, waste is manually placed into a charging hopper, and the hopper cover is closed. A fire door isolating the hopper from the incinerator opens, and the ram moves forward to push the waste into the incinerator. The ram reverses to a location behind the fire door. After the fire door closes, the ram retracts to the starting position and is ready to accept another charge. A water spray to quench the ram face as it retracts typically is provided. The entire charging sequence normally is timed and controlled by an automatic sequence. The cycle can be started manually by the operator or, in some systems, the cycle is automatically started on a predetermined basis.

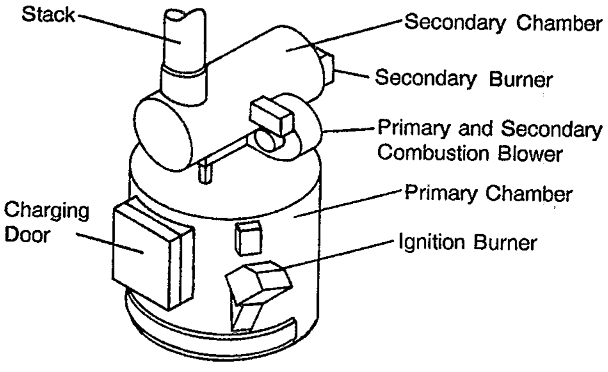

Figure 2-7. Example intermittent-duty, controlled-air incinerator.[18]

Mechanical loading systems have several advantages. First, they provide added safety to the operating personnel by preventing heat, flames, and combustion products from escaping the incinerator during charging. Second, they limit ambient air infiltration into the incinerator. This assists in controlling the combustion rate by strictly controlling the quantity of available combustion air. Third, they facilitate charging the incinerator with smaller batches of waste at regulated time intervals.[11]

With intermittent-duty incinerators, ash removal is a limiting factor for the incinerator operations. As with the single batch-operated units, the ash is removed at regular intervals (typically daily) after the incinerator has gone through a cooldown cycle. The ash usually is manually removed by raking and/or shoveling from the primary chamber.

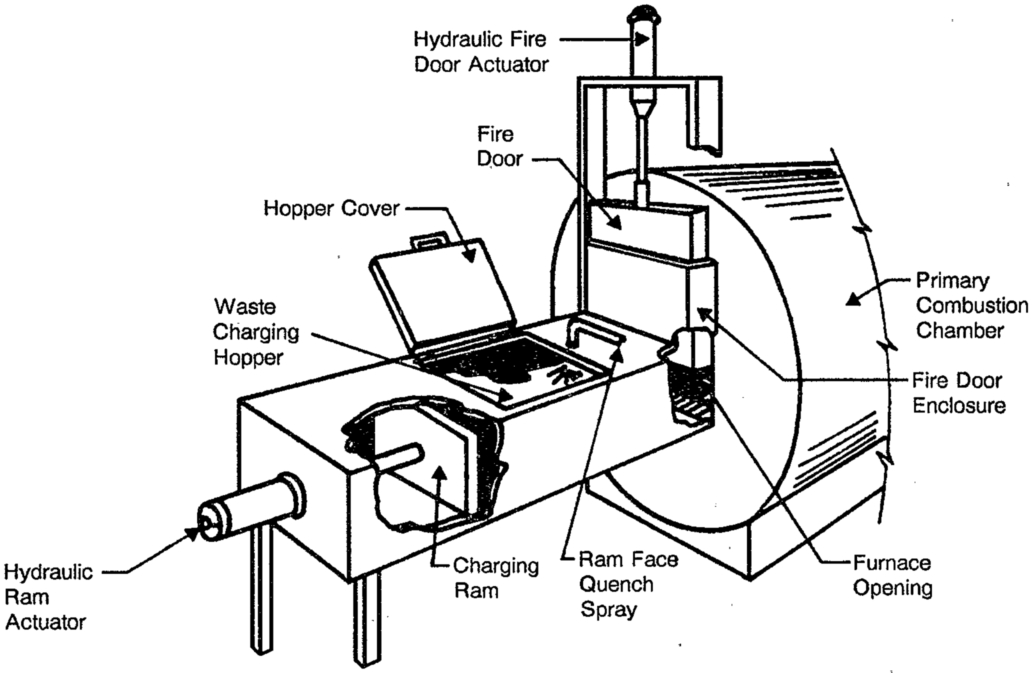

Figure 2-8. Hopper/ram mechanical waste feed system.[21]

2.4.3.4 Continuous-Duty, Controlled-Air Incinerators.

Controlled-air units intended for continuous operation are available in the 500 to 3,000 lb/h operating range. Continuous-duty, controlled-air units operate according to the controlled-air principles of the systems described earlier. However, continuous operation requires a mechanism for automatically removing ash from the incinerator hearth. The ash must be moved across the hearth, collected, and removed from the combustion chamber.

Continuous-duty units typically have mechanical waste feeding systems. For large continuous-duty units, the charging sequence may be fully automatic. The incinerator can be automatically charged with relatively small batches (in relation to the primary chamber capacity) at frequent, regulated time intervals. The use of frequent, small charges promotes relatively stable combustion conditions and approximates steady-state operation. For large systems, the mechanical charging system may include waste loading devices such as cart dumpers, which automatically lift and dump the contents of carts that are used to collect and contain the waste, into the charge hoppers. Use of these loading devices reduces the operator's need to handle infectious waste and, consequently, further improves worker safety.

For smaller units, the mechanical waste feed charging ram is sometimes used to move the ash across the hearth. As a new load is pushed into the incinerator, the previous load is pushed forward. Each subsequent load has the same effect of moving the waste across the hearth. The waste should be fully reduced to ash by the time it reaches the end of the hearth. For larger systems, one or more special transfer rams are provided to move the waste across the hearth. A continuous-duty, controlled-air incinerator with a stepped hearth and multiple ash transfer rams is depicted in Figure 2-9.[21] The use of the stepped hearth promotes "mixing" the ash bed as the ash is moved from hearth to hearth and, consequently, promotes improved solid-phase combustion.

Typically, when the ash reaches the end of the hearth, it drops off the end of the hearth into a discharge chute. One of two methods for collecting ash is usually used. The ash can discharge directly into an ash container positioned within an air-sealed chamber or sealed directly to the discharge chute. When the container is full, it is removed from the chamber and replaced with an empty ash container. The second method is for the ash to discharge into a water pit. The water bath quenches the ash, and it also forms an air seal with the incinerator. A mechanical device, either a rake or a conveyor, is used to remove the ash from the quench pit intermittently or continuously. The excess water is allowed to drain from the ash as it is removed from the pit, and the wetted ash is discharged into a collection container.[11]

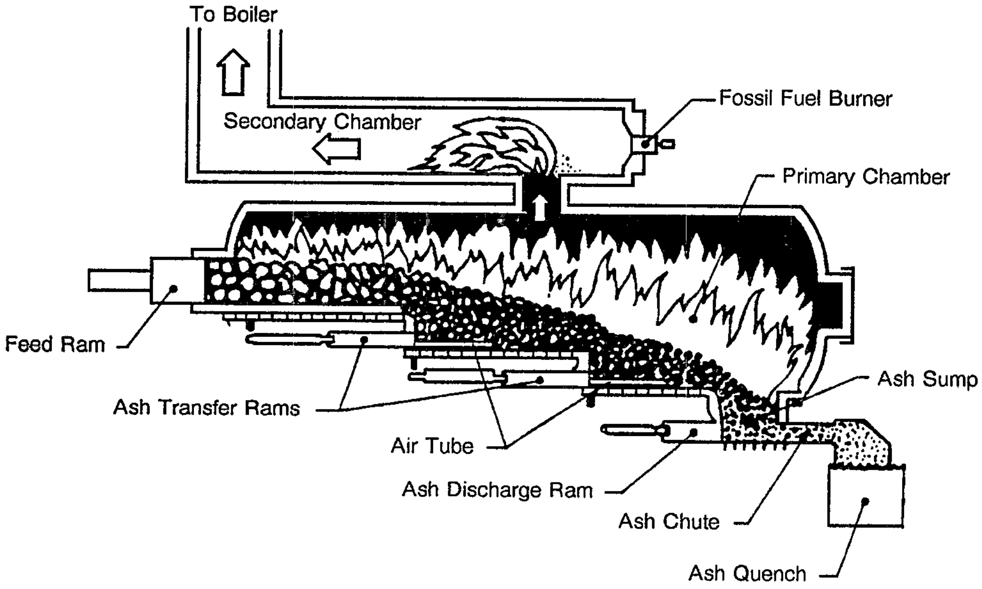

Figure 2-9. Incinerator with step hearths and automatic ash removal.[20]

2.4.4 Rotary Kilns

A rotary kiln also utilizes two-stage combustion and has two combustion chambers. Figure 2-10 is a simplified schematic of a rotary kiln. The primary combustion chamber is a rotating cylindrical chamber which is slightly inclined from the horizontal plane; hence, the name "rotary kiln." The secondary chamber often is cylindrical in shape and oriented horizontally much like the secondary chambers described for controlled-air incinerators, or it may be box-like as depicted in Figure 2-10.

2.4.4.1 Principle of Operation.

The rotating kiln is inclined at an angle determined during design of the system. Waste is fed to the higher end of the kiln by a mechanical feed system. Typically, combustion air is provided to the kiln such that an excess-air atmosphere exists. However, some manufacturers now have rotary kilns designed to operate with a substoichiometric atmosphere in the kiln; these kilns use special seals and air injection schemes. Running the kiln substoichiometrically decreases kiln sizes required and reduces auxiliary fuel usage in the secondary chamber. Inside the kiln, moisture and volatiles are vaporized from the waste, and the waste is ignited. An auxiliary burner provided in the kiln maintains the desired combustion temperature if sufficient heat input is not available from the waste. As the kiln rotates, the solids are tumbled within the kiln and slowly move down the incline toward the discharge end. The turbulence of the waste within the kiln provides exposure of the solid waste to the combustion air. Combustion of the solids occurs within the kiln, and the residue ash is discharged from the end of the kiln into an ash removal system.

The volatile gases pass into the secondary chamber where combustion of the gases is completed. A secondary burner is used to maintain the secondary chamber temperature, and secondary combustion air is added to the chamber as necessary to maintain the desired excess-air level.

2.4.4.2 Mode of Operation.

Since the solid waste continuously moves down the length of the rotating kiln, the incineration system is designed to operate in a continuous mode with a semicontinuous or continuous waste feed input. Consequently, a rotary kiln typically has a mechanical waste feed system and a system for continuous ash removal.

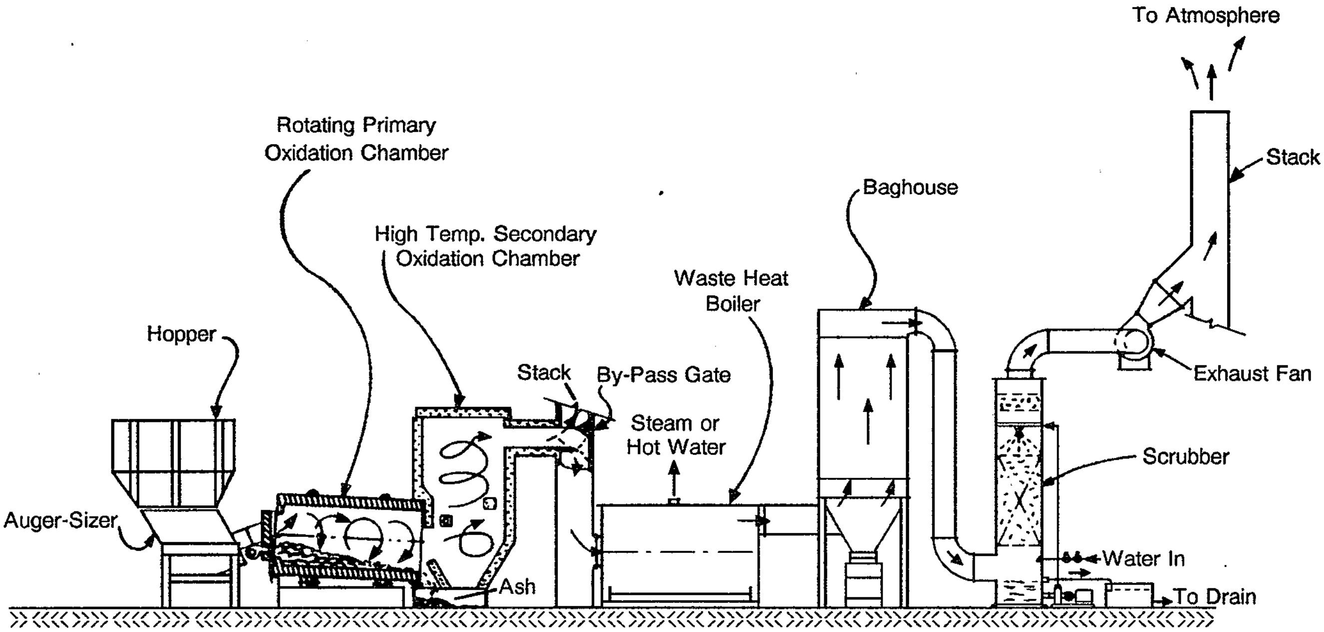

Figure 2-10. Rotary kiln with auger feed.[21]

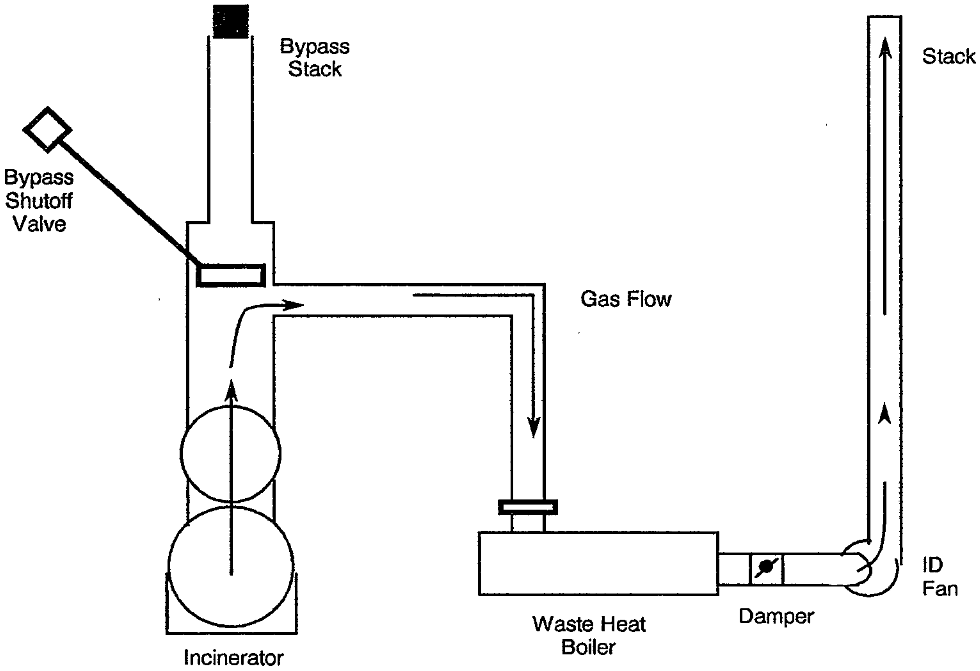

Figure 2-11. Incinerator with waste heat boiler and bypass stack.

2.4.4.3 *Charging System.*

The waste feed system must provide waste to the kiln in a continuous or semicontinuous manner. One manufacturer that provides rotary kiln incinerators for hospital waste applications uses an auger-feeder system to feed the waste continuously to the kiln.[22] Waste is fed to the feed hopper, and the auger-feeder continuously discharges the waste from the bottom of the hopper to the kiln.

The hopper/ram feed system of the type previously described also has been used for feeding rotary kilns (particularly in hazardous waste incineration applications).

2.4.4.4 *Ash Removal.*

As the kiln rotates, the ash is continuously discharged from the end of the kiln. A system for collecting the ash and continuously or semicontinuously removing the ash is required. Automated ash removal systems such as those previously described for the continuous-duty, controlled-air incinerators are used.

2.4.5 Auxiliary Equipment

2.4.5.1 *Waste Heat Boilers.*

Incinerator manufacturers often provide waste heat boilers as an option to their incineration units. Waste heat boilers are used in conjunction with a hospital waste incinerator to generate steam or hot water for use in the hospital. The combustion gases from the incinerator pass through the waste heat boiler prior to being emitted to the atmosphere via the stack. Use of a waste heat boiler requires that an induced draft fan be added to the system. Furthermore, incinerators equipped with waste heat boilers have a system for diverting the combustion gases directly to the atmosphere and bypassing the boiler. This bypass system is required for safety (for example, to avoid excessive pressures in the incinerator should the fan cease operation) and for normal operation if demand for waste heat is low (so the boiler can be taken off line). Typical systems include either a second "bypass" stack before the waste heat boiler or a breeching directly connecting the incinerator to the stack and bypassing the boiler. Figure 2-11 is a schematic of a controlled-air unit with waste heat recovery.[16]

2.4.5.2 *Auxiliary Waste Liquid Injection.*

Incinerators also may include the capability to inject liquid wastes into the primary chamber. Generally liquid waste incineration is accomplished through either an atomizing nozzle or burner assembly in the primary chamber. Wastes such as used solvents can be readily incinerated via liquid injection.

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Chapter 3
Air Pollution Control

3.1 Introduction

Hospital incinerators are potentially significant sources of air pollutants. Pollutants of concern from hospital incinerators include particulate matter; toxic metals; toxic organics; carbon monoxide (CO); and the acid gases, hydrogen chloride (HCl), sulfur dioxide (SO_2), and nitrous oxides (NO_x). Emission rates of these pollutants can be limited by removing pollutant generating materials from the waste feed material, proper operation of the incinerator, and add-on pollution control equipment. The objectives of this Chapter are to describe the factors affecting formation and generation of the pollutants and to identify and discuss control strategies that can be used to control the pollutant.will describe The factors affecting pollutant formation and generation, including the effects of waste feed composition, are described in Section 3.2. Air pollution control strategies are discussed in Section 3.3. Electrostatic precipitators are not discussed in this chapter because they are not commonly used for air pollution control on "local" hospital incinerators. They are more likely to be used for large regional-type facilities, possibly in conjunction with a dry-scrubbing system. Information on their operation and maintenance can be found in reference 2 of Chapter 8.

3.2 Pollutant Formation and Generation

The pollutants of concern from hospital incinerators either exist in the waste feed material or are formed in the combustion process.

Particulate matter. Particulate matter emissions from the combustion of hospital wastes are determined by three factors: (1) suspension of noncombustible materials, (2) incomplete combustion of combustible materials, and (3) condensation of vaporous materials. The ash content of the waste feed material is a measure of the noncombustible portion of the waste feed and represents those materials which will not burn under any conditions in the incinerator. Emissions of noncombustible materials result from the suspension or entrainment of ash by the combustion air added to the primary chamber of the incinerator. The more air added, the more likely that noncombustibles will become entrained. Particulate emissions from incomplete combustion of combustible materials result from improper combustion control of the incinerator. Condensation of vaporous materials results from noncombustible substances that volatilize at primary combustion chamber temperatures with subsequent cooling in the flue gas. These materials usually condense on the surface of other fine particles.

Toxic metals. Particulate metal emissions are dependent on the metals content of the feed material. Metals may exist in the waste as parts of discarded instruments or utensils, in plastics, paper, pigments, and inks, or as discarded heavy metals used in laboratories. Many metals are converted to oxides during combustion and are emitted primarily as submicron to micron size particles. Metals that volatilize at primary combustion chamber temperatures may selectively condense on small, difficult to control particles in the incinerator flue gas. Metals generally thought to exhibit fine-particle enrichment are arsenic (As), cadmium (Cd), chromium (Cr), manganese (Mn), nickel (Ni), molybdenum (Mo), lead (Pb), antimony (Sb), selenium (Se), vanadium (V), and zinc (Zn).[1]

Toxic organics. Organic material found in the waste feed material theoretically can be completely combusted to form water (H_2O) and carbon dioxide (CO_2). However, incomplete combustion will result in emissions of organics found in the waste feed and in the generation of new organic species from complex chemical reactions occurring in the combustion process. When chlorine is available in the form of PVC plastic materials, these organics can include highly toxic chlorinated organics, such as dioxins and furans. Combustion conditions that favor increased particulate matter emissions due to incomplete combustion also favor increased organic emissions.

Carbon monoxide (CO). As noted above, complete combustion of organic material will result in the formation of H_2O and CO_2. The concentration of CO in the incinerator exhaust gas stream is an indicator of the combustion efficiency of the unit. The formation of CO is dictated by the oxygen concentration in the incinerator, the degree of mixing of the fuel and air, and the temperature of the gases.

Carbon monoxide is an intermediate product of the reaction between carbonaceous fuels and oxygen. Combustion conditions that result in incomplete combustion will produce CO as well as particulate matter and organics.

Acid gases. The principal acid gas of concern from hospital incinerators is HCl. The determining factor in HCl formation and emission is the availability of chlorine in the feed material. In the presence of available hydrogen, as would exist in highly organic hospital wastes, most of the available chlorine will be converted to HCl. Sulfur dioxide generation is similar to HCl; most of the sulfur in the wastes will be converted to SO_2 during combustion regardless of incinerator design or operation.

Nitrogen enters the combustion chamber as a component of the waste and in the combustion air. It can react in the combustion chamber to produce NO_x.

3.3 Control Strategies

Formation and generation of all of the pollutants discussed above are dependent on either the availability of certain materials in the waste feed or on the efficiency of the combustion process. Removing problem materials from the waste feed and improving combustion efficiency are, therefore, two control strategies for reducing pollutant emissions. If pollutants are formed and generated, add-on pollution control equipment represents a third control strategy for emissions reduction. Table 3-1 presents the control strategies that can be effective for each of the pollutants of concern.

3.3.1 Controlling Feed Material

Controlling feed material consists of either establishing procedures that eliminate the use of certain materials, specifying segregation of certain wastes at the point of origin, or removing problem materials from the waste material prior to incineration. Obviously, eliminating the use of certain materials or establishing segregation procedures are more feasible. The substitution of nonchlorinated plastics (e.g., polyethylene) for PVC, where possible, would reduce the chlorine input to the incinerator. Materials that could be segregated from waste to be incinerated include noncombustible fine dust and powders that could contribute to particulate matter emissions, heavy metals from dental clinics or laboratories, PVC plastics that contribute to HCl formation, and other chlorine- or sulfur-containing materials.

3.3.2 Combustion Control

Complete combustion of combustible material requires adequate temperatures, excess air, turbulence, mixing, and retention time. Because of the variability in hospital waste with respect to heating values, moisture contents, etc., incinerator operating parameters should be varied with the variations in the waste to maximize combustion. In general, higher temperatures, excess air rates, mixing, and retention time result in improved combustion and lower emissions of particulate matter, organics, and CO. However, as these factors are increased there is an economic penalty in auxiliary fuel costs and energy loss. In addition, combustion control has little or no effect on emissions of HCl and SO_2. In both cases, most of the chlorine and sulfur will be converted to HCl and SO_2 under the entire range of combustion conditions which normally occur in a hospital incinerator. As opposed to the other pollutants, both NO_x and toxic metal emissions can actually be increased by combustion adjustments that increase temperatures and excess air rates. Therefore, the waste feed composition should be considered before making adjustments to control combustion.

3.3.3 Add-On Air Pollution Control Systems

Add-on air pollution control systems (APC's) used on hospital incinerators are usually wet scrubbers, fabric filters, or dry scrubbers. Wet scrubbers, in their various designs, are used to remove particulate matter as well as HCl and SO_2; fabric filters are used to remove particulate matter; dry scrubbers are used to remove HCl and SO_2.

3.3.3.1 Wet Scrubbers

Venturi, spray tower, and packed-bed scrubbers are the most common types of wet scrubber systems used on hospital incinerators. Venturi scrubbers are used primarily for particulate matter control and packed-bed scrubbers are used primarily for acid gas control. However, both types of systems achieve some degree of control for both particulate matter and acid gases. A third scrubber type is spray towers. Spray towers are used to remove particulate matter; however, they are relatively inefficient for the removal of fine particulate matter. These units are not effective for controlling particulate emissions from controlled-air incinerators and are used exclusively on multiple-chamber units which can emit significant quantities of large particles. There are other scrubber types with potential application to hospital waste incinerators including (but not limited to) the wet ionizing scrubber, the collision scrubber, and the Hydro-sonic® steam ejector scrubber.[3,4] Hydro-sonic® scrubber uses supersonic steam ejector drives to accelerate the injected water droplets and provide mixing. The Hydro-sonic® scrubbers are reported to offer high efficiency on fine particulate emissions at relatively low energy costs where there is a source of waste heat for steam production. Use of these scrubbers is not widespread on hospital waste incinerators. Detailed operation and maintenance

Table 3-1. Control Strategies for Air Pollutants from Hospital Waste Incinerators

	Control strategy		Add-on pollution control equipment			
Pollutants	Controlling feed material	Combustion control	Venturi scrubber[a]	Packed-bed scrubber[b]	Fabric filter	Dry scrubber
Particulate matter	X	X	X	c	X	
Toxic metals	X		X	c	X	
Toxic organics		X	c	c		c
Carbon monoxide		X				
Hydrogen chloride	X		c	X		X
Sulfur dioxide	X		c	X		X
Nitrous oxides	X	X				

[a] Venturi scrubber with water as the scrubbing media.
[b] Packed-bed scrubber utilizing an alkaline sorbent.
[c] Will achieve some limited control but not designed for high-efficiency collection.

information for these units controlling hospital waste incinerators is not readily available, and they will not be discussed in this document.

Wet scrubbing principles.[2] Wet scrubbers capture relatively small dust particles with large liquid droplets. Droplets are produced by injecting liquid at high pressure through specially designed nozzles, by aspirating the particle-laden gas stream through a liquid pool, or by submerging a whirling rotor in a liquid pool. These droplets collect particles by using two primary collection mechanisms--impaction and diffusion.

In a wet scrubbing system, dust particles will tend to follow the streamlines of the exhaust stream. However, when liquid droplets are introduced into the exhaust stream, particles cannot always follow these streamlines as they diverge around the droplet (Figure 3-1). The particle's mass causes it to break away from the streamlines and impact on the droplet. Impaction is the predominant collection mechanism for scrubbers having gas stream velocities greater than 0.3 meters per second (m/s) (1 ft/s). Most scrubbers operate with gas stream velocities well above 0.3 m/s. Therefore, at these velocities, particles having diameters greater than 1.0 micrometer (µm) are collected by this mechanism.

Very small particles (less than 0.1 µm in diameter) experience random movement in an exhaust stream. These particles are so tiny that they are bumped by gas molecules as they move in the exhaust stream. This bumping, or bombardment, causes them to move first one way and then another in a random manner, i.e., diffuse, through the gas. This irregular motion can cause the particles to collide with a droplet and be collected.

The rate of diffusion depends on relative velocity, particle diameter, and liquid-droplet diameter. As with impaction, collection due to diffusion increases with an increase in relative velocity (liquid- or gas-phase input) and a decrease in liquid-droplet size. However, collection by diffusion increases as particle size decreases. This mechanism enables certain scrubbers to remove the very tiny particles effectively.

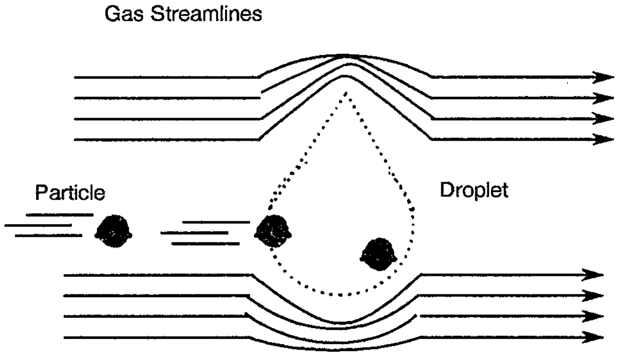

Figure 3-1. Impaction.[5]

The process of dissolving gaseous pollutants in a liquid is referred to as absorption. Absorption is a mass-transfer operation in which mass is transferred as a result of a concentration difference. Absorption continues as long as a concentration differential exists between the liquid and the gas from which the contaminant is being removed. In absorption, equilibrium depends on the solubility of the pollutant in the liquid.

To remove a gaseous pollutant by absorption, the exhaust stream must be passed through (brought in contact with) a liquid. Three steps are involved in absorption. In the first step, the gaseous pollutant diffuses from the bulk area of the gas phase to the gas-liquid interface. In the second step, the gas moves (transfers) across the interface to the liquid phase.

This step occurs extremely rapidly once the gas molecules (pollutant) arrive at the interface area. In the third step, the gas molecule(s) diffuses into the bulk area of the liquid, thus making room for additional gas molecules to be absorbed. The rate of absorption (mass transfer of the pollutant from the gas phase to the liquid phase) depends on the diffusion rates of the pollutant in the gas phase (first step) and in the liquid phase (third step).

To enhance gas diffusion, and, therefore, absorption:

1. Provide a large interfacial contact area between the gas and liquid phases;

2. Provide good mixing of the gas and liquid phases (turbulence); and

3. Allow sufficient residence, or contact, time between the phases for absorption to occur.

Venturi scrubbers. A venturi scrubber consists of a liquid sprayed upstream from a vessel containing a converging and diverging cross-sectional area as illustrated in Figure 3-2. The portion of the venturi which has the minimal cross-sectional area and consequently the maximum gas velocity is commonly referred to as the throat. The throat can be circular as shown in Figure 3-2 or rectangular as shown in Figure 3-3. As the gas stream approaches the venturi throat, the gas velocity and turbulence increases. Liquid droplets serve as the collection media and can be created by two different methods. The most common method is to allow the shearing action of the high gas velocity in the throat to atomize the liquid into droplets. The other method is to use spray nozzles to atomize the liquid by supplying high pressure liquid through small orifices.

To attain a high collection efficiency, venturi scrubbers need to achieve gas velocities in the throat in the range of 10,000 to 40,000 feet per minute. These high gas velocities atomize the water droplets and create the relative velocity differential between the gas and the droplets to effect particle-droplet collision. The effectiveness of a venturi scrubber is related to the square of the particle diameter and the difference in velocities of the liquor droplets and the particles.

The performance of a venturi scrubber is strongly affected by the size distribution of the particulate matter. For particles greater than 1 to 2 µm in diameter, impaction is so effective that penetration is quite low. However, penetration of smaller particles, such as the particles in the 0.1 to 0.5 µm range is very high. Unfortunately, small particle size distribution is typical for fuel combustion sources including hospital waste incinerators and results from the

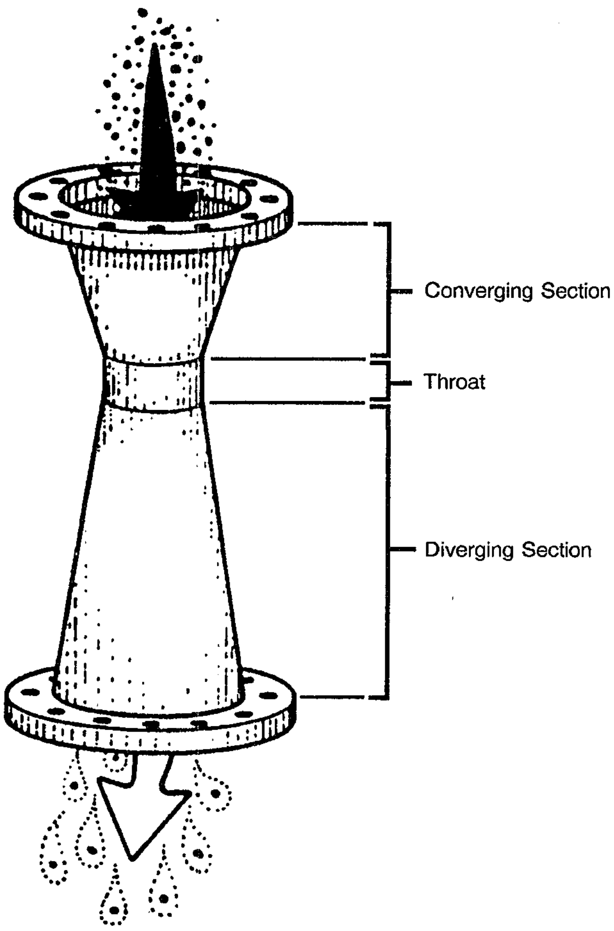

Figure 3-2. Spray venturi with circular throat.[6]

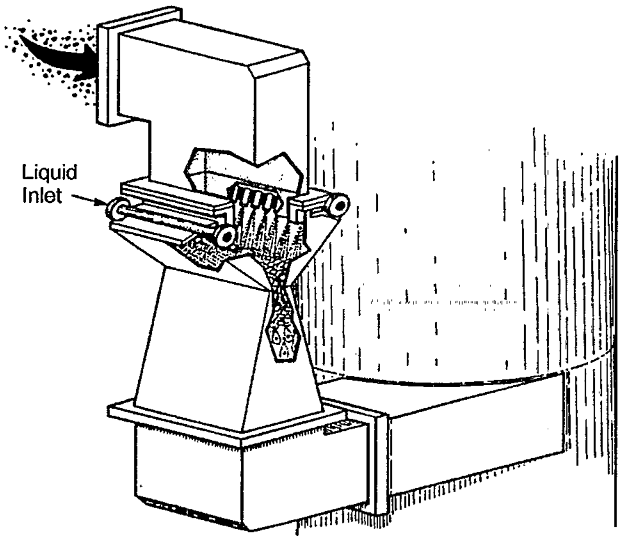

Figure 3-3. Spray venturi with rectangular throat.[7]

condensation of partially combusted organic compounds and metallic vapors.

The particulate matter collection efficiency in a venturi scrubber system increases as the static pressure drop increases. The static pressure drop is a measure of the total amount of energy used in the scrubber to accelerate the gas stream and to atomize the liquor droplets. The pressure drop across the venturi is a function of the gas velocity and liquid/gas ratio and in practice acts as a surrogate measure for gas velocity. The Calvert equation can be used to predict the pressure drop for a given throat velocity. The Calvert equation is:[8]

$$\Delta P = (5\times10^{-5})\, v^2\, (L/G) \qquad (3\text{-}1)$$

where

ΔP = pressure drop, in. w.c. (inches of water column)

v = the gas velocity in the venturi throat, ft/s (feet per second), and

L/G = the liquid-to-gas ratio, gal/Macf (gallons per thousand actual cubic feet).

The equation implies that pressure drop is equal to the power required to accelerate the liquid to the gas velocity. The Calvert equation predicts pressure drop reasonably well for the range of L/G ratios from 5 to 12 gal/Macf. At L/G ratios above 12, measured pressure drops are normally about 80 percent of the value predicted by the Calvert equation. In practice, an inadequate liquid supply to cover the venturi throat completely has resulted from L/G ratios less than 3 gal/Macf.

Other variables that are important to venturi scrubber performance are the liquid surface tension and liquid turbidity. If surface tension is too high, some small particles which impact on the water droplet will "bounce" off and not be captured. High surface tension also has an adverse effect on droplet formation. High liquid turbidity, or high suspended solids content, will cause erosion and abrasion of the venturi section and ultimately lead to reduced performance of the system.

A list of the major components of commercial scrubber systems follows:

1. Venturi section;
2. Spray nozzles;
3. Liquor treatment equipment;
4. Gas stream demister;
5. Liquor recirculation tanks, pumps, and piping;
6. Alkaline addition equipment;
7. Fans, dampers, and bypass stacks; and
8. Controllers for venturi throat area, caustic feed, makeup water, and emergency water quench for temperature excursions.

Packed-bed scrubbers. A packed-bed scrubber generally is used for acid gas removal. The large liquor-to-gas surface area created as the liquor gradually passes over the packing material favors gas diffusion and absorption. Packed-bed scrubbers are not effective as stand-alone scrubbers for collection of fine particulate matter (less than 2.5 µm) since the gas velocity through the bed(s) is relatively low. However, packed beds are effective for the removal of particle-laden droplets or charged particles when used as a downstream collector behind a venturi or electrostatically-enhanced wet scrubber.

Packed beds can be either vertical or horizontal. Figure 3-4 illustrates a vertically oriented scrubber. Regardless of the orientation of the bed, the liquor is sprayed from the top and flows downward across the bed. Proper liquor distribution is important for efficient removal of gases.

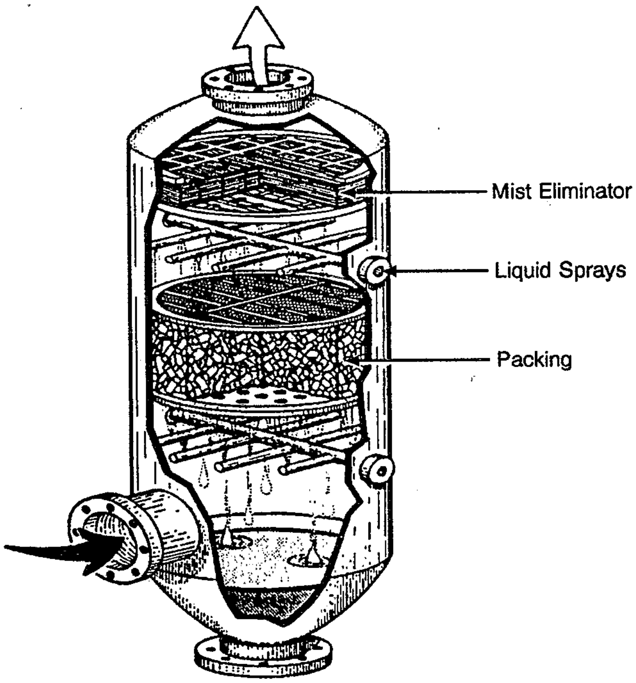

Figure 3-4. Countercurrent packed tower absorber.[9]

Absorption is the primary means of collection of acid gases in packed-bed scrubbers. The effectiveness of absorption in packed beds is related to the uniformity of the gas velocity distribution, the surface area of the packing material, the amount and uniform distribution of scrubber liquid, and the pH and turbidity of the scrubbing liquid.

Gas absorption is affected by the extensive liquid surface contacted by the gas stream as the liquid flows downward over the packing material. A variety of available packing materials offer a large exposed surface area to facilitate contact with and absorption of acid gases. The packing materials range in size from 0.5 to 3 in. and are randomly oriented in the bed.

Typically, sodium hydroxide (NaOH), or occasionally sodium carbonate (Na_2CO_3), is used with water to neutralize the absorbed acid gases in a packed-bed scrubber. These two soluble alkali materials are preferred because they minimize the possibility of scale formation in the nozzles, pump, and piping. For the typical case of using NaOH as the neutralizing agent, the HCl and SO_2 collected in the scrubber react with NaOH to produce sodium chloride (NaCl) and sodium sulfite (Na_2SO_3) in an aqueous solution.

One of the major problems with these scrubbers is the accumulation of solids at the entry to the bed and within the bed. The dissolved and suspended solids levels in the liquor must be monitored carefully to maintain performance.

Spray Towers.[2] Spray towers are relatively simple scrubbers. Most units consist of an empty cylindrical steel vessel containing nozzles that spray the liquid scrubbing media into the vessel. Most units use countercurrent flow with the exhaust gas stream entering the bottom of the vessel and moving upward, while the liquid is sprayed downward. Figure 3-5 shows a typical countercurrent flow spray tower. Countercurrent flow exposes the exhaust gas with the lowest pollutant concentration to the freshest scrubbing liquid.

Many nozzles are placed across the tower at different heights to spray all of the exhaust gas as it moves up through the tower. The major purpose of using many nozzles is to form a tremendous amount of fine droplets for impacting particles and to provide a large surface area for absorbing gas. Theoretically, the smaller the droplets formed, the higher the collection efficiency achieved for both gaseous and particulate pollutants. However, the liquid droplets must be large enough to **not** be carried out of the scrubber by the exhaust stream. Therefore, spray towers use nozzles to produce droplets that are usually 500 to 1000 µm in diameter. The exhaust gas velocity is kept low, from 0.3 to 1.2 m/s (1 to 4 ft/s) to prevent excess droplets from being carried out of the tower. Because of this low exhaust velocity, spray towers must be larger than other scrubbers that handle similar exhaust stream flow rates. Another problem occurring in spray towers is that after the droplets fall short distances, they tend to agglomerate or hit the walls of the tower. Consequently, the total liquid surface area for contact is reduced, thus reducing the collection efficiency of the scrubber.

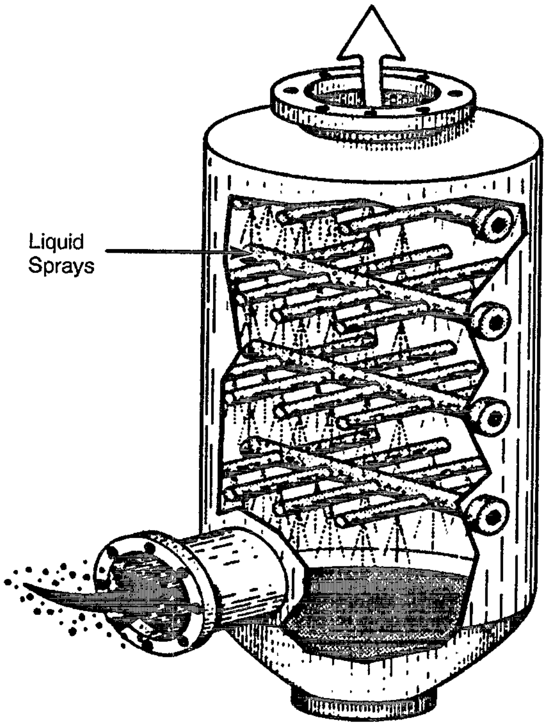

Figure 3-5. **Countercurrent-flow spray tower.**[10]

Spray towers are low-energy scrubbers. Contacting power is much lower than in venturi scrubbers, and the pressure drops across such systems are generally less than 2.5 cm (1 in.) of water. The collection efficiency for small particles is correspondingly lower than in more energy-intensive devices. They are adequate for the collection of coarse particles larger than 10 to 25 µm in diameter, although with increased liquid inlet nozzle pressures, particles with diameters of 2.0 µm can be collected. Smaller droplets can be formed by higher liquid pressures at the nozzle. The highest collection efficiencies are achieved when small droplets are produced and the difference between the velocity of the droplet and the velocity of the upward-moving particles is high. Small droplets, however, have small settling velocities, so there is an optimum range of droplet sizes for scrubbers that work by this mechanism.

Because of their inherent design, particulate matter emissions from controlled-air incinerators are usually composed of relatively fine particulate matter. Therefore, spray towers are not commonly applied to controlled-air units. Multiple-chamber incinerators, however, can emit large quantities of relatively large particle particulate matter and are often controlled by spray towers.

3.3.3.2 *Fabric Filters*

Fabric filters (i.e., baghouses) are used on a limited number of hospital incinerators for control of particulate matter emissions. They have some advantages over wet scrubbers in that they are highly efficient at removing fine particles if they are properly operated and maintained. However, poor operation and maintenance (O&M) can result in bag blinding, bag corrosion, or bag erosion.

Filtration principles.[11] Fabric filtration is one of the most common techniques used to collect particulate matter. A fabric filter is a collection of bags constructed of a fabric material (nylon, wool, or other) hung inside a housing. The combustion gases are drawn into the housing, pass through the bags, and are exhausted from the housing through a stack to the atmosphere. When the exhaust stream from the incinerator is drawn through the fabric, the particles are retained on the fabric material, while the cleaned gas passes through the material. The collected particles are then removed from the filter by a cleaning mechanism typically by using blasts of air. The removed particles are stored in a collection hopper until they are disposed.

With a new filter, the open areas in the fabric are of sufficient size that particles easily penetrate the bag. Over time, a cake builds on the bag surface, and this cake acts as the primary collection medium. Particles are collected on a filter and cake by a combination of several mechanisms. The most important are impaction and direct interception.

In collection by impaction, the particles in the gas stream have too much inertia to follow the gas streamlines around the fiber and are impacted on the fiber surface. In the case of direct interception, the particles have less inertia and barely follow the gas streamlines around the fiber. If the distance between the center of the particle and the outside of the fiber is less than the particle radius, the particle will graze or hit the fiber and be "intercepted". Impaction and direct interception mechanisms account for 99 percent collection of particles greater than 1 µm aerodynamic diameter in fabric filter systems.

Fabric filter performance. Generally, fabric filters are classified by the type of cleaning mechanism that is used to remove the dust from the bags. The three types of units are mechanical shakers, reverse air, and pulse jet. To date, the only hospital incinerators that have been identified as having fabric filters use pulse jet units. The paragraphs below briefly describe the design and operating characteristics of pulse jet filters and identify key design parameters.

A schematic of a pulse jet baghouse is shown in Figure 3-6. Bags are supported internally by rings or cages. Bags are held firmly in place at the top by clasps and have an enclosed bottom (usually a metal cap). Dust-laden gas is filtered through the bag, depositing dust on the outside surface of the bag. Pulse jet cleaning is used for cleaning bags in an exterior filtration system.

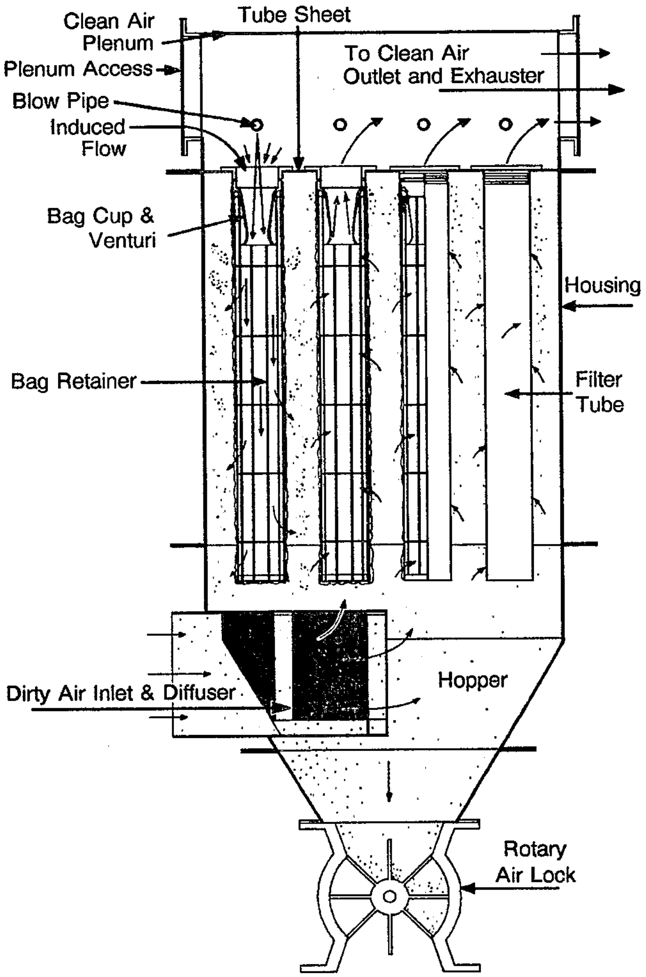

Figure 3-6. Pulse jet baghouse.[12]

The dust cake is removed from the bag by a blast of compressed air injected into the top of the bag tube. The blast of high pressure air stops the normal flow of air through the filter. The air blast develops into a standing or shock wave that causes the bag to flex or expand as the shock wave travels down the bag tube. As the bag flexes, the cake fractures and deposited particles are discharged from the bag. The shock wave travels down and back up the tube in approximately 0.5 seconds.[11]

The blast of compressed air must be strong enough for the shock wave to travel the length of the bag and shatter or crack the dust cake. Pulse jet units use air supplies from a common header which feeds into a nozzle located above each bag. In most baghouse designs, a venturi sealed at the top of each bag is used to create a large enough pulse to travel down and up the bag. The pressures involved are commonly between 414 and 689 kPa (60 and 100 psig). The importance of the venturi is being questioned by some pulse jet baghouse vendors. Some baghouses operate with only the compressed air manifold above each bag.[11]

Most pulse jet filters use bag tubes that are 10 to 15 cm (4 to 6 in.) in diameter. Typically the bags are 3.0 to 3.7 m (10 to 12 ft) long, but they can be as long as 7.6 m (25 ft).[11] Generally, these bags are arranged in rows, and the bags are cleaned one row at a time in sequence. Cleaning can be initiated by a pressure drop switch, or it may occur on a timed sequence.

The key design and operating parameters for a pulse jet filter are the air-to-cloth ratio (or the filtration velocity), the bag material, operating temperature, and operating pressure drop.

The air-to-cloth ratio is actually a measure of the superficial gas velocity through the filter medium. It is a ratio of the flow rate of gas through the fabric filter (at actual conditions) to the area of the bags and is usually measured in units of acfm/ft^2. No operating data were obtained for hospital incinerators, but generally, the air-to-cloth ratio on waste combustion units is in the range of 0.025 to 0.05 m^3/s/m^2 (5 to 10 acfm/ft^2) of bag area.[13]

Generally, bag material is specified based on prior experience of the vendor. Key factors that generally are considered are: cleaning method, abrasiveness of the particulate matter and abrasion resistance of the material, expected operating temperature, potential chemical degradation problems, and cost. To date, no information has been obtained on types of material typically used for hospital incinerator applications.

The operating temperature of the fabric filter is of critical importance. Since the exhaust gas from a hospital incinerator can contain HCl, the unit should be operated at sufficiently high temperatures to assure that no surfaces drop below the acid dewpoint. Otherwise, condensation of HCl will result in corrosion of the housing or bags. The boiling point of HCl (aqueous hydrochloric acid) is 110°C (230°F); gas temperatures should be maintained at 150°C (300°F) to ensure that no surfaces are cooled below the dewpoint. Above a maximum temperature that is dependent on filter type, bags will degrade or in some cases fail completely. Gas temperatures should be kept safely below the allowed maximum.

Pressure drop in fabric filters generally is maintained within a narrow range. Pressure drops below the minimum indicate that either (1) leaks have developed, or (2) excessive cleaning is removing the base cake from the bags. Either condition results in reduced performance. Pressure drops greater than the maximum indicate that either (a) bags are "blinding", or (b) excessive cake is building on the bags because of insufficient cleaning. The primary problem that results from excessive pressure drop is reduced flow through the system and positive pressure at the combustor. Over time, high pressure drops also lead to bag erosion and degradation.

3.3.3.3 *Dry Scrubbers*

Dry scrubbers use absorption for the removal of sulfur dioxide, hydrogen chloride, hydrogen fluoride, and other acid gases. Some adsorption of vapor state organic compounds and metallic compounds also occurs in some dry scrubber applications. Basically, dry scrubbers use an alkaline sorbent to react with and neutralize the acid gas. The reaction product is a dry solid which can be collected by a particulate control device. Dry scrubbers usually are followed by either fabric filters or electrostatic precipitators (ESP's) for collection of the reaction products and the unreacted sorbent. Currently, there are not any hospital incinerators known to be using spray dryer absorption systems. There are at least three hospital waste incinerators which are known to be using dry injection control systems.[a]

Components and operating principles of dry scrubber systems.[13,14] There is considerable diversity in the variety of processes which are collectively termed dry scrubbing. Dry scrubbing techniques that could be applied to hospital incinerators can be grouped into two major categories: (1) spray dryer absorbers, and (2) dry injection absorption systems. Specific types of dry scrubbing processes within each group are listed below. Alternative terms for these categories used in some publications are shown in parentheses.

1. Spray dryer absorption (semiwet)
   - Rotary atomizer spray dryer systems
   - Air atomizing nozzle spray dryer systems
2. Dry injection absorption (dry)
   - Dry injection without recycle
   - Dry injection with recycle (sometimes termed circulating fluid bed absorption)

Simplified block diagrams of the two major types of dry scrubbing systems are presented in Figures 3-7 and 3-8. The main differences between the two systems are the physical form of the alkaline reagent and the design of the vessel used for contacting the acid gas-laden stream. The alkaline feed

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[a] Southland Exchange Joint Ventures, Hampton, South Carolina (dry injection/ESP); Fairfax County Hospital, Falls Church, Virginia (dry injection/baghouse); Borgess Medical Center, Kalamazoo, Michigan (dry injection/baghouse).

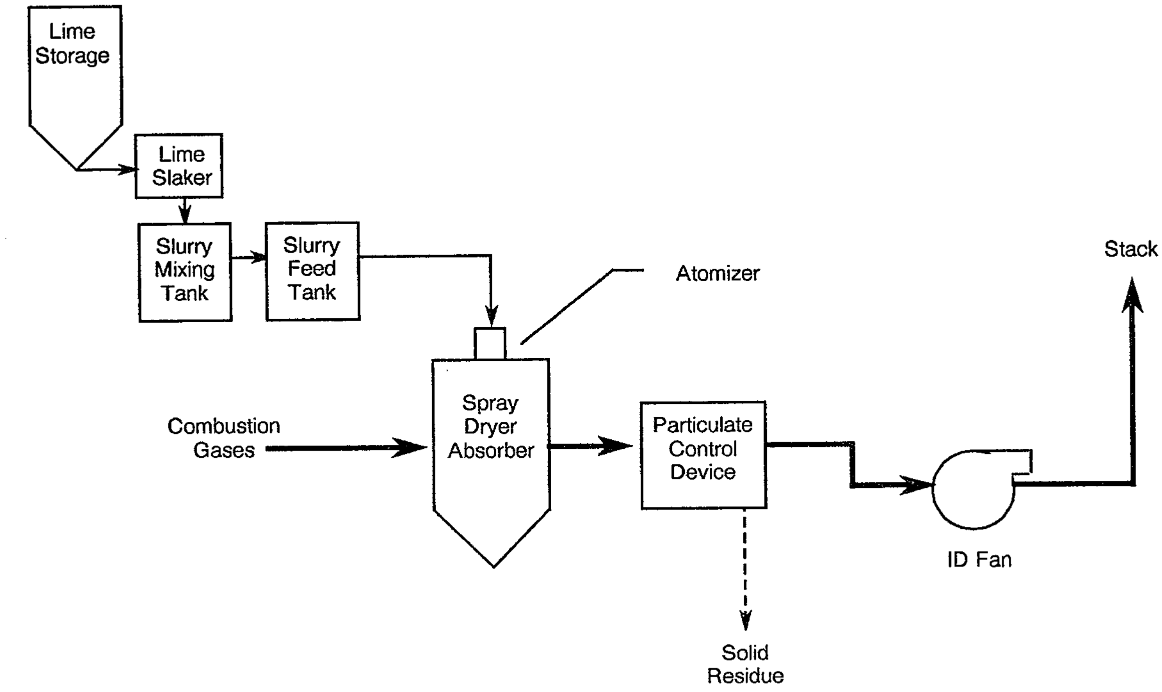

Figure 3-7. **Components of a spray dryer absorber system (semiwet process).**

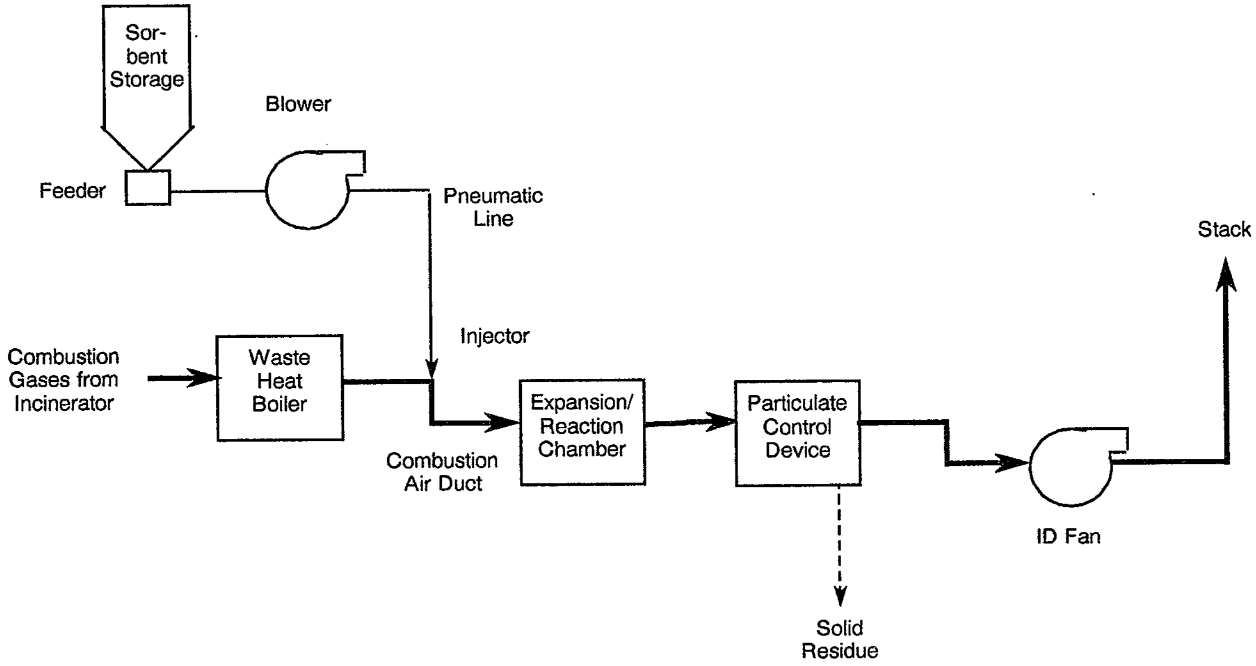

Figure 3-8. **Components of a dry injection absorption system (dry process).**

requirements are much higher for the dry injection system. Conversely, the spray dryer system is much more complicated.

Spray dryer absorbers. In this type of dry scrubbing system, the alkaline reagent, usually pebble lime, is prepared as a slurry containing 5 to 20 percent by weight solids. This reagent must be slaked in order to prepare the reactive slurry for absorption of acid gases. Slaking is the addition of water to convert calcium oxide to calcium hydroxide. Proper slaking conditions are important to ensure that the resulting calcium hydroxide slurry has the proper particle size distribution and that no coating of the particles has occurred due to the precipitation of contaminants in the slaking water. The prepared slurry is atomized in a large absorber vessel having a residence time of 6 to 20 seconds. Atomization of the slurry is achieved through the use of: (1) rotary atomizers or (2) air atomizing nozzles. Generally, only one rotary atomizer is included in a spray dryer absorber. However, a few applications have as many as three rotary atomizers.

In rotary atomizers, a thin film of slurry is fed to the top of the atomizer disk as it rotates at speeds of 10,000 to 17,000 revolutions per minute. These atomizers generate very small slurry droplets having diameters in the range of 100 microns. The spray pattern is inherently broad due to the geometry of the disk.

High pressure air is used to provide the physical energy required for droplet formation in nozzle type atomizers. The typical air pressures are 70 to 90 pounds per square inch, gage (psig). Slurry droplets in the range of 70 to 200 microns are generated. This type of atomizer generally can operate over wider variations of the gas flow rate than can be used in a rotary atomizer. However, the nozzle atomizer does not have the slurry feed turndown capability of the rotary atomizer. For these reasons, different approaches must be taken when operating at varying system loads.

The shape of the scrubber vessel must be designed to take into account the differences in the slurry spray pattern and the time required for droplet evaporation for the two types of slurry atomizers. The length-to-diameter ratio for rotary atomizers is much smaller than that for absorber vessels using air atomizing nozzles.

All of the slurry droplets must evaporate to dryness prior to approaching the absorber vessel side walls and prior to exiting the absorber with the gas stream. Accumulations of material on the side walls or at the bottom of the absorber would necessitate an outage since these deposits would further impede drying. Proper drying of the slurry requires generation of small slurry droplets and adequate mixing with the hot flue gases.

Drying that is too rapid can reduce pollutant collection efficiency since the primary removal mechanism is absorption into the droplets. There must be sufficient contact time for the absorption. For this reason, spray dryer absorbers are operated with exit gas temperatures 90° to 180°F above the saturation temperature.

Dry injection absorption systems. This type of dry scrubber uses injection of a finely divided alkaline sorbent such as calcium hydroxide (hydrated lime) or sodium bicarbonate for the absorption of acid gases. The reagent feed has particle sizes which are 90 percent by weight through 325 mesh screens. This size is approximately the consistency of talcum powder. This size is important to ensure an adequate alkaline sorbent surface area for high efficiency pollutant removal.

Proper particle sizes are maintained by transporting the sorbent to the dry scrubber system by means of a positive pressure pneumatic conveyor. This provides the initial fluidization necessary to break up any clumps of reagent which have formed during storage. The air flow rate in the pneumatic conveyor is kept at a constant level regardless of system load to ensure proper particle sizes.

Fluidization is completed when the alkaline sorbent is injected countercurrently into the gas stream. The alkaline sorbent may be injected directly into a reaction vessel or may be injected directly into the ducting with a reaction vessel (expansion chamber) located downstream to increase residence time. The gas stream containing the entrained sorbent particles and fly ash is then ducted to a fabric filter or ESP. When a fabric filter is used for particulate control, acid gas removal may be further enhanced by the reaction with the sorbent in the filter cake.

In one version of the dry injection system, solids are recycled from the particulate matter control device back into the flue gas contactor. The primary purpose of the recycle stream is to increase reagent utilization and thereby reduce overall calcium hydroxide costs.

3.4 References for Chapter 3

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Chapter 4
Operation

The success of incineration as a technique for treating hospital waste depends on the proper operation of the incinerator and its air pollution control devices. Proper operating techniques can affect equipment reliability, on-line availability, combustion efficiency, and compliance with air pollution regulations. The operator is in control of many of the factors that affect the performance of a hospital incinerator including: (1) waste charging procedures, (2) incinerator startup and shutdown, (3) air pollution control device startup and shutdown, (4) monitoring and adjusting operating parameters for the incinerator and air pollution control system, and (5) ash handling. This section identifies key operating parameters, identifies operating ranges for key parameters, and discusses general operating procedures that can minimize unexpected malfunctions and improve the performance of the incinerator and air pollution control devices. Appropriate monitoring procedures also are discussed in this section.

4.1 General Objectives

The primary objectives associated with the proper operation of a hospital waste incineration system are to operate the system in a manner so that infectious materials in the waste are rendered harmless, waste volume is reduced, good ash quality (from an aesthetic standpoint) is ensured, and air pollution emissions of particulate matter, organic compounds, carbon monoxide, and acid gas are minimized. The operator is responsible for knowing key operating parameters and the proper operating ranges for these parameters to assure that the system is operated at its design efficiency. The operator also should know the operating procedures and monitoring techniques which will assist in maintaining those parameters within the acceptable operating range.

Because each incinerator model is designed differently, design criteria, operating parameters, and operating procedures will vary. Nonetheless, recommended operating ranges can be established for some general key parameters to assist in meeting the objectives of the incineration process – destruction of pathogens and reduction of waste volume – while minimizing air pollution and maintaining good ash quality. To identify these key parameters and discuss proper operating procedures, incineration systems have been categorized as follows:

1. Batch/controlled-air incinerators;
2. Intermittent-duty, controlled-air incinerators;
3. Continuous-duty, controlled-air incinerators;
4. Multiple-chamber incinerators; and
5. Rotary kilns.

The operation of air pollution control systems is addressed later in this chapter.

Currently, most hospital waste incineration systems do not include an air pollution control device mainly because with proper combustion control through proper operation, the systems can meet current emission regulations. However, a growing number of States have promulgated or will soon promulgate more stringent regulations governing hospital waste incinerators that will increase the numbers of incinerators requiring add-on air pollution control devices to meet the regulations. When an air pollution control system is included as part of the incineration system, the operation of the incinerator and the control device are interrelated. Therefore, the optimum approach to describing the proper operation of incineration systems (including air pollution control devices) would be to discuss the operation of each of the possible combinations of incinerators and control devices. However, because of the large number of combinations of equipment types that may constitute an incineration system, the proper operation of incinerators and air pollution devices will be discussed separately.

This document provides a discussion of operating ranges for the key operating parameters and presents an overview of proper operating procedures and monitoring techniques. This information will provide the reader with a basic understanding of what constitutes good operating practice. However, it does not substitute for manufacturers' operating procedures. Specific steps and operating procedures for equipment will be specified by each manufacturer; furthermore, the control and monitoring systems used by each manufacturer may be different. Consequently, a specific manufacturer's recommended and detailed operating procedures should be followed.

4.2 Incinerator Key Operating Parameters

4.2.1 Introduction

The interrelationship among an incinerator's thermal capacity, waste feed characteristics, heat input rate from the waste feed, and combustion air was discussed in Chapter 2. This section identifies the operating parameters and presents recommended operating ranges for these parameters. The majority of the key parameters and the recommended operating ranges remain the same for the different incinerator systems, but because they do differ somewhat for different types of incinerators, the parameters are presented for each type system that was described in Chapter 2. Controlled-air incinerators, multiple-chamber incinerators, and rotary kilns are discussed in order.

4.2.2 Controlled-Air Incinerators

Table 4-1 summarizes the key incinerator operating parameters and the operating range for each parameter. These parameters assume the waste is primarily a heterogeneous mixture of hospital infectious waste with a Btu content that will sustain combustion (i.e., greater than 6,000 Btu/lb). For "pathological" incinerators, burning pathological wastes, the recommended operating ranges are slightly different because waste characteristics differ significantly. An explanation of why each key operating parameter in Table 4-1 is important and a discussion of each operating range is presented below.

4.2.2.1 Primary and Secondary Combustion Chamber Temperatures.

Maintaining the desired operating temperatures within each combustion chamber is critical to proper operation of a controlled-air incinerator. Both upper and lower limits on the temperature range for each chamber are of interest. The desired range of operation is different for the ignition (primary) and combustion (secondary) chambers because the functions of these chambers differ.

The literature indicates that typical operating ranges for the ignition chamber of controlled-air incinerators range from 400° to 980°C (750° to 1800°F).[1,2] The ignition chamber must be maintained at a minimum temperature sufficient to sustain combustion, combust the fixed carbon in the ash bed, and kill any microorganisms in the waste bed so that the remaining ash is sterile. The temperature also must be maintained below a level that will damage the refractory and result in slagging of the waste.

Few studies have been conducted to determine the conditions necessary to achieve complete pathogen kill in incinerators. Barbeito et al., conducted a study on a multiple-chamber, industrial-refuse incinerator to determine the minimum operating temperatures required to prevent release of viable microorganisms into the atmosphere. His research indicated that the destruction of the microorganisms within the incinerator depends on the temperature and time of exposure. These parameters are affected by many factors, including charging beyond incinerator capacity and exceeding design linear velocities, which reduces retention time. Barbeito recommended a minimum primary chamber temperature of 760°C (1400°F).[1,3]

From an operational (operating efficiency) standpoint, it is desirable to operate the primary or ignition chamber at a temperature high enough to sustain combustion in the chamber and to generate sufficient volatile combustion gases and heat to maintain the desired secondary combustion temperature without the use of auxiliary fuel. Consequently, the desired primary chamber temperature will depend somewhat on the waste composition. Furthermore, a sufficiently high temperature to effectively combust the fixed carbon in the waste bed is desired. One manufacturer's experience indicates that this temperature is in the 760° to 870°C (1400° to 1600°F) range for continuous-duty incinerators.[2] This temperature may be as low as 540°C (1000°F) for batch feed and intermittent-duty units because the burnout time can be extended in these units.[2] Operating batch feed incinerators at a low primary chamber temperature (relative to continuous-duty incinerators) helps assure that volatiles are not generated at a rate which cannot be handled by the secondary chamber.

When the waste stream contains a significant amount of plastics, "cracking" of light hydrocarbons can be significant and can affect the combustion gas volume in the secondary chamber. Operating the primary chamber at lower temperatures (540° to 650°C [1000° to 1200°F]) may help to minimize rapid increases in flue gas volume.[4] Some incinerator manufacturers use water quenching in the primary chamber to maintain gas temperatures below the 930° to 980°C (1700° to 1800°F) range and minimize cracking.[5]

At the same time, the primary chamber temperature must be maintained below the point that will result in refractory damage. Modern incinerators commonly use nominal 1540° to 1650°C (2800° to 3000°F) quality refractory. Although this refractory is rated at 1540° to 1650°C (2800° to 3000°F), reactions can occur with contaminants in the combustion gas, making it desirable to expose this refractory to no higher than 1200°C (2200°F) on a continual basis.[2] Another, perhaps more important, limiting factor for

Table 4-1. **Key Incinerator Operating Parameters and Recommended Operating Range: Controlled-Air Incinerator**

Parameter	Incinerator type Batch feed	 Intermittent feed	 Continuous duty
Ignition chamber temperature, °F	1000° to 1800°	1000° to 1800°	1400° to 1800°
Combustion (secondary) chamber temperature, °F	1800° to 2200°	1800° to 2200°	1800° to 2200°
Charging rate, lb/hr	Fill chamber once at beginning of cycle	10 to 25 percent of rated capacity at 5 to 15 min intervals	10 to 25 percent of rated capacity at 5 to 15 min intervals
Ignition chamber combustion air (percent of stoichiometric)	30 to 80	30 to 80	30 to 80
Total combustion air (percent excess air)	140 to 200	140 to 200	140 to 200
Combustion gas oxygen concentration, percent	12 to 14	12 to 14	12 to 14
Ignition chamber draft, in w.c.	-0.05 to -0.1	-0.05 to -0.1	-0.05 to -0.1
Burndown period, h	2 to 5	2 to 5	Not applicable

the upper operating temperature of the primary chamber is slagging of the waste. Most ash residues begin to become soft at temperatures in the range of 1200° to 1370°C (2200° to 2500°F).[2] While thermocouples in the primary chamber indicate the temperature of the combustion gas exiting the primary chamber, the temperature in the ash bed at the hearth adjacent to the underfire air ports can be consistently higher. Consequently, although the combustion gas temperature can indicate that clinker (fused slag) formation should not be a problem, the ash bed can be hot enough to form clinkers. Experience has shown that a control temperature of 980°C (1800°F) can be used in most cases with acceptable performance with regard to clinker formation and carbon burnout, but the performance problems due to slagging may begin to occur at primary chamber temperatures as low as 760°C (1400°F).[2,6]

The secondary chamber serves to complete the combustion process initiated in the primary chamber. As with the primary chamber, it is desirable to operate within a lower and upper range. At temperatures that are too low, complete combustion may not occur. At temperatures that are too high, refractory damage may occur, residence time may be decreased, and auxiliary fuel may be unnecessarily wasted.

A minimum temperature is needed to prevent the discharge of potentially toxic products of incomplete combustion. Experimental work conducted at the University of Dayton Research Institute (UDRI) indicates that temperature is the primary factor that affects these emissions.[7] The experimental data for thermal decomposition indicate that the destruction of a species depends predominantly on the temperature, and effectively a threshold temperature exists above which the compound will rapidly combust. The threshold temperature found for polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzofurans (PCDF) and potential precursors (e.g., hexachlorobenzene) is near 930°C (1700°F).[7]

Sufficient temperature in the secondary chamber is necessary to kill microorganisms entrained in the gas stream from the primary chamber. Again, little information on the required temperature is available, and data from studies conducted on specific incinerators are specific to those incinerators and the experimental operating conditions, e.g., residence time and turbulence. Based upon his incineration study, Barbeito recommended a minimum secondary combustion chamber temperature of 980°C (1800°F).[1] The limiting factor for the secondary combustion chamber temperature upper operating range is refractory damage. The upper limit will depend on the refractory used, but a typical limit is 1200°C (2200°F) on a continual basis.[2]

In summary, temperatures in both chambers should be maintained at high enough levels to ensure complete combustion of the waste but not so high that refractory damage or slagging of the ash occurs. A minimum temperature for the primary chamber in the range of 540° to 760°C (1000° to 1400°F) should be maintained to ensure pathogen kill, sterile ash, and good ash quality. The minimum temperature required for proper operation will depend on waste characteristics as well as the retention time of the ash in the primary chamber and consequently the incinerator design. To prevent clinker formation, the recommended upper bound primary chamber temperature is 980°C (1800°F). To assure complete combustion, yet conserve auxiliary fuel and prevent refractory damage, an operating range of 980° to 1200°C (1800° to 2200°F) is recommended for the secondary combustion chamber.

4.2.2.2 Charging Rate

An incinerator system is designed for a particular thermal input rate. The thermal input comes from the waste and, as necessary, the auxiliary fuel. Under ideal conditions, the incinerator operates under conditions of a constant thermal input. For controlled-air incinerators, the thermal release from the "fuel" (the waste in the chamber) is controlled, to the extent possible, by controlling the available combustion air (the typical ranges for combustion air will be discussed in the next section). Additional control of the thermal input is obtained by controlling the quantity and frequency of waste charges to the incinerator. The charging process, thermal input, and combustion approaches a steady state condition as the waste homogeneity increases, the charge loads decrease in size, and the frequency of charges increase. Therefore, a charging scenario of more frequent charges of smaller volume is more desirable than one of a single large charge.[8]

4.2.2.2.1 Batch feed incinerators. By nature of their design, batch feed incinerators are intended to accept a single load of waste at the beginning of their incineration cycle; the heat release rate is controlled solely by controlling the size of the initial charge and the available air for combustion. The primary chamber acts as a fuel storage area. Manufacturers of batch operated incinerators recommend that the primary chamber be filled to capacity, but not overfilled or stuffed so full that the flame port to the secondary chamber or the ignition burner port assembly are blocked.[9] If wastes containing an unusually high volatile content are charged to the unit, a full load may contain enough volatiles that, even if the primary air is controlled, the capacity of the secondary combustion chamber will be exceeded. Therefore, it may be necessary to decrease the size of the charge to the incinerator. That is, volume of waste is an imperfect method for determining the thermal input to the incinerator. The incinerator chamber size is designed for a particular volume of waste with a particular Btu content. If the waste being charged is significantly higher in Btu content, even though the volume capacity of the chamber is not exceeded, the thermal capacity of the incinerator may be exceeded. Consequently, it will be necessary to decrease the thermal input of the batch charge by decreasing the volume input.

Regardless of the type, incinerators should never be overcharged above the manufacturer's specifications. In the case of batch feed incinerators where all charging occurs at the beginning of the incineration cycle, there may be a tendency to stuff that last bag of waste into the incinerator so that no waste is left over for the next burn. This practice can lead to excessive emissions, incomplete combustion, and damage to the incinerator. Overcharging with waste adds more fuel to the incinerator than it can handle, may block the incinerator air ports, and damage the primary burner. Excessive fuel combined with an inadequate air supply causes excessive amounts of volatile material to be passed to the secondary chamber which cannot be handled effectively in the secondary chamber and results in high particulate matter emissions. Additionally if a large quantity of plastic material is charged, the excessive temperatures produced can cause refractory damage and clinker formation. Higher primary chamber temperatures also cause higher gas volumes and velocities which effectively reduces the secondary chamber retention time.

4.2.2.2.2 Intermittent-feed and continuous-duty incinerators. Intermittent- and continuous-duty, controlled-air incinerators are designed to accommodate semicontinuous charging. The primary design change for this type unit is that the charging system is set up with some type of a mechanical device (either manually or automatically operated) which allows the operator to safely add charges while the system is operating. The mechanical device is designed to protect the operator from exposure to the flame and heat of the primary combustion chamber. Additionally, the mechanical charging device may be designed to limit air in-leakage to the incinerator during charging to maintain control of the combustion air level. The primary difference between the "intermittent" and "continuous" duty units is not in the charging rate or operation, *per se*, but that the continuous-duty system has a means for continuously removing the ash generated by the waste. Consequently, this type unit can maintain continuous "steady state" operation. The intermittent unit can maintain continuous "steady-state" operation only for a limited time; once the ash in the incinerator builds up to an unacceptable level, the unit must be shutdown and the ash removed.

To approach a steady thermal input, manufacturers recommend that multiple charges be made at equally timed intervals. The recommended charge size is 10 to 25 percent of the rated capacity charged at 5 to 15 minute intervals.[10,11] The charging frequency may need to be adjusted based upon variations in moisture content, volatile content, and overall Btu value. The procedures that the operator can use to monitor the charging rate and to make appropriate decisions is discussed in Section 4.4.

4.2.2.3 Primary and Secondary Combustion Air Rate and Combustion Gas Oxygen Concentration

For controlled-air units, the volatilization/combustion rate in the primary chamber is controlled by using combustion airflow rate to control the chamber temperature. The typical combustion air operating range for the ignition chamber is 30 to 80 percent of stoichiometric conditions.[1,2] Typically, about 20 percent of the total air requirement to the incinerator is supplied as underfire air to the ignition chamber.[2] The remainder of the air is supplied to the secondary mixing chamber.

Approximately 80 percent of the total combustion air required during incineration is supplied to the secondary combustion chamber. Typically, the total combustion air level is 140 to 200 percent excess air.[12,13] Measurement of the oxygen concentration provides a convenient way of determining and monitoring the excess-air level. Operating the incinerator at a total excess-air level in the range of 140 to 200 percent will result in stack gas oxygen concentrations in the range of 12 to 14 percent.

4.2.2.4 *Combustion Chamber Pressure (Draft)*

A typical draft for controlled-air incinerators is in the range of -0.05 to -0.1 in. water column (w.c.). Excessive draft is not desirable because increased carryover of particulate matter to the secondary chamber can occur.

4.2.2.5 *Burndown Period*

After volatilization diminishes, sufficient time must be provided for the fixed carbon in the waste bed to combust.

For continuous-duty incinerators, there is no distinct burndown period since the burndown occurs continuously as the waste moves through the system during the "steady state" operation. However, on some continuous-duty incinerators with internal transfer rams, once the last load of waste is charged, each ram may go into a burndown mode sequentially where the rams' strokes are increased to push the waste from one hearth to the next. For example, the ram on the first or drying hearth will stroke at the same time intervals but will stroke several inches more on each stroke. During this period, the ash underfire air to this part of the hearth is shut off. On the last stroke, the ram is at the edge of the hearth, and all of the waste falls to the next hearth which then goes into its burndown mode, and so on. This burndown sequence is usually preset at the factory but can be changed by the manufacturer if ash quality is poor. On these units, the burndown sequence is normally in the range of 4 to 6 hours.[14]

For batch and intermittent-duty operations, there is a distinct burndown period associated with the operating cycle. During this period, the volatiles have been combusted, and the fuel remaining in the waste bed is slowly diminishing. In order to combust the fixed carbon remaining in the waste, a higher temperature is required and, therefore, more underfire air is introduced into the primary chamber.[10] As the burndown proceeds and the fuel is further diminished, the temperature slowly decreases. During burndown, a minimum temperature level (e.g., 1400°F) is maintained for a predetermined time period; auxiliary fuel may be required to maintain this temperature. It is difficult to recommend a required burndown period because it is somewhat experimental and will vary depending upon the waste composition and combustion air rate. According to one manufacturer, a rule of thumb for a trial burndown setting for an intermittent-duty, small capacity incinerator is 1 hour plus an additional 20 minutes for each hour of operation.[10] Therefore, a trial burndown setting for a unit that operated 6 hours would be (1 hour) + (6 x 20 minutes) = 3 hours. A typical burndown period for batch and intermittent units is in the range of 2 to 4 hours.[11,14]

4.2.3 Multiple-Chamber Incinerators

Traditionally, multiple-chamber units were designed specifically to burn pathological waste and contained a fixed (solid) hearth. Other multiple-chamber incinerators use a grate type of hearth. Combustion of medical waste containing significant quantities of fluids and/or infectious material is not recommended in multiple-chamber units with grates. Both type units employ large quantities of excess air for combustion and will operate at similar temperature ranges. The operating parameters and ranges for a multiple-chamber incinerator are summarized in Table 4-2 and are briefly discussed below.

4.2.3.1 *Primary and Secondary Chamber Temperatures*

As discussed for controlled-air incinerators, the temperature in the primary chamber must be maintained at such a level as to assure pathogen kill. Most multiple-chamber incinerators operate on a batch or intermittent-duty basis. An extended burndown period is available to assure adequate ash burnout and sterilization of the waste. A minimum primary chamber temperature in the range of 540° to 760°C (1000° to 1400°F) is recommended. The upper operating range for the primary chamber should be established to prevent refractory damage. As previously mentioned for controlled-air units, sustained operation above 2200°F is generally not desirable.

Pathological wastes have a high moisture content and low volatile and fixed carbon content. For pathological wastes, continuous operation of an auxiliary burner is required to maintain the primary chamber temperature. To facilitate burndown of the pathological wastes, a minimum primary combustion chamber temperature of 1600°F is recommended.[15]

A minimum secondary chamber temperature of 1600°F for pathological incinerators is recommended in the Air Pollution Engineering Manual to assure complete combustion.[15] As discussed in Section 4.2.2.1 for controlled-air incinerators, a minimum temperature to prevent the discharge of potentially toxic products of incomplete combustion is required; a minimum secondary combustion

Table 4-2. Key Incinerator Operating Parameters and Recommended Operating Range: Multiple-Chamber Incinerator

Parameter	Pathological waste	General refuse
Ignition chamber temperature, °F	1600 to 1800	1000 to 1400
Combustion (secondary) chamber temperature, °F	1800 to 2200	1800 to 2200
Charging rate	Single layer on hearth	10 to 25% of rated capacity at 5- to 15-min intervals
Ignition chamber combustion air (percent excess air)	80	150
Total combustion air (percent excess air)	120 to 200	250 to 300
Combustion gas oxygen concentration, percent	10 to 14	15 to 16
Ignition chamber draft, in. w.c.	-0.05 to -0.1	-0.05 to -0.1

chamber temperature of 980°C (1800°F) is recommended for multiple-chamber incinerators.

4.2.3.2 Charging Rate

Whether a multiple-chamber unit is incinerating red bag waste or pathological waste affects the charging rate and procedures because the volatile content, moisture content, and Btu value of these wastes are so different. An incinerator system is designed and sized for a particular thermal input rate. The thermal input comes from the waste and, as necessary, the auxiliary fuel. Unlike a controlled-air unit, the combustion rate in a multiple-chamber unit cannot be controlled by controlling the combustion air to the primary chamber. Accordingly, the controlling factor for the combustion rate is essentially the availability of fuel; i.e., the amount of waste charged when general refuse/red bag waste is being incinerated. The thermal input to the incinerator and the combustion approaches a steady-state condition as the waste homogeneity increases, the charge loads decrease in size, and the frequency of charges increase. Therefore, charging procedures using more frequent charges of smaller volume are more desirable than one single large charge. A charge rate of 10 to 15 percent of the rated capacity at regular intervals is recommended. Note that if a mechanical feeder is not used, the more frequently the charging door is opened, the greater the risk to the operator. Consequently, safety considerations make less frequent charging desirable, which contradicts the more frequent charging procedures desired from a thermal input standpoint. Thus, the objective should be to assure that the individual charges to the incinerator are not so large and infrequent that the capacity of the incinerator is exceeded by rapid volatilization of combustibles resulting in excess emissions. Therefore, charging frequency and load size will depend on waste characteristics and incinerator design.

Pathological wastes have a low Btu content and a low volatiles content. Consequently, rapid volatilization and rapid changes in heat release to the primary chamber are not a concern when charging pathological wastes. The primary chamber burner(s) provides a steady heat input to the incinerator. Because of the high moisture and low volatile carbon content of pathological waste, the burner flame must impinge on or near the waste for efficient combustion to occur. Accordingly, fresh pathological waste should not be charged into the incinerator until the previous waste charge has burned down almost completely. Completeness of burndown can be determined by inspection through a view port and examining the waste bed.

4.2.3.3 Primary and Secondary Chamber Combustion Air Levels

For multiple-chamber incinerators the primary chamber excess-air level is typically 150 percent or greater. Overall excess-air levels for multiple-chamber incinerators are typically 250 to 300 percent.[15] This roughly corresponds to a combustion gas oxygen concentration of 15 to 16 percent. When incinerating pathological wastes, since the primary heat release is coming from the auxiliary burner, the combustion air can be controlled at a lower level than for a typical multiple-chamber incinerator.

4.2.3.4 Chamber Pressures

A negative draft is maintained in the combustion chambers. A typical range for the ignition chamber draft is -0.05 to -0.1 in. w.c.[15]

4.2.4 Rotary Kiln Incinerators

Currently, there are relatively few rotary kiln incinerator installations at hospitals for incinerating hospital medical waste. Consequently, little information is available on the application of rotary kilns to this waste type. However, rotary kilns are a proven technology and have been used for a wide variety of industrial applications including hazardous waste incineration. The operating parameters identified below are based mainly on the application of rotary kilns to the incineration of hazardous waste because of the availability of information in this area.

4.2.4.1 *Ignition and Combustion Chamber Temperatures*

As discussed in Chapter 2, a rotary kiln incineration system consists of an inclined rotary kiln which serves to volatilize the waste and a secondary combustion chamber which completes the combustion process by burning the volatiles in the kiln off-gas. Temperatures in rotary kiln incinerators usually range from about 760° to 1670°C (1400° to 3000°F) depending on the types of waste being burned and on the location in the kiln.

In evaluating the application of rotary kiln incineration to hospital medical waste, it is likely that the kiln (primary chamber) and secondary chamber operating temperatures will be similar to those identified for other hospital medical waste incineration systems, i.e., a primary chamber temperature of 760°C (1400°F) and a secondary chamber temperature of 980°C(1800°F).

4.2.4.2 *Charging Rate*

Rotary kiln incinerators may be batch or continuously fed and have a feed capacity that ranges from 600 to 2,000 kg/h (1,300 to 4,400 lb/h).

The waste throughput of a rotary kiln is determined both by the speed of rotation and by the incline angle (rake). Typically, rotary kilns rotate at a speed that ranges from 0.25 to 1.5 revolutions per minute and are oriented at a rake of less than 3 percent (i.e., around 11° from horizontal). Both of these parameters may be adjusted depending on the throughput desired. However, once the rake is set, it is usually not altered. Assuming that all other operating parameters are in the normal operating ranges, incompletely burned material in the ash is an indication that waste is traveling through the kiln too quickly. The waste throughput may be reduced by reducing the speed of rotation of the kiln which in turn must include a corresponding decrease in the charging rate. Some experimentation with charge rates and speed of rotation may be required to obtain optimum ash quality and throughput.

4.2.4.3 *Ignition and Combustion Chamber Air Levels*

Based on information available on hazardous waste rotary kiln incinerators, the rotary kiln excess-air level ranges from 140 to 210 percent or greater, depending on the desired operating temperature and the heating value of the waste. When high aqueous wastes are being burned, lower excess-air rates may be needed to maintain adequate temperature. Secondary chamber excess-air levels are approximately 80 percent of the rotary kiln excess-air levels. For example, in a typical system operating at 820°C (1500°F) in the kiln and 980°C (1800°F) in the secondary chamber, approximately 160 to 170 percent excess air would be maintained in the secondary chamber compared to about 210 percent in the kiln. Manufacturers are now designing rotary kilns utilizing special kiln seals and air injection that operate with substoichiometric air levels in the kiln. Operating the kiln at substoichiometric air levels decreases the kiln size and reduces auxiliary fuel usage.[4]

4.3 *Waste Feed Handling*

The physical and chemical properties of wastes and the effects of these properties on the incineration process were presented in Chapter 2. Furthermore, typical characteristics of hospital infectious wastes were presented and discussed. In most cases, the operator of an incinerator does not have control over the quantity or types of wastes which are transported to the incinerator for disposal. However, the operator does have control over two of the most important parameters – how the waste is charged and at what rate. Waste charging procedures are specific to the type incinerator and the incinerator's mode of operation; proper charging procedures will be discussed in Section 4.4. In this section, some general concepts with regard to types of waste and handling of the wastes are discussed. Although the operator does not have control (or has very little control) over the waste which is to be incinerated, the operator must understand how waste composition affects operation of the incinerator and must learn to recognize problems related to waste composition or to identify significant changes in waste composition. The operator then can modify charging procedures, modify incinerator combustion parameters (if properly trained to make such adjustments), and/or notify the appropriate hospital administrators of continued waste related problems which are severely affecting incinerator operation. The remainder of this section addresses the following concerns:

1. Safe waste handling procedures; and
2. Wastes that should not be incinerated.

4.3.1 Proper Waste Handling

Infectious waste will be delivered to the incinerator area in "red bags." The primary concern is to avoid exposure to pathogens; consequently red bag wastes should be handled in a manner which maintains the integrity of the container. Proper procedures dictate that:

1. Sturdy containers are used;
2. Waste handling is minimized;
3. The waste storage area is secure if wastes are to be stored; and
4. Mechanical handling/loading systems are properly operated and maintained.

Plastic bags are the typical containers used for infectious waste. Tear-resistant bags that will maintain their integrity during the handling/transporting process should be used. The two main criteria used to evaluate bag durability are bag thickness and the ASTM dart test.[3,16]

Some State regulations specify minimum bag requirements based on one of these two criteria.[3] For example, Massachusetts specifies a minimum bag thickness while California requires use of the ASTM dart test.[3] Even if appropriate bag materials are used, overloading of bags, placement of sharp objects within the bags, or mishandling can result in tearing. "Sharps" (e.g., needles, broken glass) should be placed in special rigid sealed containers; these containers can then be placed in the red bag. The options that can be used if bag tearing is a problem include double bagging and the use of rigid containers to contain the bags. Rigid containers such as reusable metal/plastic drums or disposable cardboard drums or boxes can be used to contain the individual plastic bags. If reusable containers are used, the plastic bag would be placed as a liner in the container (much like one might do at home for household garbage). When filled, the bag is sealed, and a lid is placed on the container. The container is then transported to the incineration area. Reusable containers have some disadvantages in that they require additional handling and will need to be disinfected after each use.[1] Because the waste is to be incinerated, disposable cardboard cartons that can be loaded directly into the incinerator and disposed with the waste is a reasonable alternative. Use of disposable containers with mechanical charging systems also minimizes the potential for spillage in and contamination of the charging equipment during operation of the incinerator.

Another approach to enhancing integrity of the red bags is to use rigid carts, usually made of rigid plastic or of metal, to collect and transport the red bags. These rigid carts protect the waste bags from bumping, tears, etc.; the integrity of the bags is more easily maintained. Also, should a bag tear or break, the waste is contained, even if liquids are involved. Finally, handling of the waste can be minimized by the use of rigid carts. Once the red bags are placed in the cart, they need not be handled again until they are loaded directly into the incinerator or into the mechanical charging system for the incinerator. Since waste handling is minimized, the approach of keeping the wastes in the transport cart up until the time it is charged to the incinerator is preferred over the approach of unloading the waste to a storage area or charging pile on the floor. When rigid transport carts are used for large automated incineration systems, the waste may never need to be handled manually after collection. Charging systems are available which will automatically lift and dump the contents of the collection transport carts into the charging hopper without handling of the waste by the operator.[8,17] Consequently, use of rigid type transport carts can be effective in minimizing waste handling.

To assure the integrity of the red bags, mechanical means of transporting the waste should not be used, except for final charging into the incinerator. For example, dumb-waiters, chutes or conveyors should not be used to transport the waste.[3] The mechanical charging systems for the incinerator should be designed and operated to minimize bag-breakage, spillage, and possible contamination. For example, trash compactors should not be used since when the bags are compacted, they will likely break open. Furthermore, compaction will affect the wastes' bulk/density (lb/ft^3) which will consequently affect the combustion process.[3]

The treatment of infectious waste as soon as possible after generation is preferable. However, because same-day treatment is not always possible, the incinerator operator may be responsible for waste storage. If the waste must be stored prior to incineration, four factors should be considered:

1. Maintaining container integrity and minimizing handling;
2. Storage temperature;
3. Storage duration; and
4. Location of the storage area.

The waste storage area should be a "secure" area, out of the way from normal hospital traffic and should have restricted access. Certainly, the area should be secure from public access. The storage area and/or the containers should be secure from rodents and vermin which can contract and transmit disease.

As temperature and storage time increases, decay occurs and unpleasant odors result. There is no unanimous opinion on acceptable storage temperature or times. The EPA Office of Solid Waste simply recommends that storage times be kept as short as possible.[3] Some States do regulate storage times. For example, Massachusetts allows infectious waste to be stored for 24 hours (1 day) at room temperature or for 72 hours (3 days) at refrigerated temperatures (34° to 45°F).[3]

Obviously, the level of control that the incinerator operator has over the items just discussed will vary with the situation and with the particular waste handling issue. That is, the operator may have little control over what strength red bag is used, but may have a great deal of control over whether red bags are removed from transport carts to a "charging floor" or whether the bags are simply loaded into the incinerator directly from the cart – thus eliminating handling each bag two more times.

The operator does, however, have control of personal protection items used. It is prudent that when handling infectious waste, an operator should always wear hard-soled shoes to avoid the potential for punctures and thick rubber gloves to resist cuts and punctures and to prevent direct contact with fluids. Safety precautions are discussed further in Chapter 9. The operator must remember that his/her safety is at stake and should bring deficiencies in waste handling practices (e.g., consistent tearing of bags due to poor bag quality) to the hospital administrator's attention.

4.3.2 Restricted Wastes

It is inappropriate to dispose of some wastes in a hospital waste incinerator unless special permits are obtained. Wastes which should not be incinerated, unless special permits are obtained include: (1) radioactive wastes, and (2) hazardous wastes regulated under the Resource Conservation and Recovery Act (RCRA).

Some State regulations or specific operating permits may dictate charging limits for certain types of wastes. For example, an operating permit may allow only up to 5 percent of the hourly charging rate to be human or animal parts (i.e., "pathological waste"). Obviously, the operator cannot tell whether the waste contains 4 percent or 5 percent of pathological wastes; nor should the operator ever open red bag wastes to examine the contents. Nonetheless, the operator must be aware of the regulations and must be attuned to spotting problem wastes, either by the obvious (e.g., gallon jugs of liquids, containers marked "radioactive") or by more subtle means (i.e., identifying large quantities of human/animal anatomical parts in the incinerator waste bed, while viewing the bed through a glass covered viewport).

4.4 Incinerator Operation, Control, and Monitoring

The key operating parameters for incinerators were presented in Section 4.2. This section provides a summary of the operating procedures, parameters which can be automatically controlled, and monitoring techniques for incineration systems. The operation, monitoring, and control of these four "typical" systems are discussed:

1. Batch feed controlled air;
2. Intermittent-duty controlled air;
3. Continuous-duty controlled air; and
4. Multiple chamber.

The operation, control, and monitoring of rotary kilns is not presented here because very few units are used to incinerate hospital waste and detailed information regarding their operation was not available.

4.4.1 Batch Feed Controlled-Air Incinerator

This type incinerator typically is a small unit, up to 500 lb/h, but more typically less than 200 lb/h capacity. The incinerator is operated in a "batch mode" over a 12- to 24-h period which entails a single charge at the beginning of the cycle, followed by combustion, ash burnout, cooldown, and ash removal. The operating cycle from startup to shutdown is discussed in the following sections. Parameters which can be automatically controlled and monitoring techniques also are discussed.

4.4.1.1 Incinerator Operating Procedures

4.4.1.1.1 Ash removal. Startup of the incinerator actually begins with removal of the ash generated from the previous operating cycle. The following are guidelines for good operating practice:[10]

1. In general, allowing the incinerator to cool overnight is sufficient for the operator to remove the ash safely. This cooling can take as long as 8 h.

2. The operator should open the ash cleanout door slowly both to minimize the possibility of damage to the door stop and seal gasket and to prevent ash from becoming entrained.

3. The operator should exercise caution since the refractory may still be hot and the ash may contain local hot spots, as well as sharp objects.

4. The ash and combustion chamber should not be sprayed with water to cool the chamber because rapid cooling from water sprays can adversely affect the refractory.

5. A flat blunt shovel, not sharp objects that can damage the refractory material, should be used for cleanup.

6. Avoid pushing ash into the underfire air ports.

7. Place the ash into a noncombustible heat resistant container, i.e., metal. Dampen the ash with water to cool and minimize fugitive emissions.

8. Once the ash has been removed and prior to closing the ash cleanout door, the operator should inspect the door seal gasket for frayed or worn sections. Worn seal gaskets should be replaced.

9. To prevent damage to the door seal gasket, the operator should close the ash cleanout door slowly and should not overtighten the door clamps. Overtightened door clamps may cause the seal gasket to permanently set and allow infiltration of outside air around the door face.

4.4.1.1.2 Waste charging. The operator may have the option of selecting which items are included in a particular charge. Waste properties which should be considered when the waste is segregated into charges include: (1) the heating value, (2) the moisture content, (3) the plastics content, and (4) the amount of pathological wastes. The heating value and moisture content of waste affects the performance of an incinerator. A charge of waste with a very high heating value may exceed the thermal capacity of the incinerator. The result is high combustion temperature, which can damage the refractory of the incinerator and can result in excessive emissions. Similarly, a charge of waste with a very high moisture content will not provide sufficient thermal input, and the charge will require the use of more auxiliary fuel than usual.

Plastic items are an example of materials with high heating values. Large quantities of plastic, which may contain polyvinyl chloride, should be distributed through many waste charges, not concentrated in one charge, if possible. When sorting loads of waste to be incinerated, the operator should try to create a mixture of low, medium, and high heating value wastes in each charge, if possible, to match the design heat release rate of the incinerator. In general, lighter bags and boxes will contain high levels of low density plastics which burn very fast and very hot. Heavier containers may contain liquids (e.g., blood, urine, dialysis fluids) and surgical and operating room materials which will burn slowly. As a general rule for segregating waste into charges, the operator may mix light bags and heavy bags to balance the heating value of each charge. If several different types of waste, (i.e., red-bag, garbage (cafeteria wastes), and trash) are being charged to the incinerator, charging the incinerator with some of each waste type is better than charging it with all of one waste type. Special care should be taken to avoid overcharging the incinerator (beyond its intended use) with anatomical wastes.

Prior to initiating charging, operation of the combustion air blowers and ignition and secondary burners should be checked. Follow the manufacturers' recommendations. The proper operation of the primary and secondary burners is best achieved by observing the burner flame pattern through the viewports in the incinerator wall or in the burner itself. Some burners are equipped with one observation point to view the main flame and another to view the pilot flame. The flame pattern will likely vary with the type of burner. However, the length of the flame should be such that the flame touches the waste but does not impinge directly on the refractory floor or wall. Obviously, the absence of a flame indicates a problem with the burner or the system that controls the burner. Most burners are equipped with a flame safeguard system that includes a flame detector that effectively cuts off the fuel (gas or oil) supply to the burner if a flame is not detected. When the burner is first started, the burner blower starts and when it reaches full speed, a purge timer starts. When the purge timer times out, the flame safeguard energizes the pilot relay that opens the pilot fuel supply and ignitor. When the pilot lights, a flame detector (either an ultraviolet scanner [gas or oil] or flame rod circuit [gas only]) detects the flame and causes the main flame relay to activate the fuel supply to the main burner. The pilot then ignites the main burner. The flame detector continues to operate and shuts the burner down if the main burner fails. Additionally, if the air supply is lost both pilot and flame relays shut off the fuel supply. The pilot usually is ignited for no more than 15 seconds (interrupted pilot). If the main burner does not ignite during the period, the flame safeguard system shuts the entire system down.[18]

The incinerator is charged cold. Because these units generally are small, they are usually loaded manually. The waste is loaded into the ignition chamber, which is filled to the capacity recommended by the manufacturer. Typically, the manufacturer will recommend filling the incinerator completely, but not overstuffing the chamber. Overstuffing can result in blockage of the air port to the combustion chamber and in premature ignition of the waste and poor performance (i.e., excess emissions) during startup. Overstuffing also can result in blockage of the ignition burner port and damage to the burner. After charging is completed, the charge door seal gasket is visually checked for irregularities. The door is then slowly closed and locked. The charge door seal gasket should then be inspected for any gaps that would allow air infiltration into the primary chamber. Once operation is initiated, no further charges will be made until the next operating cycle is initiated, i.e., after cooldown and ash removal.

4.4.1.1.3 Waste ignition. Prior to ignition of the waste, the secondary combustion chamber is preheated to a predetermined temperature by igniting the secondary burner. A minimum secondary chamber temperature of 980°C (1800°F) is recommended prior to ignition of the waste. The manufacturer should be consulted regarding proper preheat procedures; improper preheat can result in refractory damage.

After the secondary chamber is preheated, the secondary combustion air blower is turned on to provide excess air for mixing with the combustion gases from the primary chamber.

The primary chamber combustion air blower is activated and the primary burner is ignited to initiate waste combustion. When the primary chamber reaches a preset temperature (i.e., the minimum operating temperature for the primary chamber, see Table 4-1) and the waste combustion is self-sustaining, the primary burner is shutdown.

The primary combustion air and secondary combustion air are adjusted to maintain the desired primary and secondary chamber temperatures. (Typically this adjustment is automatic and can encompass switching from high to low settings or complete modulation over an operating range.)

During operation, the primary burner is reignited if the ignition chamber temperature falls below a preset temperature. Similarly, the secondary burner is reduced to its lowest firing level if the secondary chamber rises above a preset high temperature setting. Again, control of the burners, like the combustion air, is typically automated. A barometric damper on the stack is used to maintain draft. The incinerator chambers should both be maintained under negative draft.

4.4.1.1.4 Burndown. After the waste burns down and all volatiles have been released, the primary chamber combustion air level is increased to facilitate complete combustion of the fixed carbon remaining in the ash. The temperature in the primary chamber will continue to decrease indicating combustion is complete. During the burndown period, the primary burner is used to maintain the primary chamber temperature at the predetermined minimum level of the operating range. The length of time required for the burndown period depends on the incinerator design, waste characteristics, and degree of burnout desired. A typical burndown period is 2 to 4 h.[14] When combustion is complete, the primary and secondary burners are shutdown.

Shutdown of the secondary burner which initiates the cooldown period usually is automatically determined by a preset length of time into the cycle.[9,11] The combustion air blowers are left operating to cool the chambers prior to subsequent ash removal. The blowers are shutdown when the chambers are completely cooled or prior to opening the ash door for ash removal. Cooldown typically lasts 5 to 8 h.[14]

The final step in the cycle is examination of ash burnout quality. Inspection of the ash is one tool the operator has for evaluating incinerator performance. The operator should look for fine gray ash with the consistency of ash found in the fireplace at home or in the barbeque grill. Ash containing large pieces of unburned material (other than materials which are not combustible, such as cans) shows that incinerator performance is poor. It may be necessary to return these large pieces of material to the incinerator to be reburned because poor quality ash may be refused at landfills for disposal. Ash color also is an indicator of ash quality. White or gray ash indicates that a low percentage of carbon remains in the ash. Black ash indicates higher carbon percentages remaining. Although carbon remaining in the ash indicates that available fuel has not been used and combustion has not been complete, the fact that carbon remains in the ash is not in itself an environmental concern or an indicator that the ash is not sterile. Nonetheless, ash color can be used to assist the operator in evaluating burnout and incinerator performance.

4.4.1.1.5 Special considerations. If pathological waste is being burned, the ignition burner should be set to remain on until the waste is completely burned. Further, the volume of waste charged likely will need to be significantly reduced. The time required to burn an equivalent volume of Type 4 waste will be extended, since the waste contains high moisture and low volatile content. To destroy pathological waste efficiently, the waste must be directly exposed to the burner flame; consequently piling pathological waste in a deep pile (e.g., filling the entire chamber) will result in inefficient combustion.[15] If large volumes of pathological wastes are to be incinerated, an incinerator which is especially designed for pathological waste should be used.

4.4.1.2 Automatic Controls

Various levels of automatic controls are available for hospital incinerators, even for the smallest units sold. The smallest batch type units can be designed to use the same automatic control concepts and hardware for the key combustion control parameters (e.g., temperature and combustion air) as the larger continuous-duty incinerators.[19] The use of control systems allows key combustion parameters to be adjusted automatically based on data (e.g., temperature) from the incineration system. These automatic controls permit the combustion process to be more closely controlled.

For batch feed systems, parameters that can be automatically controlled include:

1. Charging frequency;
2. Combustion air rate;
3. Primary and secondary burner operation;
4. Temperature; and
5. Combustion, burndown, and cooldown cycle times.

4.4.1.2.1 Charging frequency. The charging frequency can be automatically controlled by providing an interlock system on the charging door. The interlock will prevent the charging door from being opened after the primary burner is ignited and will prevent additional charges to the batch system until after burndown and cooldown have been completed. The operation of the interlock can be set up in one of two ways. The interlock can be activated by a timer so that the door cannot be opened until after a preset time has elapsed (e.g., 24 hours). Alternatively, operation of the interlock can be based on temperature; the interlock is set to deactivate only after the proper temperature in the cool down cycle is attained. The latter approach truly controls operation of the unit in a manner that assures the incinerator will run through the complete charge, combustion, burnout, and cooldown cycle.

4.4.1.2.2 Combustion air rate. Combustion air rate can be automatically controlled by on/off settings, low/high settings, and full modulation of the flow over an entire operating range. The control settings can be activated based upon the value of a monitored parameter (e.g., temperature) or by a specified time in a cycle. Some manufacturers are now using different types of more advanced combustion air controls that sense parameters such as gas flow, opacity, oxygen concentration, and loading cycles to assure that adequate combustion air is available in the secondary chamber.[4]

4.4.1.2.3 Primary and secondary burner operation. Like the combustion air, the ignition and main combustion (secondary chamber) burners can be controlled over an entire operating range (i.e., modulated), at low/high levels, or in the on/off position. The settings can be based upon a monitored value (e.g., temperature) or as part of a timed sequence. The use of such settings in a control system is discussed in the following sections.

4.4.1.2.4 Temperature. Both the primary ignition and secondary combustion chamber temperatures can be automatically controlled. At least two levels of control are available. The first control approach is designed to control temperature in each chamber by modulating the available combustion air to each chamber. In this type system, the temperature in each chamber is monitored, and the combustion air to each chamber is separately controlled based on feedback from the thermocouples. The combustion air is modulated continuously over a wide range in order to maintain the set point temperatures. Auxiliary burners are used as necessary to maintain minimum temperatures. Since instantaneous peaks in the combustion gases generated in the primary chamber can occur, some manufacturers recommend operating the secondary burner at all times (in a low fire position if heat is not required) to assure complete combustion of primary chamber gases.[4]

This type control system effectively controls the waste combustion rate in the primary chamber by controlling the combustion air. Controlling the combustion rate in the primary chamber subsequently limits the combustion rate in the secondary chamber. Controlling the secondary chamber combustion air controls that chamber's temperature by increasing or decreasing the excess-air level. The firing rate of the main combustion burner (secondary chamber) may be modulated upward or downward if low and high temperature set points are reached in the secondary chamber. Similarly, the ignition burner can be activated automatically if the primary chamber temperature falls below the minimum set point. This type system provides a true control of the key parameter, combustion temperature, by modulating the combustion air.

One manufacturer controls the combustion rate in the primary chamber and the temperature in the secondary chamber by monitoring the oxygen concentrations in each combustion chamber and using these data to control/adjust the combustion air levels.[20]

Review of manufacturers' information indicate that a second approach to automatically controlling the combustion process is used for batch type units.[9,11] In this approach, a series of timers are used to establish a timed sequence of events and the key process equipment (i.e., burners and combustion air) have high/low or on/off settings. The switching of the burners and combustion air from one setting to another is controlled by the timed sequence. Overrides for the timed sequence are typically provided to assure that minimum or maximum set point temperatures are not exceeded.

This type control system does not offer the same level of combustion control as the modulated system previously described. Instead of continuously modulating to achieve a specific set point (i.e., temperature), this type system utilizes on/off or low/high settings to maintain control between two set points.

4.4.1.2.5 Combustion, burndown, and cooldown cycle times. An automatic control sequence operating on a timer cycle typically is used to initiate and control the length of burndown and cooldown cycles. An example timed control cycle for a batch operated incinerator is presented in Table 4-3.

4.4.1.3 Monitoring Operations

The monitoring of key operating parameters provides several benefits. First, monitoring provides the operator with information needed to make decisions on necessary combustion control adjustments. For example, continuous monitoring of the temperature and carbon monoxide level of the secondary combustion chamber effluent gas stream allows the operator to determine whether optimum combustion conditions are being maintained. Indications of an abnormally high CO level and low temperature can immediately be used to adjust the secondary burner rate to raise the combustion chamber temperature. Second, properly maintained monitoring records can provide useful information for identifying operating

Table 4-3. Example Timed Control Cycle for Batch Mode Incinerator

	Cycle	Controlling Parameter/Level	Resulting Automatic Control Action
1.	Secondary combustion chamber preheat	Manual start	Secondary burner--High fire
2.	Ignition	Combustion chamber temperature reaches 1100°F	Secondary combustion air--high level Primary combustion air--high level Primary burner on
3.	Combustion	Primary chamber temperature reaches 1000°F	Primary burner off
		Secondary temperature reaches high set point, 2000°F	Secondary burner switches to low fire
		Secondary temperature reaches low set point, 1800°F	Secondary burner switches back to high fire
		(Burner will cycle as high/low set-points are reached)	
4.	Burndown	5 hours from ignition	Primary air switched to high
		High primary temperature override	Primary air switched back to low
		1 hour after override activated	Primary air switched to high level
5.	Cooldown	8 hours from ignition	Secondary burner shuts off
		16 hours from ignition; cycle completed	Combustion air blowers shut off

trends and potential maintenance problems. This historical information can be used to make decisions with respect to modifying standard operating procedures or control set points. For example, careful visual inspection of ash quality each day complemented by comments in a daily operator's log book can be used to track ash burnout patterns. If a gradual trend towards poor ash burnout becomes evident, identification of possible reasons and corrective actions can be initiated. Finally, monitoring generally is needed to satisfy regulatory requirements.

Monitoring can be divided into three broad categories:

1. Continuous monitoring – involves continuous instrumental measurement with continuous data recording; e.g., use of a temperature sensor with a strip chart recorder.

2. Continuous measurement – involves continuous instrumental measurement but requires the operator to monitor the data output manually; e.g., use of a temperature sensor with a digital meter display.

3. Manual monitoring – involves inspection by the operator on a noncontinuous basis, e.g., visual stack gas opacity readings.

All of these techniques can be used to monitor the operation of batch type incinerators. Continuous monitoring of operating parameters will, in most cases, provide more information than manual monitoring. For example, continuous opacity monitoring of stack gas opacity will provide opacity data for the entire operating period and will provide a permanent record of changes in opacity over the operating cycle and trends over time. On the other hand, visual inspection of the stack gas opacity will provide limited data, and a record will be available only if the observer records the result.

The following operating parameters can be monitored:

1. Charge rate;
2. Combustion gas temperature;
3. Condition of the waste bed and burner flame;
4. Combustion gas oxygen level;
5. Combustion gas carbon monoxide level;
6. Combustion gas opacity;
7. Auxiliary fuel usage; and
8. Ash quality.

The techniques for monitoring each of these parameters are briefly described in the following paragraphs.

Note that this section is not intended to recommend specific monitoring requirements, but is intended to present the key parameters which can be monitored and provide a brief description of how the parameters can be monitored and what useful information monitoring can provide. Chapter 6 further discusses actual instrumental monitoring methods.

4.4.1.3.1 Charge rate. The weight of each charge can be recorded in a log book. This procedure will help to indicate whether the rated capacity of the incinerator is being exceeded. Note that incinerators are designed for a specific thermal input. Since the heat value (Btu/lb) of wastes will vary, the weight of a charge is not a true indicator of whether the rated capacity is being exceeded. Variations in heating value in the waste will need to be considered in determining charge size.

Nonetheless, monitoring the weight of the charge will provide historical data which can be used to make systematic modifications to operating procedures, i.e., reduction of the charge rate by 20 percent to evaluate the effect on resolving poor burnout problems. Monitoring this parameter will require a scale or weigh bin which can be used to weigh individual waste bags or transport carts.

4.4.1.3.2 Combustion gas temperature. The combustion gas temperatures (primary and secondary) are critical operating parameters. These parameters typically are monitored continuously using thermocouples. Permanent strip chart (or data logger records) may be kept; for small units only meters without permanent recordkeeping typically are provided.

4.4.1.3.3 Condition of waste bed and burner flame. If viewports are provided in each chamber, the operator can view the flame pattern and the waste bed. Visual observation of the combustion process provides useful information on the burner operation (i.e., potential problems such as flame impingement on the refractory, or smoking of the secondary burner flame can be identified) and on the combustion process in general (i.e., quantity and condition of remaining waste charge can be identified).

Viewports should be sealed glass covered by blastgates. "Inspection doors" which open the chamber to atmosphere should not be used for viewing the combustion process because these pose safety problems and affect the combustion air control.

4.4.1.3.4 Combustion gas oxygen level. The combustion gas oxygen concentration is a direct measure of the excess-air level. Although this measurement is not essential, it provides real-time information about changing conditions in the combustion chamber. Typically, the oxygen level of the combustion gas exiting the secondary chamber is used to assure that excess air is always available for complete combustion. A continuous oxygen monitoring system typically is used (see Chapter 6). However, a portable instrumental measurement system also can be used occasionally for monitoring oxygen levels to confirm proper operation or to provide information necessary for adjusting combustion air dampers.

4.4.1.3.5 Combustion gas carbon monoxide level. Carbon monoxide is a product of incomplete combustion; excessive levels indicate that a poor combustion condition exists. The CO concentration of the combustion chamber effluent can be monitored continuously to alert the operator to poor combustion conditions. An instrumental CO monitoring system generally is used for this procedure (see Chapter 6). Alternatively, a portable instrumental measurement system can be used to make occasional measurements of CO to monitor performance. As with the oxygen measurements, this approach often is used to check performance in conjunction with maintenance or adjustment of combustion control level settings.

4.4.1.3.6 Combustion gas opacity. Combustion gas opacity provides an indirect measurement of particulate matter concentration in the stack gas; hence opacity is an indicator of incinerator performance. As particulate concentration increases, so does the opacity. Continuous emission monitoring systems (CEMS) for measuring opacity (referred to as "transmissometers") are available (see Chapter 6). An alternative, and simpler monitoring technique, is visual observation of the stack emissions. The opacity of the stack gas can be determined accurately by a trained observer. Even an untrained observer can detect gross changes in stack gas opacity and can use visual observations to note combustion problems.

4.4.1.3.7 Fuel usage. Monitoring fuel usage provides historical data for identifying maintenance problems and for identifying the need for adjustments to control system settings to increase efficiency. Fuel usage can be monitored with a simple metering system. Fuel usage can than be determined by logging meter readings or continuously recording the metering system's output.

4.4.1.3.8 Ash quality. Ash quality is one indication of combustion performance. Visual inspection is the simplest means of determining ash quality and incinerator performance. For example, large pieces of uncombusted materials (e.g., paper) indicate very poor ash quality. The operator should inspect the ash visually and record comments on ash quality in a log book routinely.

For a more technical determination of ash quality, a chemical analysis of a sample of the ash can be conducted. The amount of combustible materials remaining in the ash can be determined by a laboratory test which subjects a sample of the ash to a combustion atmosphere and then determines the weight loss. This procedure measures the ash's "burnout" quality. A 100 percent "burnout" means no volatile or combustible materials remain in the ash; some incinerators are capable of 90 percent burnout.[21] Occasional checks of ash burnout are useful for monitoring performance of the incinerator.

4.4.2 Intermittent-Duty, Controlled-Air Incinerators

Intermittent-duty, controlled-air incinerators typically are used for "shift" type operation. The incinerator must be routinely shutdown for ash removal. Hence, there is a distinct operating cycle.

The main feature which distinguishes this type incinerator from the batch incinerator is the charging procedures which are used. The charging system is designed to accommodate multiple charges safely throughout the operating cycle rather than rely on a single batch charge at the beginning of the operating cycle. Either manual or automated charging systems can be used.

4.4.2.1 Operation.

4.4.2.1.1 Ash removal. The residual ash from the previous operating cycle must be removed before a cycle can be initiated. Ash removal procedures are essentially the same as those described in Section 4.3 for batch mode incinerators.

4.4.2.1.2 Startup. Before the operator initiates startup, proper operation of the primary and secondary burners and combustion air blowers should be checked according to manufacturer's instructions. The following steps are conducted during startup:

1. The primary and secondary burner(s) are ignited, and preheat of the combustion chambers is initiated. The manufacturer should be consulted regarding proper preheat procedures, since improper preheat can damage the refractory.

2. The secondary chamber must reach a predetermined temperature (e.g., 1800°F) before the incinerator is ready for charging; and

3. After the predetermined secondary chamber temperature is attained, the primary and secondary combustion air blowers are activated. The incinerator is ready to be charged.

4.4.2.1.3 Waste charging. Stable combustion can be maintained most readily with a constant thermal input to the incinerator. Feeding too much waste in a charge causes the incinerator to overload. These overloads can result in poor burndown (because of waste pile buildup on the hearth) or can cause excessive emissions because the rapid generation of volatiles overloads the capacity of the secondary chamber. Feeding too little waste results in inadequate thermal input and consequent excessive auxiliary fuel use.[10] A charge frequency and quantity recommended by two manufacturers is 15 to 25 percent of the rated capacity (lb/h) at 10 to 15 minute intervals.[10,11] Another rule of thumb is to recharge the incinerator after the previous charge has been reduced by 50 to 75 percent in volume, determined by observation of the waste through the view ports or operating experience.[11] Charging volume and frequency will vary with waste composition, and the operator must use some judgment to determine appropriate rates.

The temperature profile of a combustion chamber is a picture of how the temperature in the chamber fluctuates during the course of the incineration process. The variations in temperature are shown on the strip or circular chart recorder that records the temperatures measured by the thermocouples in the combustion chambers. The temperature fluctuations are affected by the frequency of waste charging and the size of the charge. Insufficient or infrequent charging may cause the temperature to become too low and necessitates the use of auxiliary fuel to help maintain the desired set point temperature. Charging too much waste may cause a rapid increase in secondary combustion chamber temperature if the waste has a high volatile content. On the other hand, if the waste has a low Btu content or contains a lot of moisture, overcharging may have the effect of first decreasing the primary combustion chamber temperature (while the moisture is being volatilized) before a temperature increase is noted. Charging on a regular basis with the same volume of waste in each charge helps to "flatten" the temperature variation and allow proper combustion while preventing refractory damage and excessive auxiliary fuel consumption. Monitoring the temperature profile of the combustion chambers will assist in determining the proper charging rates.

After the last charge of the day is completed, the incinerator is set to initiate the burndown cycle. The limiting factor on how long the charging period can be sustained without initiating the burndown cycle is the degree of ash buildup on the hearth. Typically the charging period is limited to 12 to 14 hours.[14]

4.4.2.1.4 Burndown. The burndown cycle is essentially the same as described for batch incinerators and is initiated after the last charge of the day is made. For intermittent-duty incinerators the burndown sequence can be initiated manually or may be initiated automatically. One manufacturer's control system is designed to include a control timer which is activated by the charging door.[11] Whenever the charging door is opened and then closed, the burndown timing cycle is initiated by resetting the burndown timer to a preset time period, e.g., 5 hours (the actual length of the burndown time is determined by experience with waste stream).

4.4.2.1.5 Cooldown. The cooldown period is the same as for batch incinerators.

4.4.2.2 Automatic Controls

The parameters which can be controlled automatically for intermittent-duty controlled-air incinerators are essentially the same as those already discussed for the batch-operated incinerators. The automatic control techniques used also are essentially the same. Either timed sequences with high/low burner and air settings or control systems which have fully modulated burner and air controls that are continually adjusted based on control feedback (e.g., temperature) can be used. For intermittent-duty units, the charging rate can be controlled automatically if an automatic mechanical charging system is provided with the unit. Automatic control for a ram feed charger consists of a timing sequence which will initiate the charging sequence at regularly timed intervals. The size of the charge is controlled by the volume of the feed hopper. An override on the automatic feeder can be provided so that the control system will not allow a charge to be fed at the regular interval if certain conditions are not met. For example, if the primary chamber temperature exceeds a high level set point, the incinerator is not yet ready for another "fuel" charge and the charging cycle will not initiate.

4.4.2.3 Monitoring

The operating parameters that can be monitored for intermittent-duty incinerators are the same as those parameters discussed in Section 4.4.1.3 for batch incinerators. The same monitoring techniques generally apply. However, continuous monitoring and recording of the ignition and combustion chamber temperatures have added importance for intermittent-duty incinerators. The trends in these measured values are useful to the operator in determining the appropriate charging frequency and in adjusting the charging frequency as waste characteristics change. Similarly, the use of appropriate viewports has added significance in making decisions on charging frequency based upon appearance of the waste bed.

4.4.3 Continuous-Duty, Controlled-Air Incinerators

Continuous-duty incinerators have the capability of continuously removing the ash from the incinerator hearth. Consequently, the incinerator can be operated at a near-steady-state condition by continuously charging the unit at regularly timed intervals and similarly by removing the ash at regularly timed intervals.

4.4.3.1 Operation

4.4.3.1.1 Startup. Startup procedures for continuous-duty incinerators are essentially the same as for the intermittent-duty incinerators. The chambers are first preheated before the initial charge is loaded to the incinerator. The manufacturer should be consulted regarding proper preheat procedures, since improper preheat can damage the refractory.

4.4.3.1.2 Charging. To approach steady state operation, consistently sized charges should be fed at regularly timed intervals. Practically speaking, continuous-duty incinerators are likely to be more automated than the types of units previously discussed. Continuous-duty incinerators will include a mechanical feed system, which may be fully automated so that charges are automatically fed at regularly timed intervals.

During operation, the waste bed/ash bed is typically moved through the incinerator by one of two methods. In the first method, the waste bed is continually pushed towards the back end of the chamber when each new waste charge is pushed into the incinerator by the feed ram. In the second method, where the incinerator hearth is exceptionally long, the hearth is built in a stepped fashion, and special ash rams are provided for pushing the ash from one step to the next step. Ultimately, in both systems, the ash is pushed off the hearth into an ash discharge chute.

During operation, the operator must assure that the ash is being removed from the system. For manual ash removal systems, an ash bin must be emptied routinely. The ash bin is located inside a sealed chamber at the end of the ash discharge chute or is directly sealed to the combustion chamber ash discharge chute. For fully automated ash systems, the ash is mechanically removed by a rake or conveyor from a water quench pit located at the end of the ash discharge chute. For these systems, the operator need only monitor the ash discharge system to assure that no mechanical problems have developed and to assure that the quench pit water level is maintained.

4.4.3.1.3 Shutdown. Shutdown of the incinerator involves stopping the charging process and maintaining temperatures in the combustion chamber until the remaining waste burns down to ash and is finally discharged from the system in the normal manner.

4.4.3.2 Automatic Controls

The parameters which can be controlled automatically for this type unit are essentially the same as those for the intermittent duty unit. However, when separate ash transfer rams are a part of the system, ash removal may also be automatically controlled. If the waste feed system is on an automatically timed sequence, the ash removal system likely will be integrated into the timed sequence.

The operating controls for the parameters discussed in Section 4.2.2 are more likely to be fully automated for continuous-duty incinerators than for batch units, simply because of the size and frequency of use of the units. Automated controls relieve the operator from the burden of continuously making adjustments.

4.4.3.3 Monitoring

The operating parameters that can be monitored for continuous-duty incinerators are the same as those parameters discussed in Section 4.4.2.3 for intermittent-duty incinerators. The use of automatic/mechanical feed systems simplifies the monitoring of waste feed charge frequency (and consequently volume). A recording indicator can be installed that indicates how frequently the waste feed charge system is activated. This information can be used to provide a rough estimate of the charging rate (lb/h) for the unit and also may be helpful in diagnosing other operational problems, such as reasons for temperature excursions.

4.4.4 Multiple-Chamber Incinerators

Typically, multiple-chamber incinerators are used to burn pathological waste. However, other medical waste including red bag waste are sometimes burned in these units; when burning red bag waste special precautions should be taken during charging to assure the incinerator's capacity is not exceeded. Typical applications of multiple-chamber incinerators include batch or intermittent operation; continuous-duty operation automatic ash removal is atypical. Operation of these units is discussed briefly below.

4.4.4.1 Operation

4.4.4.1.1 Ash removal. The residual ash from the previous operating cycle must be removed before a cycle can be initiated. Ash removal procedures are essentially the same as those described in Section 4.4.1.1.1 for batch mode controlled-air incinerators.

4.4.4.1.2 Startup. Startup of the excess-air incinerator is similar to startup for the batch-mode, controlled-air incinerators. The secondary chamber is first preheated to a predetermined chamber temperature. The incinerator is then charged with the waste.

4.4.4.1.3 Charging. Multiple-chamber incinerators may be either batch or intermittent duty and may be charged manually or with a mechanical loading device. Because of the significant difference in heat contents between pathological waste and red bag waste and because incinerators are designed to burn a waste with a specific heat input, the proper charging (addition of fuel) procedures are different for different wastes.

Pathological waste has a low heat content, a high moisture content, and a low percentage of volatiles. Consequently, it must be constantly exposed to the auxiliary burner(s') flame(s) to be combusted. The following proper pathological waste charging procedures are recommended:

1. The waste should be placed on the hearth in an even layer that provides maximum exposure to the burner(s) flame(s). The waste should not be deeply piled.
2. Recharging the incinerator should not be done until considerable reduction in volume (greater than 75 percent) of the previous charge has occurred.
3. When recharging the incinerator:
   a. Turn off the primary burner (some units may have an interlock system that automatically turns the burner off when the charge door is opened);
   b. Place the fresh charge in a single layer on the hearth so that the burner(s) impinge on the waste; and
   c. Close the charge door before restarting the primary burner.

The heat content of red bag waste will be variable depending on the contents of the bag. Proper operation of the incinerator dictates that: (1) sufficient waste should be charged to the unit to sustain the desired temperature without excessive use of the primary burner; and (2) to maintain the primary chamber temperature below the upper limit and to prevent emissions, the charge rate should not exceed the capacity of the incinerator at any time. Obviously, if the incinerator was designed for pathological waste, then a significantly smaller red bag waste charge should be made than is typically made of pathological waste. The following guidelines are recommended for charging red bag waste into a multiple-chamber incinerator:

1. Use of frequent, small batches rather than one large batch. The objective is to avoid causing a rapid release of volatile compounds that exceeds the combustion capacity of the incinerator. The frequency and size of each charge will be determined by the incinerator being operated and the type of waste. A recommended procedure is to charge about 1/10 the rated capacity (lb/h) every 6 minutes.
2. Keep a fairly consistent waste bed in the incinerator. The incinerator should not be jammed full, nor should it be empty.
3. Avoid "stuffing and burning" in the incinerator; that is, do not fill the incinerator chamber to full capacity, floor to ceiling, ignite the waste, and allow the incinerator to operate unattended.

4. When recharging the incinerator:
   a. Turn the primary burner off (some units may have an interlock system that automatically turns the burner off when the charge door is opened);
   b. The partially burned waste from the previous charges should be pushed towards the back of the hearth with a rake; and
   c. The new waste charge should be fed to the front end of the hearth (near the charge door). This procedure allows good exposure of the partially combusted waste to the overfire air and allows a good flame from the waste bed to be maintained. On the other hand, if cold, newly charged waste is thrown on top of the existing waste bed it partially smothers the burning bed which can result in increased emissions.
5. If the incinerator has a grate, it is important that the entire grate be covered with a waste bed.

4.4.4.1.4 Operation. When burning pathological waste, the primary burner is operated throughout the combustion cycle and thermal output should be relatively constant without rapid fluctuations. The primary chamber combustion air is preset to maintain a constant excess-air level, and primary chamber temperature is controlled by modulating the primary burner. Since the pathological waste does not contain large amounts of combustible volatiles, secondary chamber combustion settings also will remain relatively constant. The combustion air damper settings and burner settings necessary to attain the desired secondary chamber temperature and excess-air levels are set and normally do not need to be adjusted. Temperature control normally is achieved only by modulating the primary burner settings.[15]

Modulating the primary burner does not offer the same degree of control over temperature as the adjustment of air supply. If a multiple-chamber incinerator was overcharged with red bag waste, modulation of the primary burner (or even shutdown of the burner) would not reduce the temperature because once ignited, the red bag waste will continue to burn out of control with the large excess-air level carrying excessive unburned material to the secondary chamber. In such a scenario, the secondary chamber would be unable to respond to such a high carryover of volatiles. Therefore, while red bag waste may be burned in a multiple-chamber incinerator, the potential exists for high temperatures that may damage the unit and for high emissions if the unit is overcharged. Some multiple-chamber units may have an automatically modulated air supply system that adds air if the temperature rises (cools the combustion process) or restricts air if the temperature falls. However, the large excess-air level in the primary chamber will still produce carryover of particulate matter to the secondary chamber. Therefore, multiple-chamber incinerators are better suited to burn pathological waste than they are to burn red bag waste because of the relatively stable and constant heat output of pathological waste and the fact that pathological waste combustion is controlled entirely by the firing of the primary burner (i.e., pathological waste cannot sustain combustion without the primary burner and will not burn out of control as the red bag waste can).

4.4.4.1.5 Burndown. There is no burndown period in the operation of multiple-chamber incinerators. The degree of burnout achieved is dictated by the length of time that the primary burner is left in operation after the last charge. After complete destruction of the waste has been achieved (as noted by visual observation through a viewport), the primary burner is shut down. The secondary burner is not shut off until all smoldering from residual material on the hearth in the primary chamber has ceased.[15]

4.4.4.1.6 Cooldown. After all smoldering in the ignition chamber has ceased, the secondary burner is shut down, and the incinerator allowed to cool.

4.4.4.2 Automatic Controls

The primary operating parameters which are automatically controlled are the primary and secondary chamber temperatures. Control of the temperatures is achieved by modulating the burner rates. The primary and secondary combustion air levels typically are not automatically controlled, but are preset. Incinerator draft typically is controlled by a barometric damper. Charging rate also is not likely to be controlled automatically in this application.[15]

4.4.4.3 Monitoring

The same operating parameters that are monitored on controlled-air incinerators can be manually or continuously monitored during operation of the multiple-chamber unit.

4.5 Add-On Air Pollution Control Systems

Key operating parameters and procedures for wet scrubbers, fabric filters, and dry scrubbers are discussed in this section. Addition of an air pollution control system (APCS) to a hospital waste incinerator increases the number of operating parameters the operator must control, monitor, and adjust. Furthermore, addition of an APCS to an incinerator significantly modifies how at least one important incinerator operating parameter is controlled; this parameter is the incinerator draft. Operation of the APCS will require use of an induced draft (ID) fan to provide the necessary airflow through the system.

Natural draft control will no longer be applicable; gas flow through the system will be controlled by the ID fan.

4.5.1 Wet Scrubbers[22-24]

4.5.1.1 Key Operating Parameters

All wet scrubbers utilize a liquid scrubbing media to remove pollutants from the incinerator exhaust gas stream. Actual collection of the pollutant in the liquid is primarily through impaction for particulates and absorption for acid gases. The liquid/gas (L/G) ratio is an important parameter for all wet scrubbers. The appropriate L/G ratio varies with scrubber type. Venturi scrubbers require a relatively low L/G ratio with 7 to 10 gallons per thousand actual cubic feet (gal/Macf) recommended.[22] This low L/G ratio is acceptable because venturi scrubbers rely on high energy pressure drops to create high gas velocities, turbulence, and lots of small water droplets for the collection of fine particulate matter by impaction. Therefore, pressure drop (ΔP) and L/G ratio are the two key performance parameters for venturi scrubbers. Packed-bed scrubbers, however, rely on creating large surface areas of gas to liquid interface for collection of gaseous pollutants through absorption. Large pressure drops are not required by packed-bed scrubbers. However, relatively large L/G ratios are required to adequately cover the packing media and create a large wetted surface. The L/G ratio is the key performance parameter for packed-bed scrubbers used for acid gas control with 10 to 15 gal/Macf recommended.[23] Spray towers also require a L/G ratio of 5 to 20 gal/Macf.[23] While these are the most important key performance parameters, there are several key parameters for each scrubber type that can be monitored and adjusted by the operator to achieve the desired performance of the unit. Table 4-4 lists the key parameters and identifies typical operating ranges for venturi scrubbers, packed-bed scrubbers, spray towers, and mist eliminators for application to hospital waste incineration systems.

Control of scrubber liquor pH is important to minimize corrosion from acid or alkaline conditions. A scrubber liquor pH range of 5.5 to 7.0 is recommended.[22] A pH in this range represents neutral water. A lower pH indicates acidic water which can cause corrosion. Higher pH values may result in scaling.

Turbidity of the scrubber liquor feed also is an important operating parameter with regard to maintaining particulate matter control efficiencies. High turbidity (a measure of the dissolved and suspended solids in the liquid) can result in increased particulate matter emissions and plugging of nozzles.

Proper design and operation of the mist eliminator system is necessary for maintaining particulate matter control efficiencies. Scrubber system design sometimes includes a clean water spray for rinsing mesh pad eliminators and maintaining performance.

4.5.1.2 Scrubber Operation

Proper operation of a scrubber requires that the operator (1) establish a fixed liquid flow rate to the scrubbing section, (2) initiate gas flow through the system by starting a fan, and (3) set up the liquid recirculation system so that suspended and dissolved solids buildup does not create operating problems. Once the system has been started and operation has stabilized, little additional operator attention will be needed. Operators should refer to the instruction manual provided by the scrubber manufacturer for adjustment of site-specific operating conditions.

4.5.1.2.1 Scrubber Startup. The scrubber should be started prior to charging waste feed to the incinerator but not necessarily prior to preheat. The specific manufacturer's startup instructions should be followed. The following procedures in sequence are typical during startup of a scrubbing system to insure proper operation:

1. Turn on the liquid recirculation system or liquid supply(s) to the scrubber(s) and mist eliminator.
2. Adjust the liquid flow rates to those specified in the instructions supplied by the scrubber manufacturer.
3. If the induced draft or forced draft fan feeding the scrubbing system has a damper installed at its inlet or outlet, close the damper.
4. Start the induced draft or forced draft fan.
5. If the system is equipped with a damper, gradually open the damper until the proper gas flow rate is established.
6. Again recheck the liquid flow rate(s) and adjust as necessary.
7. Check the differential pressure across the scrubber and compare with the design pressure drop specified in the operating manual. If the differential pressure is too low across the scrubber, either the liquid rate is too low or the gas flow rate is too low. To correct this condition, either increase the gas flow rate by opening a damper, or increase the liquid flow rate to the scrubber. If the scrubber is a venturi unit with an adjustable throat, the pressure can be increased by decreasing the throat area.

Table 4-4. Wet Scrubber Performance Parameters for Hospital Waste Incinerators[22-24]

Parameter	Typical range[a]	Units of measure	Operating range[b]
Venturi scrubbers			
Pressure drop	15-60	in. w.c.	20-50
Liquid feed rate[c]	>35	gal/min	
Liquid-to-gas ratio	4-10	gal/Macf	7-10
Liquid feed pressure	20-60	psi	20-60
Liquid feed turbidity	1-10	Percent suspended solids	0-3
Gas flow rate[c]	>5,000	acfm	
Liquid feed pH	5-10	pH	5.5-7.0
Packed-bed scrubbers			
Pressure drop	1-5	in. w.c.	
Liquid feed rate[c]	>5	gal/min	
Liquid feed pH	5.5-7.0	pH	5.5-7.0
Liquid-to-gas ratio	10-30	gal/Macf	15-25
Liquid feed pressure	20-60	psi	30-60
Gas flow rate[a]	>5,000	acfm	
Liquid feed turbidity	1-10	Percent suspended solids	1-3
Spray towers			
Pressure drop	0.5-3.0	in. w.c.	1-3
Liquid-to-gas rate	5-20	gal/Macf	5-20
Mist eliminator			
Pressure drop	1-3	in. w.c.	1-3
Liquid feed rate[c]	>5	gal/min	
Liquid feed pressure	20-60	psi	30-60
Liquid-to-gas ratio	1-6	gal/Macf	2-3
Liquid turbidity	0-3	Percent suspended solids	0-0.5
Gas flow rate[c]	>5,000	acfm	
Liquid feed pH	5-10	pH	7

[a] The typical range is the range of operating parameters that can exist on a broad range of source categories.

[b] The operating range is the range of operating parameters specified by manufacturers for combustion sources similar to hospital waste incinerators.

[c] Values, or range of values, are dependent on the size of the scrubber system.

8. Initiate the liquid bleed to treatment or disposal as specified in the manufacturer's manual. If the bleed is taken by an overflow from the recirculation tank, the flow rate at this point is established by the rate at which makeup water is introduced to the recirculation tank. The manufacturer's manual should show the anticipated water evaporation rate in the scrubbing system. If, as an example, the evaporation rate is 1 gallon per minute, and if you wish to establish a bleed rate of 1 gallon per minute, it will be necessary to feed 2 gallons per minute of total water to the recirculation tank. The bleed rate is determined by the rate at which the solids build up in the scrubbing system. These solids can be either suspended or dissolved solids or both. A scrubber is capable of handling a maximum of 3 percent (weight) suspended solids, and it is suggested that the dissolved solids not exceed 10 percent (weight).[22] Based on design data, a recommended bleed rate from the system should be provided by the manufacturer. The operator should combine this figure with the evaporation figures to give a total recommended makeup water rate to the recirculation tank if an overflow type bleed system is used. If a bleed system is provided from a slip stream off the pump feeding the venturi scrubber, liquid makeup is normally provided by a level control device in the recirculation tank. The flow rate required will be the same as the flow rate required for the overflow bleed system. However, it is only necessary to insure that an adequate water supply is available to the level control device on a continuous basis.

4.5.1.2.2 Scrubber shutdown. To shut the system down without overloading the fan or causing any damage to the scrubbing equipment, the following procedures in sequence are typical:

1. Shut off the induced draft or forced draft fan feeding the scrubbing system.
2. Wait until the fan impeller has stopped rotation and then shut off the scrubbing water recirculation pump.
3. Shut off the makeup water supply system.

4.5.1.3 *Automatic Control*

Key operating parameters which may be automatically controlled for a scrubber system include:

1. Venturi pressure drop;
2. Scrubber liquid flow rate;
3. Scrubber liquid pH; and
4. Gas flow rate.

The venturi pressure drop is the key performance parameter for venturi scrubbers and the scrubber system can be designed to monitor this parameter and provide automatic control based on adjustment of the venturi throat.

For venturis, packed beds, and spray towers, the scrubber liquid flow rate is a key parameter. This parameter usually remains constant during operation but, nonetheless, can be designed for automatic flow rate control.

When caustic materials are added to the scrubber liquid, control of scrubber liquid pH is necessary to prevent damage to the scrubber equipment. A pH meter is used to monitor the pH of the liquid. The output of the meter is used to control the amount of caustic material added to the scrubber sump.

Gas flow rate through the system can be controlled automatically by monitoring and adjusting fan rpm for a variable speed fan, or by monitoring and controlling fan static pressure using a damper for a constant rpm fan. Gas flow rate is controlled to maintain the desired draft in the incinerator combustion chambers, as well as the desired pressure drop across the scrubber.

4.5.1.4 *Monitoring*

Scrubber parameters which can be monitored by the operator include:

1. Venturi pressure drop;
2. Scrubber liquid flow rate;
3. Scrubber liquid pH;
4. Fan static pressure, rpm, or amperage; and
5. Gas inlet temperature.

The first four items listed were discussed in the section above with regard to using these parameters for automatic system control. Gas inlet temperature is of interest to the operator because excessive temperatures can damage the pollution control equipment, especially in systems where fiber reinforced plastic materials are used. A thermocouple is used to monitor the gas inlet temperature.

4.5.2 Fabric Filters[25-27]

4.5.2.1 *Key Operating Parameters*

The key operating parameters for fabric filter control systems are summarized in Table 4-5. To prevent damage to the system the gas temperature must be maintained in a range between the dewpoint of the gas and the upper temperature limit of the fabric. The upper operating temperature of the fabric will depend on the fabric type; the manufacturer should be consulted regarding the upper temperature limit.

Table 4-5. Key Operating Parameters for Fabric Filter Control Systems

Parameter	Operating range[26]
Upper gas temperature, °F	Below upper limit for fabric[a]
Lower gas temperature, °F	Above dewpoint[b]
Pressure drop, in. w.c.	5-9
Cleaning air pressure, psig	60-100

[a] The upper temperature limit will be dependent on fabric type. Consult manufacturer.
[b] The gas temperature usually is maintained above 300°F.

The pressure drop across the system for pulse jet baghouses typically is maintained within a range of 5 to 9 in. w.c.[25] Pressure drop gives an indication of filter cake formation. Filter cake formation is dependent on the effectiveness of the bag cleaning cycle. The frequency and dwell of bag cleaning must be set to maintain the desired pressure drop. The cleaning pressure must be maintained at sufficient pressure to properly clean the bags; the desired range is 60 to 100 psig.[25]

4.5.2.2 *Operation of Fabric Filters*

While the performance of a fabric filter is dependent on proper design and the timely detection of upset conditions, proper operation and preventive maintenance procedures dictate satisfactory long-term performance. This section discusses general operating procedures that can minimize unexpected malfunctions and improve the performance of the fabric filter. Preventive maintenance practices are discussed in Chapter 5. Proper operating procedures are important during startup, normal operation, shutdown, and emergency conditions.

4.5.2.2.1 Startup Procedures. Prior to operation of new fabric filters, a complete check of all components is recommended including the cleaning system, the dust-discharge system, and the isolation dampers and fans. Clean, ambient air should be passed through the system to confirm that all bags are properly installed. New bags are prone to abrasion if subjected to high dust loadings and full-load gas flows, particularly during the initial startup before new bags have the benefit of a dust buildup cake to protect the fibers from abrasion or to increase their resistance to gas flow. Full gas flow at high dust loadings can allow the particulate matter to impinge on the fabric at high velocity and result in abrasion that may shorten bag life. In addition, the dust may penetrate so deeply into the fabric that the cleaning system cannot remove it, and a "permanent" pressure drop results. Bag abrasion may be prevented by either (1) initially operating the incinerator at a low throughput and reduced gas volume to allow the dust cake to build gradually or (2) precoating the bags to provide a protective cake before the incinerator exhaust is introduced. The baghouse manufacturer should be consulted regarding proper startup procedures and acceptable precoat materials.

The fabric filter should not be operated at temperatures approaching the dewpoint of water and/or the hydrochloric acid formed by the combustion of chlorinated plastics because if the dewpoint is reached, serious operating problems may arise. Warm moist gas that is introduced into a cool or cold fabric filter will cause condensation on the bags or on the fabric filter shell. Condensation can cause a condition known as "mudded" bags where the bags are blinded by dust and moisture. The acid dewpoint depends on the amount of moisture and acidic material in the gas stream. Condensation of acid can cause corrosion of the fabric filter components, sticky particulate and cake-release problems, and acid attack on some fabrics. Preheating the fabric filter to a temperature above the acid dewpoint will prevent condensation and enhance fabric filter performance. Since the incinerator goes through a warmup period using natural gas or fuel oil burners prior to waste combustion, the problems associated with condensation of water or hydrochloric acid are unlikely to occur.

Unstable combustion during startup can cause some carbon carryover, which may result in a sticky particulate. This situation creates the potential for fires in the fabric filter when a combustion source and an adequate oxygen supply are available. Therefore, during startup, the fabric filter hoppers that collect the particulate should be emptied continually. More importantly, unstable combustion conditions during startup should be minimized by going through proper incinerator startup procedures.

4.5.2.2.2 Normal operating procedures. Under normal conditions, operation of the fabric filter is straightforward. The operator has to do very little other than monitor the key parameters, as discussed later in Section 4.5.2.4. Combustion gas flow rate through the system must be maintained at the level necessary to maintain negative draft in the combustion chambers.

4.5.2.2.3 Shutdown procedures. The top priority during shutdown of a fabric filter is avoiding dewpoint conditions. Bag cleaning and hopper emptying are lower priority items.

When processes operate on a daily cycle, the last operation of the day should be to purge moisture and acidic materials from the fabric filter without passing through the dewpoint. In the case of a hospital waste incinerator, the operator should leave the secondary chamber burner on for a few minutes after combustion is completed to remove moisture from the fabric filter. Ambient air could then be drawn through the system to purge the remaining combustion products.

After shutdown, the fabric filter should be allowed to go through a complete bag cleaning cycle. This procedure will help prevent blinding of the bags. Additionally, continuing to operate the hopper discharge system while the cleaning system is in operation will minimize the potential of hopper plugging.

When emergency conditions are encountered such as high temperatures, spark detection, or other process upsets, the fabric filter is usually bypassed to prevent damage to the system. If a fire occurs in the hopper, the addition of water under oxygen-starved conditions is not advisable because the water will hydrolyze forming hydrogen and causing the potential for an explosion inside the fabric filter. Both the fabric filter manufacturer and insurance carrier should be contacted whenever a known potential for fires/explosions exists.

Other process failures may necessitate only temporary bypassing of the fabric filter, and operation can be restored in a matter of minutes. In these cases, the fabric filter generally does not have to be shut down completely and purged. If the upset cannot be corrected within a reasonable amount of time, however, shutdown and the subsequent startup of the fabric filter may then be necessary to prevent dewpoint problems.

It is important to note that bypassing the fabric filter during startup, soot blowing, or an emergency may not be acceptable to the applicable regulatory agency. Such occurrences should be investigated and addressed during the design stages of development.

4.5.2.3 Automatic Controls

Operating parameters which are controlled automatically for fabric filter control systems include the bag cleaning cycle and the ash removal system.

The combustion gas flow rate through the system also can be controlled automatically. Control is achieved by adjusting fan rpm's (variable speed fans) or fan static pressure by way of a damper. Proper gas flow through the system must be maintained to assure sufficient negative draft in the combustion chambers. Reduction of the gas stream temperature to the fabric filter typically is achieved by passing the combustion gases through a waste heat boiler. Temperature monitoring systems are available that will cause automatic bypass of the fabric filter under high temperature conditions.

4.5.2.4 Monitoring

A well-designed and maintained fabric filter should provide adequate control of particulate matter emissions. Parameters that can be monitored to maintain optimum performance include opacity, pressure drop, fan motor amperage, and temperature.

Opacity readings can help to determine the presence of pinholes and tears in bags and, in some cases, the general location of the bag failure. These visible emissions are usually the first indicator of poor fabric filter performance. The failed bags should be replaced as necessary.

The pressure drop across the fabric filter is another indicator of poor performance. A high pressure drop outside the normal operating range may indicate inadequate cleaning of the fabric, bag blinding, or excessive gas volume through the system. In some cases, the pressure drop before and after cleaning increases steadily as the bags age. Excessively low pressure drop may indicate inadequate filter cake formation resulting from too frequent cleaning.

When used in conjunction with the pressure drop across the fabric filter, measurement of fan motor amperage also can provide an indication of the gas flow rate. In general, an increase in current combined with an increase in pressure drop indicates an increase in gas volume, and a decrease in amperage reflects a decrease in gas volume. These changes, however, must be normalized for temperature (density) changes because temperature influences the energy required to move the gas through the system.

High-temperature operations such as hospital waste incinerators should be equipped with continuous strip chart recorders and high-temperature alarms. The high-temperature alarms should provide some margin for corrective action, i.e., set points of 50° to 75°F below the high temperature limit of the fabric. The temperature alarm/recorder also may be connected to an automatic damper system to control the temperature or to bypass the fabric filter. Although some differential between the maximum temperature and the alarm activation must be provided, the temperature set point should not be so low that the alarm is continually activated. The temperature indicator also will monitor against excessively low temperatures and dewpoint problems.

4.5.3 Spray Dryers[7,28]

4.5.3.1 Key Operating Parameters

The key parameters that are necessary for effective operation of a spray dryer are slurry feed rate, slurry sorbent content, and the outlet gas wet and dry bulb temperatures. Effective operation of a spray dryer system requires that adequate sorbent is provided in the slurry for reaction with the acid gases and that all slurry moisture is evaporated in a time frame that allows for reaction with the acid gases. Drying that is too rapid can reduce acid gas collection efficiency. Drying that is too slow will result in solids buildup on the sides of the reaction vessel that will further impede drying. The liquid slurry feed rate and sorbent content should be balanced with the hot flue gas volume and acid gas content to ensure the desired removal of acid gases and the timely evaporation of all water. The recommended slurry sorbent content is 5 to 20 percent by weight solids. The slurry moisture added to the flue gas serves to cool and increase the moisture content of the gas stream. The difference between the wet bulb and dry bulb temperatures gives an indication of the saturation of the gas stream and the potential for evaporation of the slurry moisture. As the slurry feed rate is increased, the wet bulb and dry bulb temperature difference will decrease. The recommended wet bulb/dry bulb outlet gas temperature difference (for Municipal Solid Waste Systems) is 30° to 80°C (90° to 180°F).[28]

4.5.3.2 Spray Dryer Operation

The design specifications for the dry scrubber should identify the sorbent-to-water ratio for the mix tank. The sorbent content should be set at a level that will provide ample sorbent for the range of acid gas concentration expected to occur. Proper operation of the dry scrubber requires that the operator adjust the slurry flow rate to the atomizer in the reaction vessel to maintain an acceptable wet bulb/dry bulb temperature difference. If the wet bulb/dry bulb temperature difference is too low, the slurry feed should be decreased.

4.5.3.2.1 Spray dryer startup. Startup of a spray dryer should follow procedures that ensure evaporation of all slurry moisture in the reaction vessel and that prevent condensation of moisture in the fabric filter. One method of ensuring evaporation and prevention of condensation in the fabric filter is to use auxiliary fuel firing in the incinerator to bring the exhaust gas temperature up to the normal operating range before injecting the slurry. Slurry injection should be initiated before charging the incinerator with waste feed material. An alternative method would be to gradually increase the slurry feed rate during startup to maintain a 90° to 180°F wet bulb/dry bulb temperature differential.

4.5.3.2.2 Spray dryer shutdown. Proper shutdown procedures for spray dryers should ensure that no liquid moisture remains in the spray dryer or that condensation in the fabric filter does not cause bag blinding or corrosion. Slurry remaining in the system after shutdown can cause solids buildup. Also, the reaction products resulting from the neutralization of the acid gases include highly corrosive salts such as NaCl and $CaCl_2$. After the waste material in the incinerator has been combusted, auxiliary fuel firing should be used to maintain temperatures above saturation until all sorbent is purged from the system. To prevent bag blinding and reaction product salt corrosion that could occur in the presence of condensation, the fabric filter should go through a complete cleaning cycle to remove the filter cake after shutdown of the incinerator and spray dryer.

4.5.3.3 Automatic Control

The most important key parameter from a control standpoint is the slurry feed rate. The slurry feed rate determines the amount of sorbent available for acid gas collection (along with the sorbent content of the slurry) and the outlet gas wet bulb/dry bulb temperatures. Slurry feed rate can be automatically controlled in response to monitoring of HCl outlet gas concentration or wet bulb/dry bulb temperature. In less complex systems, the slurry sorbent content is fixed and the slurry feed is automatically increased or decreased in response to the outlet gas temperatures. Under conditions of low inlet HCl concentrations these systems will use excessive amounts of sorbent. More complex systems are available that automatically adjust the sorbent feed to the slurry mix tank in response to HCl concentration and slurry feed rate to the atomizer in response to outlet gas temperatures.

4.5.3.4 Monitoring

Spray dryer parameters which can be monitored by the operator include:

1. Sorbent feed to the mix tank;
2. Slurry feed rate to the atomizer;
3. Gas inlet temperature;
4. Gas outlet wet bulb and dry bulb temperature; and
5. HCl and SO_2 outlet gas concentrations.

The most important parameters are the outlet gas HCl concentration which indicates the performance of the unit and the outlet gas wet bulb/dry bulb temperatures which determine evaporation rate. As explained earlier, the evaporation rate is important to ensure that adequate absorption time is available for acid gas removal and that all moisture is evaporated prior to leaving the reaction vessel.

4.5.4 Dry Injection

4.5.4.1 Key Operating Parameters

The key operating parameters for a dry injection system are the sorbent injection rate and the particle size of the sorbent. The sorbent injection rate should provide adequate sorbent for neutralization of the acid gases and is dependent on the acid gas content of the flue gas. The sorbent feed rate for dry injection systems is usually three to four times the stoichiometric requirements.[27]

The acid gas/sorbent reaction requires that the acid gas come in physical contact with the surface of the solid sorbent particles. To maximize the efficiency of the collection process it is necessary to maximize the surface area of the sorbent material. Because the surface area-to-volume ratio increases with decreasing particle size, acid gas removal efficiency increases with the decreasing particle size of the sorbent. Generally, the sorbent feed should have a particle size where 90 percent by weight will pass through a 325 mesh screen.[28]

4.5.4.2 Dry Injection Operation

Dry injection systems are relatively simple to operate compared to spray drying systems. The particle size of the sorbent should be specified to the supplier. To ensure that the particles do not agglomerate prior to injection, the airflow rate in the pneumatic transfer line should be set and maintained at the manufacturer's specified rate. Proper airflow in the pneumatic line will fluidize the sorbent particles and prevent agglomeration. Sorbent injection rates for dry injection systems, as stated above, are usually three to four times stoichiometric requirements. The large amount of extra sorbent can handle moderate variations in inlet acid gas concentrations. For systems that are not equipped with outlet acid gas continuous monitors, the sorbent injection rate can be set at a constant level or varied with flue gas flow rate. If the system is equipped with an outlet monitor for HCl, the sorbent injection can be varied as needed.

4.5.4.2.1 Dry injection startup. There are no special considerations for dry injection startup. At startup of the incinerator, sorbent injection can be initiated.

4.5.4.2.2 Dry injection shutdown. The only special concern for shutdown of a dry injection system is to put the fabric filter through a cleaning cycle after sorbent injection is stopped. This prevents possible blinding from condensation and reaction product salt damage to the fabric filter components.

4.5.4.3 *Automatic control*

Dry injection systems can be equipped with outlet gas HCl continuous monitors. The sorbent injection rate can be controlled automatically based on the outlet HCl concentration.

4.5.4.4 *Monitoring*

Dry injection system parameters which can be monitored by the operator include:

1. Sorbent injection rate;
2. Pneumatic transfer line airflow rate;
3. Flue gas flow rate; and
4. HCl and SO_2 outlet gas concentrations.

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Chapter 5
Maintenance

Efficient operation of a hospital waste incinerator and any associated air pollution control device requires an aggressive preventive maintenance (PM) program. Effective maintenance will prolong the service life of the equipment, reduce the frequency of upset conditions and air pollution episodes, and save the hospital money by avoiding costly repairs. Information on the types and frequency of equipment inspections and maintenance procedures for incinerators, wet scrubbers, and fabric filters is provided in this chapter. The information provided represents only general guidance and should not be substituted for the equipment manufacturer's recommended maintenance schedule. Recordkeeping, which is an important part of a PM program, is mentioned briefly below and is discussed more fully in Chapter 8. Records of maintenance activities can help pinpoint problems and show trends in maintenance activities that may increase the life of the equipment and minimize emissions.

5.1 Hospital Waste Incinerators

Typically, the incinerator operator does not perform PM but makes hourly and daily inspections to ensure proper operation of the incinerator and its air pollution control device and the identification of potential problems. The hospital's maintenance department performs PM on the incinerator on a set schedule and corrects any potential problems identified by the operator. At some hospitals, the maintenance department performs PM on a work order system.[1] In practice, minimizing the number of PM items per work order ensures that PM is performed properly and with less downtime.[1]

Because of the diversity in both size and design of hospital waste incinerators, specific recommendations on PM practices and frequency that would be applicable to all units are impossible to make. Also, as noted above, the manufacturer's or vendor's recommended PM schedule for a particular unit should be followed, and the information presented here should only be used to supplement, not replace, that schedule. In general, however, PM activities for any hospital waste incinerator involve inspection, cleaning, and lubrication of incinerator components on a regular basis. Table 5-1 presents a typical PM program for a hospital waste incinerator. Note that both the components listed on the table for maintenance and the maintenance frequency will vary depending on the type and amount of waste being incinerated and the type of incinerator used. The sections below discuss the items on Table 5-1 in greater detail and are organized according to hourly/daily maintenance, weekly/biweekly maintenance, and monthly/semiannual maintenance.

5.1.1 Hourly/Daily Maintenance

The hourly maintenance activities described in Table 5-1 are simple inspections that are applicable to large, continuous-feed incinerators. These large units may be equipped with a water quench pit and an ash removal conveyor system that continuously removes ash from the incinerator.[2] The operator must routinely replenish the water in the quench pit because water is constantly removed by evaporation and by the ash removal system.[2,3] The water quench pit is used to quench or extinguish the hot ash as it is removed from the incinerator and to provide an air seal for the ash removal conveyor.[3] Therefore, it is essential that sufficient water be available. In addition, the operator should check the ash removal conveyor system frequently to remove any debris that could cause it to jam.[3] Small, batch-feed incinerators will likely have neither a water quench pit nor an automatic ash removal conveyor system.

Daily maintenance activities involve checking the operation of any opacity, oxygen, and CO monitors. These monitors indicate whether the operating/combustion conditions of the incinerator are within an acceptable range; for some units, the oxygen monitor may also be used to control the combustion air rate. Before the incinerator is started up, the opacity monitor and the CO monitor should read 0 percent opacity and 0 parts per million (ppm), respectively. The oxygen monitor should read about 21 percent oxygen (ambient air). If these monitors are equipped to conduct for daily calibration checks, the calibration checks should be conducted and the calibration values noted to assure that they are in the proper range. If not, maintenance personnel should be informed. An additional check for the opacity monitor is to observe the stack emissions and

Table 5-1. Typical Maintenance Inspection/Cleaning/Lubrication Schedule for a Hospital Waste Incinerator[4]

Activity frequency	Incinerator component	Procedure
Hourly	Ash removal conveyor	Inspect and clean as required.
	Water quench pit	Inspect water level and fill as required.
Daily	Opacity monitor	Check operation of the opacity monitor and check exhaust for visible emissions.
	Oxygen monitor	Check operation of the oxygen monitor.
	Thermocouples	Check operation of the thermocouples.
	Underfire air ports	Inspect and clean as required.
	Limit switches	Inspect for freedom of operation and potential obstructing debris.
	Door seals	Inspect for wear, closeness of fit, and air leakage.
	Ash pit/internal dropout sump	Clean after each shift on batch units that do not have continuous ash conveyor cleaning system.
Weekly	Heat recovery boiler tubes	Inspect and clean as required. (Clean weekly for 6 weeks to determine optimum cleaning schedule.)
	Blower intakes	Inspect for accumulations of lint, debris; clean as required.
	Burner flame rods (gas-fired units)	Inspect and clean as required.
	U.V. scanner flame sensors	Inspect and clean as required.
	Swing latches and hinges	Lubricate.
	Hopper door support pins	Lubricate.
	Ram feeder carriage wheels	Lubricate.
	Heat recovery induced-draft fans	Inspect and clean fan housing as required. Check for corrosion and V-belt drives and chains for tension and wear.
Biweekly	Hydraulic systems	Check hydraulic fluid level and add the proper replacement fluid as required. Investigate sources of fluid leakage.
	Ash removal conveyor bearings	Lubricate.
	Fuel trains and burners	Inspect and clean as required. Investigate sources of fuel leakage as required.
	Control panels	Inspect and clean as required. Keep panel securely closed and free of dirt to prevent electrical malfunction.
Monthly	External surface of incinerator and stack	Inspect external "hot" surfaces. White spots or discoloration may indicate loss of refractory.
	Refractory	Inspect and repair minor wear areas with plastic refractory material.
	Internal ram faces	Inspect for wear. These stainless steel faces may wear out and may require replacement in 1 to 5 years depending on service.
	Upper/secondary combustion chamber	Inspect and vacuum any particulate matter that has accumulated on the chamber floor.
	Large combustion air blowers and heat recovery induced draft fans (those fans whose bearings are not sealed)	Lubricate.
	Hydraulic cylinder clevis and trunnion attachments to all moving components	Lubricate.
	Burner pilots	Inspect and adjust as required.
Semiannually	Hot external surfaces	Inspect and paint with high-temperature paint as required.
	Ambient external surfaces	Inspect and paint with equipment enamel as required.
	Chains	Inspect and brush clean as required. Lubricate.

compare the observation to the opacity monitor reading. For example, if the opacity monitor, which normally reads below 5 percent, reads 25 percent, and a simple check of the exhaust stack shows an opacity of 0 percent, then something is wrong with the opacity monitor.

The thermocouples that indicate the temperature of the primary and secondary chambers should also be checked daily.[4] It is essential that these thermocouples be operating properly because the temperature monitored by these thermocouples typically is the parameter that controls the combustion airflow into the incinerator (controlled-air units) and burner operation.[2] The temperature readings should be ambient prior to incinerator startup. A thermocouple problem may be indicated if the operator notices a significant change in startup conditions, i.e., if significantly more auxiliary fuel is required than normal, or if it takes significantly longer to heat the incinerator than normal.[4] Also, a noticeable change in response time of the thermocouple is an indication of problems. Unfortunately, there is no simple way to check the accuracy of a thermocouple; either the thermocouple must be removed and tested or a second thermocouple must be inserted in a second thermocouple port, if available.

The remaining daily maintenance activities involve inspection for slagging and plugging (underfire air ports); inspection for obstructing debris (e.g., limit switches on charging doors, charging rams, hopper doors, etc.); inspection of door seals for wear, closeness of fit, and air leakage; and cleaning the ash from the hearth on batch and intermittent-duty incinerators.[4] The underfire air ports must be kept clean so that the proper amount of underfire air can reach the burning waste in a well distributed manner. Limit switches must be kept clear of debris because they control the proper adjustment of the charging door and the ram feeder (if installed).[2] Proper functioning of charging door and hopper/ram limit switches is essential because these switches ensure that the doors are fully opened/closed at the proper times and help prevent excessive air in-leakage to the incinerator during charging and operation.[2] Improperly sealed doors, which result in excessive air leakage, will not only affect incinerator operation, but also may result in more severe maintenance requirements (damage to seals or warpage due to excessive heat), as well as causing a fire/safety hazard. Finally, the ash typically is allowed to cool overnight and is removed from the hearth on batch and intermittent-duty incinerators the day after the burn.[1]

5.1.2 Weekly/Biweekly Maintenance[4]

Some of the large hospital waste incinerators (20 to 25 tons waste/d) may employ a waste heat recovery boiler to produce steam for use in the hospital. When first installed, the heat recovery boiler tubes should be cleaned weekly. The first indication of fouled tubes on the gas side will be the gradual increase of boiler outlet gas temperature. All blower intakes and the heat recovery induced-draft fan housing should be inspected weekly and cleaned as required. The burner flame rods (gas-fired units) or ultraviolet scanner flame sensors (other units) should also be inspected weekly and cleaned as required. The swing latches and hinges, the hopper door support pins, and the ram feed carriage wheels should all be lubricated weekly.

The biweekly maintenance items include the inspection of the fuel trains, burners, and control panels. These pieces of equipment should also be cleaned as required. Any sources of fuel leakage should be investigated. The hydraulic fluid level should be checked on all hydraulic systems, and the appropriate replacement fluid should be added as needed. Only the fluid recommended by the manufacturer should be used because other fluids may damage the hydraulic seals. The ash removal conveyor bearings on large incinerators should be lubricated biweekly.

5.1.3 Monthly/Semiannual Maintenance[4]

On a monthly basis, the incinerator operator should inspect the external hot surfaces of both the incinerator vessels and stack for white spots or other discoloration that may indicate a loss of refractory inside. Additionally, whether white spots are evident or not, the refractory lining inside the incinerator should be inspected for wear areas and any buildup of ash or metal oxides such as calcium, potassium, and sodium. Any minor wear areas in the refractory should be repaired using plastic refractory material. The metal oxides can cause a marked decrease in the softening temperature of the refractory that effectively reduces the operating temperature range. Any ash and metal oxide buildup should be washed off only after the incinerator has cooled to avoid damaging the refractory if the temperature of the wash water is significantly different from that of the refractory.

Large incinerators may be equipped with internal ash rams that push burning waste from one hearth to the next. The rams typically are made of refractory material with the exception of the front face of the ram, which is made of stainless steel. These stainless steel ram faces should be inspected for wear and damage each month initially until an optimum inspection schedule can be established. The ram faces may last from 1 year to 5 years depending upon the type of service in which they are used.

In controlled-air incinerators, the primary chamber is operated at less than stoichiometric air (starved-air) conditions, which minimizes the amount of fly ash carryover to the secondary (excess-air) chamber. However, in multiple-chamber (excess-air) designs, carryover of fly ash to the secondary chamber should be expected; the carryout of carryover will depend on the amount of excess air at which the primary chamber is operating. Therefore, a monthly inspection and cleaning schedule for the secondary chamber is appropriate for multiple-chamber units but may be unnecessary for controlled-air units. Manufacturers of controlled-air units specify vacuuming ash from the secondary chamber at least every 6 months. Therefore, an effective cleaning schedule for these units may be every 3 to 4 months until an optimum cleaning schedule can be established.

Large fans (those that do not have sealed bearings) and the hydraulic cylinder clevis and trunnion attachments should be lubricated monthly. Lastly, the burner pilots should be inspected and adjusted as required.

The semiannual maintenance activities include the inspection of all hot external surfaces, all ambient external surfaces, and any conveyor chains. All external surfaces should be cleaned; high-temperature paint should be applied to hot surfaces, and equipment enamel should be applied to ambient surfaces as required. The chains should be brushed clean if necessary and lubricated.

5.2 *Wet Scrubbers*[5-7]

A typical maintenance inspection, cleaning, and lubrication schedule for a wet scrubber is presented in Table 5-2. As with incinerators, the frequency with which these activities take place will depend on a number of variables including the size and complexity of the scrubber, the number of hours per day it operates, and the volume and pollutant concentration of the exhaust gas it handles. In addition, not all of the maintenance activities listed in Table 5-2 will be required at each scrubber installation. The type and frequency of maintenance activities will depend in large part on the scrubber vendor's recommendations and the experience of personnel with the unit.

5.2.1 Daily/Weekly Maintenance

The daily maintenance activities described in Table 5-2 are simple inspections that are applicable to all scrubbers. Most of these inspections involve checking various components for proper operation and fluid leakage. These inspections should be carried out after the scrubber has been started up and prior to startup of batch-feed incinerators so that any necessary repairs can be made before the scrubber has to control emissions. Scrubbers controlling continuous-feed incinerators should be inspected while both units are in operation.

Failure of components such as the scrubber liquid pump and variable throat activator (on venturi scrubbers) will cause the scrubber to be ineffective in controlling emissions from the incinerator. In such cases, the incinerator may have to be shut down depending on both the severity of the problem and any State regulations concerning operation of the incinerator without its attendant air pollution control device. Liquid leakage from these components also can have a detrimental effect on the performance of wet scrubbers. The sources of such leaks should be investigated and repaired as required.

Fans in wet scrubber service operate under substantially more severe conditions than those serving dry systems because humid conditions enhance the possibility of condensation of acids on the fan and fan housing. In the case of hospital waste incinerators, scrubbers and fans are likely to experience hydrochloric acid mist as a result of the combustion of chlorinated plastic material. Therefore, acid-resistant materials should be used in the construction of the scrubber interior and more frequent cleaning of the fan system serving the scrubber should be practiced. Unusual noise or vibration from any part of the fan system, including the bearings or belt, may indicate that replacement is necessary.

The weekly maintenance items include more inspections of components. The fan and the scrubber liquid pump oil levels should be checked and adjusted as appropriate. Additionally, the fan oil temperature and color should be checked. Temperature or color readings that are outside of the manufacturer's recommended ranges may indicate excessive wear and/or contamination of the oil. Both the fan and scrubber liquid pump bearings should be lubricated weekly.

5.2.2 Monthly/Semiannual Maintenance

The monthly maintenance activities consist of additional inspections and appropriate corrective actions as required. Clogged pipes, manifolds, and spray nozzles can hinder the proper operation of the scrubber. The pressure drop of the scrubber will be lower than normal if plugging is experienced. The pressure drop is a critical indicator of scrubber performance in removing particulate from the incinerator exhaust, and the pressure gauges should be checked and calibrated for accuracy. Some regulations may require a minimum pressure drop to be achieved across the venturi to assure a minimum pollutant removal efficiency. Therefore, it is important that the pressure gauges operate properly.

The main body of the scrubber, fan blades, and internal fan housing are subject to buildup of particulate matter that can adversely affect both scrubber and fan performance. These components

Table 5-2. Typical Maintenance Inspection/Cleaning/Lubrication Schedule for a Wet Scrubber

Inspection frequency	Component	Procedure
Daily	Scrubber liquid pump	Check for proper operation and leakage. Investigate sources of fluid leakage and repair as required.
	Variable throat activator	Check for proper operation and leakage.
	Scrubber liquid lines	Check for leakage. Repair as required.
	Mist eliminator pressure lines	Check for leakage. Repair as required.
	Reagent feed system	Check for leakage. Repair as required.
	Fan	Check for vibration and proper operation.
	Fan bearings	Check for abnormal noise.
	Fan belt[a]	Check for abnormal noise.
Weekly	Fan	Check oil level, oil color, oil temperature, and lubricate.
	Scrubber liquid pump	Check oil level and lubricate pump motor bearings.
	Damper air purge system	Check for proper operation.
Monthly	Duct work	Inspect for leakage.
	Fan and motor bearings	Inspect for leaks, cracks, and loose fittings.
	Fan blades and internal housing	Inspect for material buildup and clean as required. Inspect for abrasion and corrosion and repair as required.
	Drain chain drive mechanism	Check chain tension, sprocket wear and alignment, and oil level.
	Pipes and manifolds	Inspect for plugging/leaking and clean/repair as required.
	Dampers	Check for leakage.
	Spray bars	Inspect for nozzle wear and plugging and clean as required.
	Pressure gauges	Check for accuracy.
	Main body of scrubber	Inspect for material buildup and clean as required. Inspect for abrasion and corrosion and repair as required.
Semiannually	Fan, pump, motor, and drag chain bearings and gear reducers	Inspect clearances and wear, pitting, and scoring. Inspect for leaks, cracks, and loose fittings.
	Flowmeters	Check for accuracy.
	Damper drive mechanism	Check for proper operation and alignment.
	Damper seals, bearings, blades, blowers	Check for wear and leakage.

[a] Check fan belt tension whenever fan is out of service.

should be inspected and cleaned monthly. In addition, these components should be inspected for any abrasion caused by particulate matter or corrosion caused by hydrochloric acid mist that might adversely affect performance.

Fan and motor bearings should be inspected for leaks, cracks, and loose fittings. Dampers and ductwork should be checked for any air leakage. Leakage of air can cause condensation of moisture and acid gases due to the introduction of cool ambient air. Also, a large number of leaks in the ductwork will cause the induced-draft fan to pull more air, and the incinerator operator will have less control over the air introduced into the incinerator. The drag chain drive mechanism used on some automatic ash removal systems should be inspected for wear, chain tension, and sprocket alignment. The oil level also should be checked on this component and adjusted as required.

The semiannual maintenance activities include inspections of all bearings on fans, pumps, motors, and gear reducers for leaks, cracks, and loose fittings. Additionally, the clearances and any wear, pitting, or scoring should be checked on these components. The flow meters on the scrubber should be checked for accuracy. State regulations, in addition to requiring a pressure drop, also may require a specific water flow rate. Therefore, the flow meters should operate properly. The damper drive mechanism should be checked for proper operation and alignment; and the damper seals, bearings, blades, and blowers should be inspected for wear and leakage.

5.3 Maintenance of Fabric Filters[8,9]

Although the frequency and components of a PM program for a fabric filter system will depend on the type of system and the vendor's recommendations, the major components should be inspected on a routine basis, and any needed maintenance should be performed. The following sections describe the daily, weekly, monthly/quarterly, and semiannual/annual inspections/maintenance that are recommended. A specific PM program should be established based on the manufacturer's recommendations. A typical maintenance inspection, cleaning, and lubrication schedule for a fabric filter is presented in Table 5-3.

5.3.1 Daily Inspection/Maintenance

At least twice per shift (and perhaps as often as every 2 hours), plume opacity (visual inspection of stack outlet) and pressure drop should be checked. Sudden changes in these values along with those of temperature and gas volume may indicate a problem. For example, the failure or partial failure of the cleaning system generally will cause a relatively rapid increase in pressure drop in most systems. Timely identification, location, and correction of this problem can minimize operating problems and long-term effects on bag life. Although identification and subsequent correction of relatively minor problems have little effect on fabric life, some minor problems tend to turn into major failures. The ability to perform on-line maintenance depends on the design of the control equipment.

Routine checks of the fabric filter include pressure drop (and patterns if a ΔP indicator and recorder are used), plume opacity at the outlet, dust discharge operation, and external checks (i.e., visual inspection) of the cleaning system operation. Other factors that can be checked include temperature (range) and fan motor current. If a check of these factors reveals a sudden change, maintenance should be scheduled as soon as possible.

5.3.2 Weekly Inspection/Maintenance

The extent of the weekly maintenance program depends greatly on access and design of the fabric filter. Where possible, quick visual inspections should be conducted; however, not all systems or processes are amenable to this type of review. A weekly lubrication schedule should be established for most moving parts. Manometer lines should be blown clear, and temperature monitors should be checked for proper operation.

When a fabric filter is the air pollution control device of choice for a hospital waste incinerator, it is almost always a pulse-jet fabric filter. The following items should be checked weekly. On the dirty side of the tubesheet, bags should be checked for relatively thin and uniform exterior deposits. Bags also should be checked for bag-to-bag contact (points of potential bag wear). On the clean side of the tubesheet, each row of bags should be examined for leakage or holes. Deposits on the underside of the blowpipes and on the tubesheet may indicate a bag failure. The cleaning system should be activated (the inspector should use hearing protection), and each row of bags should fire with a resounding "thud." The blowpipes should remain secured, and there should be no evidence of oil or water in the compressed air supply. The surge tank or oil/water separator blowdown valve should be opened to drain any accumulated water. Misaligned blowpipes should be adjusted to prevent damage to the upper portion of the bag. The compressed air reservoir should be maintained at about 90 to 120 psi.

On a weekly basis, the dust removal system including hopper and screw conveyor should be inspected to make sure that dust is being removed from the system by checking the conveyor for jamming, plugging, wear and broken parts, etc. Problems with the conveyor system are indicated when the conveyor appears to be moving but no dust is dropping into the dust storage container, when the conveyor does not move, or when the conveyor makes unusual sounds.

5.3.3 Monthly/Quarterly Inspection/Maintenance

Requirements for monthly or quarterly maintenance and inspection for fabric filters are very site specific. Clear-cut schedules cannot be established for such items as bag replacement and general maintenance of the fabric filter. Some items, however, may warrant quarterly or monthly inspections, depending on site-specific factors. Items to be checked include door gaskets and airlock integrity to prevent excessive in-leakage (both air and water) into the enclosure. Any defective seals should be replaced. Baffles or blast plates should be checked for wear and replaced as necessary, as abrasion can destroy the baffles. Some facilities prefer to use fluorescent dye to check the integrity of the bags and bag seals. Any defective bags should be replaced, and leaking seals should be corrected.

Bag failures tend to occur shortly after installation and near the end of a bag's useful life. A record of bag failures and replacements is invaluable for identifying recurrent problems and indicating when the end of bag life has been reached. Initial bag failures usually occur because of installation errors or bag manufacturing defects. When new bags are installed, a period with few or no bag failures is normally expected unless serious design or operation problems exist. As the bags near the end of their useful life, however, the number of bag failures may increase dramatically. When weighed against factors such as downtime for rebagging, the cost of new bags, and the risk of limited incinerator operating time as the result of keeping the old bags in service, the most economical approach may be to replace all the bags at one time to eliminate or minimize failure rate.

In some cases, bags can be washed or drycleaned and reused, e.g., when dewpoint limits are approached or the bags are blinded in some manner. Although cleaning may shorten bag life somewhat, cleaning may still be more economical than replacement if

Table 5-3. Typical Maintenance Inspection/Cleaning/Lubrication Schedule for a Fabric Filter System[8,9]

Inspection frequency	Component	Procedure
Daily	Stack	Check exhaust for visible dust.
	Manometer	Check and record fabric pressure loss and fan static pressure. Watch for trends.
	Compressed air system	Check for air leakage (low pressure). Check valves.
	Collector	Observe all indicators on control panel and listen to system for properly operating subsystems.
	Damper valves	Check all isolation, bypass, and cleaning damper valves for synchronization and proper operation
	Rotating equipment and drives	Check for signs of jamming, leakage, broken parts, wear, etc.
	Dust removal system	Check to ensure that dust is being removed from the system.
Weekly	Filter bags	Check for tears, holes, abrasion, proper fastening, bag tension, dust accumulation on surface or creases and folds.
	Cleaning system	Check cleaning sequence and cycle times for proper valve and timer operations. Check compressed air lines including oilers and filters. Inspect shaker mechanisms for proper operation.
	Hoppers	Check for bridging or plugging. Inspect screw conveyor for proper operation and lubrication.
Monthly	Shaker mechanism	Inspect for loose bolts.
	Fan(s)	Check for corrosion and material buildup and check V-belt drives and chains for tension and wear.
	Monitor(s)	Check accuracy of all indicating equipment.
Quarterly	Inlet plenum	Check baffle plate for wear; if appreciable wear is evident, replace. Check for dust deposits.
	Access doors	Check all gaskets.
	Shaker mechanisms	Tube type – (tube hooks suspended from a tubular assembly): inspect nylon bushings in shaker bars and clevis (hanger) assembly for wear. Channel shakers – (tube hooks suspended from a channel bar assembly): inspect drill bushings in tile bars and connecting rods for wear.
Semiannually	Motors, fans, etc.	Lubricate all electric motors, speed reducers, exhaust and reverse-air fans, and similar equipment.
Annually	Collector	Check all bolts and welds. Inspect entire collector thoroughly, clean, and touch up paint where necessary.

more than half a bag's "normal" life expectancy remains.

5.3.4 Semiannual/Annual Inspection/Maintenance

Some motors and packaged blowers are supplied with sealed bearings and, therefore, require no lubrication. Semiannual fabric filter system maintenance activities include the lubrication of the following components having nonsealed bearings: all electric motors, speed reducers, exhaust and reverse air fans, and similar equipment.

Annual maintenance activities include checking the tightness and fit of all bolts and welds on the fabric filter. Additionally, the unit should be cleaned and painted as appropriate.

5.4 References for Chapter 5

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Chapter 6

Control and Monitoring Instrumentation

6.1 Operating Parameters that Should be Monitored

Proper operation of incinerators depends to a large extent on certain operating parameters that are commonly monitored to provide necessary information to properly control the process. These usually consist of:

1. Temperature;
2. Pressure;
3. Oxygen;
4. CO;
5. Opacity; and
6. Charge rate.

Although all of the above parameters provide useful information, many hospital incinerators monitor only temperature and pressure. The other parameters listed are sometimes monitored on larger incinerators or if regulatory agencies require that monitoring be conducted (e.g., opacity).

The temperature and oxygen level are key parameters, and incinerators are normally designed to monitor one or both of these parameters to provide the necessary information for automatic control of combustion air input and auxiliary fuel rates. To maintain the desired draft in the incinerator, control loops may be used to adjust incinerator draft by means of barometric dampers or the induced draft fan. The other parameters provide additional information that operators can use to maintain proper operation (e.g., charge rate, oxygen levels).

Proper operation of wet scrubber systems is dependent on several operating parameters that are commonly monitored, usually consisting of:

1. Pressure and pressure drop;
2. Scrubber liquid flow;
3. Scrubber liquid pH;
4. Temperature.

For venturi scrubbers, pressure drop is normally monitored and automatically controlled to a fixed level by adjusting the venturi throat. For venturis and packed beds, the scrubber liquid flow is usually established at a constant rate and is not automatically controlled during operation. For both types of scrubbers, control of pH is necessary to prevent damage to the scrubber equipment. Most scrubbers are designed to monitor and control pH automatically. Gas flow and temperature are often monitored to provide operators with additional information useful in maintaining proper operation by indicating potential problems and the need to make manual adjustments. Other instrumentation and control often includes an automatic liquid level control for the scrubber liquid sump, and a temperature switch/solenoid valve to activate an emergency quench spray and/or an emergency bypass stack.

For fabric filters, the key operating parameter which typically is monitored is pressure drop across the bags. Temperature also is monitored to assure that the temperature does not decrease below the dewpoint or increase to a level which will cause bag damage.

The next section describes the typical instrumentation used to monitor/control these key parameters and briefly discusses its proper use and operation.

6.2 Typical Instrumentation

6.2.1 Temperature Sensors

Thermocouples are used to monitor temperatures in the combustion chambers and the air pollution control system. The thermocouples are always enclosed in a thermowell to protect the small thermocouple wires and the critical thermocouple junction from direct exposure to the combustion gases and entrained dust particles, among other vagaries. Thermocouples are usually located near the exit of the combustion chamber to provide a representative temperature reading away from the flame zone, which can otherwise cause erratic temperature readings as well as damage to the thermocouple. Thermowells may extend several inches past the inner wall of the refractory into the gas stream, or may extend only to the depth of the refractory. Thermowells that extend past the refractory provide a more accurate measure of the gas temperature and respond more quickly to temperature changes; however, this type also may be subject to dust and slag buildup, which can slow response to temperature changes. Generally, thermocouples also are located upstream of the air pollution control system to provide a warning or control mechanism for high temperature excursions that could damage control equipment.

The different types of thermocouples are identified by the metal used for the thermocouple junction wires. The most common types are listed in Table 6-1. Replacement thermocouples must always be the same type as the original because the receiver to which a thermocouple is connected is designed to receive the signal from a specific type of thermocouple. Thermocouples generate a small millivolt signal that increases with increasing temperature, but the amount of voltage for a given temperature is different for each type of thermocouple. It is important to realize that thermocouples operate on the basis of a junction between two different metals that generates only a small millivolt signal. Consequently, any wiring connections from the thermocouple to the receiver or any interfering electrical signals can affect the resulting temperature reading. This sensitivity necessitates the special shielding of the wire in electrical conduit.

Table 6-1. Thermocouple Types

Type	Materials	Upper temp., °F
J	Iron/Constantan	1400
E	Chromel/Constantan	1650
K	Chromel/Alumel	2300
S	Pt 10% Rhodium/Pure Pt	2650
R	Pt 13% Rhodium/Pure Pt	2650
B	Pt 30% Rhodium/Pt 6% Rhodium	3100

Although thermocouples typically are very reliable, they can fail or give erroneous readings. For example, the thermocouple junction or wire may break after long exposure to high temperatures. However, a thermocouple can give erroneous readings for reasons that are not as obvious as a broken junction or wire. For example, if mechanical vibration abrades the insulation and one of the thermocouple wires comes into contact with the metal wall of the thermowell or other grounded metal surface, an erroneous temperature reading will likely result. As noted earlier, faulty thermocouple readings may also be the result of external conditions; for example, excessive dust buildups around a thermowell can insulate it from the gas stream and result in erroneously low temperature readings. To have the ability to compare readings to identify a faulty thermocouple, dual thermocouples are often used at nearby locations in the incinerator chamber. The second thermocouple enables continued monitoring of temperatures while the faulty thermocouple is being checked or replaced.

Periodic replacement of thermocouples, and checking the physical integrity of the thermowell and any outer dust buildup, is probably the best maintenance procedure. Because it is not practical to perform a high temperature calibration of the thermocouple, only periodic replacement ensures that a properly operating thermocouple is in place. The receiver should be checked periodically using calibrated equipment that produces a known millivolt signal equivalent to a specific temperature reading for a particular type of thermocouple. The generated signal can be applied to the thermocouple leads to check that the receiver's output produces the correct "temperature" reading.

Close monitoring of temperatures is essential to good incinerator operation. It is essential, therefore, to identify possible thermocouple problems because the temperature signal is usually the primary measurement used for the automatic control of auxiliary fuel burners and combustion air input. Any problem with the thermocouple temperature reading can cause the automatic control system to make inappropriate changes in the controlled variable in an attempt to maintain the desired (setpoint) temperature.

6.2.2 Pressure

The incinerator draft is measured in units of gauge static pressure, but it is actually a measure of the differential pressure (ΔP) between the inside of the chamber and the outside air. Monitoring of ΔP can be done with a common U-tube manometer, but for incineration systems, a differential pressure gauge (e.g., Magnehelic®) or a differential pressure transmitter typically is used. All of these instruments use the same basic method to monitor incinerator draft. One side (the high-pressure side) of the instrument is always open to the ambient air; the other (low-pressure) side is connected by tubing or piping to the incinerator.

These types of pressure monitors also are used to measure differential pressure across an air pollution control system (e.g., venturi scrubber throat or fabric filter baghouse). For this application, the low-pressure side is connected to a pressure tap in the ductwork downstream from the control device and the high-pressure side is connected upstream from the control device.

A differential pressure transmitter contains a diaphragm with two tubes connected on each side of the diaphragm; the diaphragm moves or deflects as a result of changes in pressure. The transmitter is designed so that any change or deflection causes a change in an electrical output signal from the transmitter. The electrical signal is sent to the monitor in the control room that indicates the incinerator draft or the pressure differential across the air pollution control system.

Several problems can cause faulty incinerator draft readings. Transmitters used to measure ΔP are sensitive devices that can be damaged by excessive vibration or sudden shocks. The severe hot and dirty conditions in the incinerator may also cause problems such as plugging in the tubing and its connections. When faulty incinerator pressure readings are suspected, several procedures for correcting them can be used. Air can be blown through the tubing to clear any plugging, and a known ΔP can be applied to the transmitter to check its response and span. Disconnecting any instrumentation should be done by experienced instrumentation personnel and must be coordinated with the operator so that the appropriate instrument can be put on manual control. For example, if the incinerator's automatic control system maintains incinerator draft via a damper on the ID fan inlet duct, disconnecting the pressure tap would probably cause the ID fan to increase flow in an effort to maintain the draft setpoint, thereby upsetting the temperature and other process operating parameters.

6.2.3 Oxygen Concentration[1]

Some incinerators may be equipped with oxygen analyzers to monitor the oxygen concentration in the combustion gases from the secondary combustion chamber to help ensure that adequate oxygen is available for proper combustion (i.e., that the excess-air level is sufficient). In some incinerators, the oxygen levels measured by the monitor are used to control air feed rates for control of the combustion process. In essence, lower waste feed rates require lower air feed rates in order to maintain essentially constant temperature and constant percent oxygen in the combustion gases, so long as the characteristics of the waste feed are the same. However, if the composition of the feed changes (i.e., its heating value changes), more or less air will be needed to maintain the same temperature and oxygen content in the combustion gases. Thus, the oxygen content is a useful parameter to monitor and is an important control parameter if the incinerator is set up to control based on oxygen level rather than temperature.

Oxygen monitors may be of two types: in situ or extractive. In situ merely means that the analyzer's sensor is mounted in direct contact with the gas stream. In an extractive system, the gas sample is continuously withdrawn (extracted) from the gas stream and directed to the analyzer which may be located several feet or several hundred feet away. Extractive analyzers include a conditioning system to remove dust and moisture from the gas sample; thus, the oxygen concentration measurement is on a dry basis. In situ analyzers, on the other hand, do not include a conditioning system, and the oxygen concentration measurement is on a "wet basis." For the same gas stream, the oxygen measurement obtained with an in situ analyzer will be slightly lower than that obtained with an extractive analyzer. For example, a typical combustion gas stream that contains 10 percent water vapor will yield a reading of 8 percent oxygen using an in situ analyzer and a reading of 10 percent oxygen using an extractive analyzer.

Regardless of the type of analyzer, the location of the sampling point is very important to ensure that a representative sample is obtained. The monitoring point may be in the stack, the combustion chamber exit, or other locations within the process (e.g., duct between air pollution control system and the stack). In most cases, the intent is to monitor the combustion gases at the exit of the combustion chamber and that, in fact, is where the sampling point is often located. One of the main problems related to sampling location that can occur is obtaining a nonrepresentative sample due to in-leakage of air. For example, substantial air in-leakage can occur through emergency stack dampers. Any such in-leakage affects the analyzer reading if the sample point is downstream of the in-leakage. However, there are practical limitations with regard to locating oxygen monitors. The in situ sensor or probe for extracting the sample must be located in an environment consistent with the monitor's design. High temperatures, particulate concentrations, and acid gas concentrations can have adverse effects on the monitoring system resulting in operational and/or maintenance problems.

Oxygen analyzers are capable of good accuracy (±1 percent of full scale) as long as the actual gas to be sampled reaches the analyzer (no plugging or in-leakage of air), the conditioning system (if one is present) is operating properly, and the instrument is calibrated. Electrocatalytic in situ monitors have rapid response times (i.e., seconds). The response times for polarographic and paramagnetic extractive analyzers are slower (several seconds to a minute). Extractive systems inherently involve longer response times, usually on the order of 1 to 2 minutes, depending on the sampling rate and the volume of the sampling line and conditioning system.

Problems with oxygen analyzer systems may be difficult to discern since they commonly are associated with slowly developing plugging in the system, or small air in-leaks, etc. The extractive systems should be checked daily by the operators, and maintained and calibrated on a weekly basis by the incinerator instrument personnel.

6.2.3.1 In-Situ Oxygen Analyzers

In situ analyzers provide rapid response to changes in the oxygen content of the gas because the sensor is in direct contact with the gas stream. In most cases, the sensing element is enclosed in a sintered stainless steel tube, which allows the gas to permeate through the tube but prevents particles in the gas stream from entering. Most in situ oxygen analyzers are equipped with connections so that zero gas (nitrogen) or calibration gas (air) can be flushed through the permeable tube and in contact with the sensing element. Flushing provides a means of zeroing and spanning the analyzer, and also creates reverse flow of gas through the permeable tube that helps to remove dust particles that eventually will clog the tube and slow the detector's response time. Even so, the tube periodically must be removed for cleaning or replaced if warranted.

Most in situ oxygen analyzers are of the electrocatalytic type, sometimes referred to as fuel-cell analyzers. Operation of these analyzers is based upon an electron flow created by reaction of oxygen with a solid zirconium oxide electrolyte. Consequently, manufacturers recommend that the sensing element be replaced after several months of service.

6.2.3.2 Extractive Oxygen Analyzers

Extractive analyzers always involve a "conditioning system" for removal of water, dust, and sometimes other constituents that would interfere with operation of the analyzer. An example extractive system is illustrated in Figure 6-1. The moisture knockout for removal of water vapor and the normal connections for zeroing and calibrating the analyzer are shown.

The integrity of the sample line and the conditioning system is crucial to obtaining a representative sample and accurate results. Any in-leakage of air can drastically distort the reading. As shown in Figure 6-1, the extractive system requires a pump to draw the sample gas continuously through the sample line, conditioning system, and analyzer. Most systems include a small rotameter (flowmeter) which shows that sample gas is flowing through the system. This flowmeter is always one of the first items that should be checked if any problem is suspected because loss of flow will occur if the pump fails or the system is plugged. However, even if the flow rate is correct, the measured gas concentration will not be correct if there is any problem with in-leakage of air.

Two types of extractive oxygen analyzers, paramagnetic and polarographic analyzers, are available in addition to the electrocatalytic type described previously for in situ analyzers. Paramagnetic analyzers measure the oxygen concentration as the strength of a magnetic field in which oxygen molecules are present. Oxygen molecules are somewhat unique in displaying a permanent magnetic moment (paramagnetism), allowing oxygen concentration to be differentiated from the stack gas sample. Calibration is performed by monitoring an inert gas such as nitrogen (zero) and a gas of known oxygen concentration (span). A potential problem with this type of analyzer is its susceptibility to paramagnetic molecules other than oxygen. Nitrogen oxide and nitrogen dioxide in particular display a high degree of paramagnetism (about one-half that of oxygen), but their concentration is usually low compared to that of oxygen.

Polarographic analyzers monitor oxygen concentration by allowing oxygen to pass through a selective, semipermeable membrane and react at an electrode in an oxidation-reduction reaction. Measuring the current produced by the reaction indicates the oxygen concentration. Improper conditioning of the sample gas is a potential problem with these analyzers, since moisture and particles will hinder performance of the semipermeable membrane. Calibration is performed by zeroing with an oxygen-free gas (nitrogen) and spanning with a gas of known oxygen concentration (e.g., air). Furthermore, these monitors contain a liquid electrolyte that has a limited life span and must be replaced at regular intervals.

6.2.4 Carbon Monoxide[1]

Carbon monoxide (CO) analyzers are used to measure emissions of CO and indicate whether proper combustion conditions are being maintained. Carbon monoxide analyzers typically are not part of the automatic process control system. In general, a problem with CO levels (i.e., high level) indicates some other problem in the process and its control system (e.g., feed rate or temperature).

Location of the CO sampling point may vary, although it is most commonly in the stack or at the exit of the combustion chamber. As with oxygen monitors, CO analyzers can be affected by upstream in-leakage of air, but usually not as dramatically as oxygen monitors.

Carbon monoxide analyzers also may be in situ or extractive, but by far the most common type is extractive. Both types are based on the principle that CO will absorb specific wavelengths of light in the infrared region. They are therefore referred to as nondispersive infrared (NDIR) analyses.

In situ CO monitors involve an infrared signal that is transmitted across the duct or stack to a receiver or

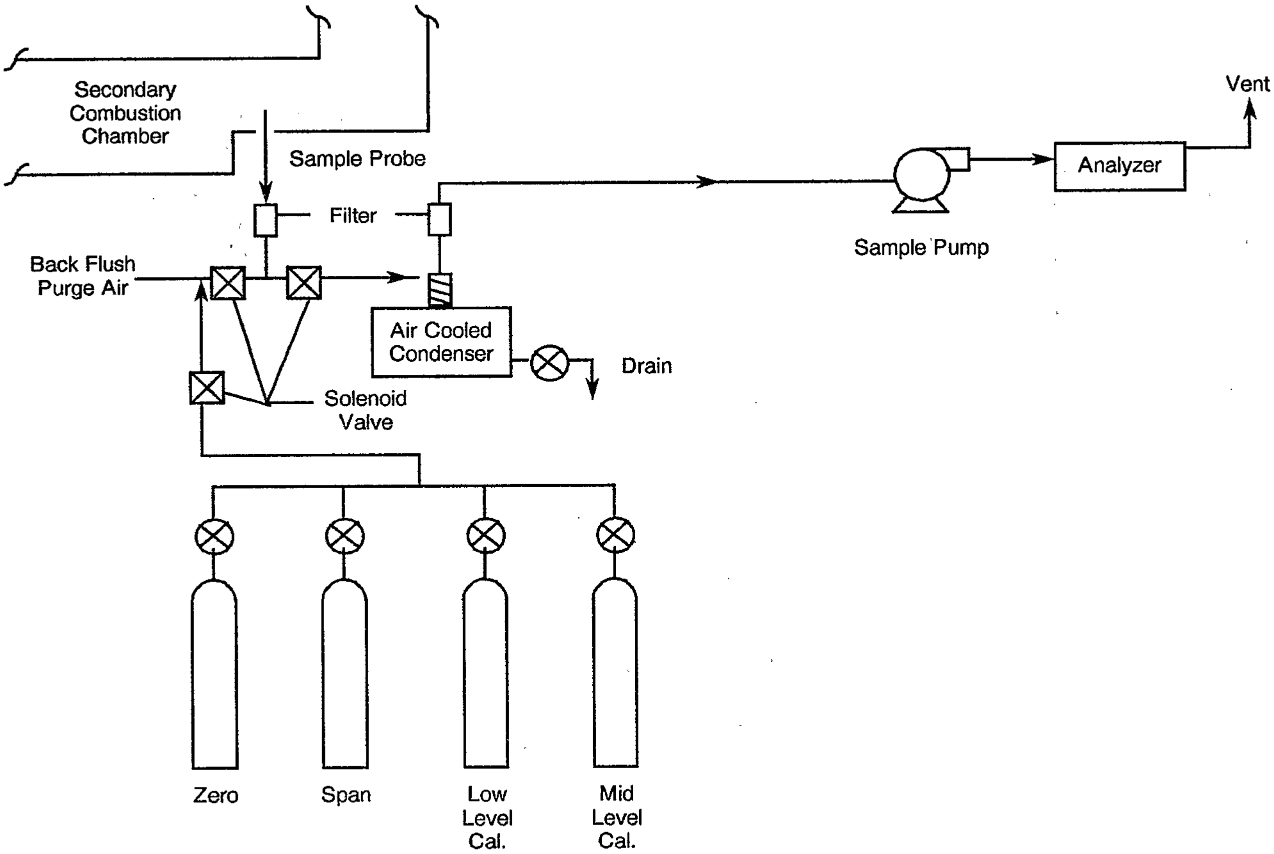

Figure 6-1. Schematic of an extractive monitoring system.

reflector on the opposite side. The change in the signal, due to absorbence by CO, is processed by the analyzer system and output as an equivalent CO concentration. In situ CO monitors are difficult to calibrate directly because the duct cannot be filled with a gas of known concentration. Therefore, calibration is performed using an optical filter that can be moved into the signal path, or a calibration gas that can be put through a separate cell through which the infrared signal can be sent.

In most cases, in situ systems are installed at a location in a stack after pollution control devices have removed most of the particulate matter because solid particles also absorb the IR signal. Water vapor and carbon dioxide also may interfere with the signal. Because all these interferences can be removed by a sample conditioning system, the extractive systems are more commonly used.

Much of the previous discussion on extractive oxygen systems applies to extractive CO systems. In fact, the same extraction/conditioning system often is used for both monitors. Daily checks of the system should be made by the operator, with weekly maintenance and calibration by the instrument personnel.

Currently, there are no specific EPA performance requirements for CO analyzers on hospital incinerators. However, EPA is developing guidelines for CO monitors that are required on hazardous waste incinerators permitted under the Resource Conservation and Recovery Act (RCRA).

6.2.5 Opacity[1,2]

Like CO monitors, opacity monitors (or transmissometers) are used as indicators of proper operation rather than as a part of the automatic control system and almost always are located in the stack or in the ducting to the stack downstream of air pollution control devices. The operating principle for these transmissometers involves measurement of the absorbence of a light beam across the stack or duct. Consequently, they are not applicable in saturated wet streams downstream of wet scrubbers unless the gas has been reheated to vaporize any water droplets.

Transmissometers involve a light source directed across the stack and a detector, or reflector, on the opposite side. The amount of light absorbed or scattered is a function of the particles in the light path, path length (duct diameter), and several other variables that are considered in the design and installation. A typical transmissometer is depicted in Figure 6-2.

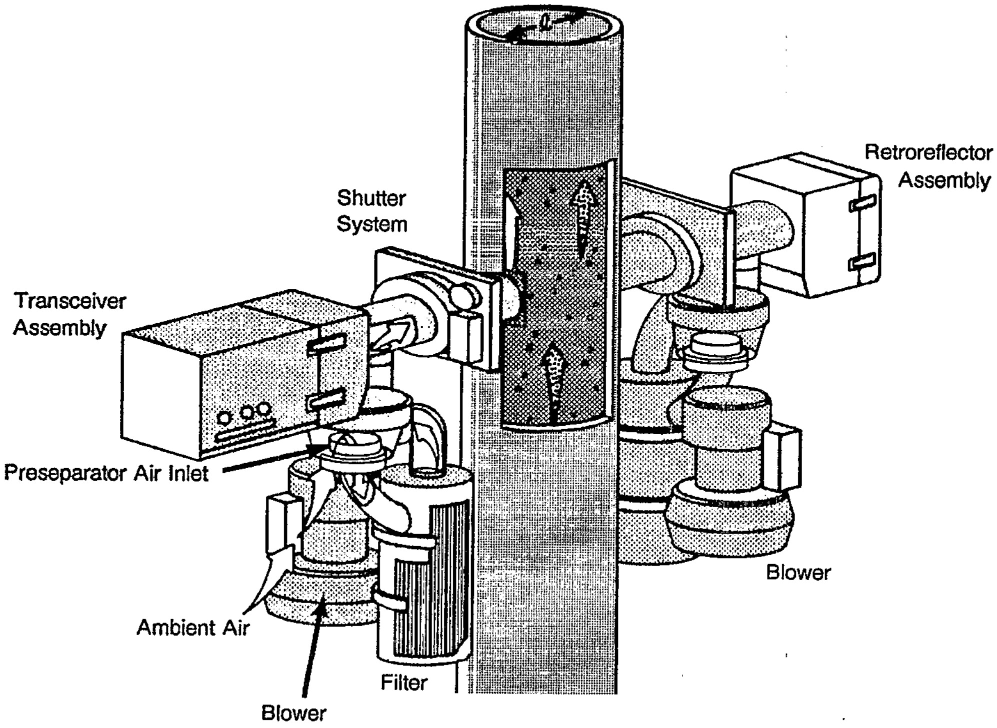

Figure 6-2. Typical transmissometer installation for measuring opacity.[1]

The lenses on the light source and the detector must be kept clean of any buildup of dust. For this reason, the systems often include air blowers and filters that continuously blow clean air past the lenses to prevent contact with the gas and dust in the stack (see Figure 6-2). These blowers and filters should be checked and cleaned regularly but often are neglected because of their location on the stack.

The EPA has promulgated[3] performance specifications for opacity monitoring systems that are required at some types of plants as summarized in Table 6-2. The calibration procedure for this performance specification, or normal checking of the instrument, is based on filters having known light absorbence that can be placed in the light path. Some systems automatically calibrate on a regular schedule that is evident to the operator because it usually activates a high opacity alarm or a spike on the opacity recorder.

Table 6-2. Performance Specifications for Opacity Monitors[3]

Parameter	Specifications
Calibration error[a]	≤3 percent opacity
Response time	≤10 seconds
Conditioning period[b]	≤168 hours
Operational test period[b]	≤168 hours
Zero drift (24-hour)[a]	≤2 percent opacity
Calibration drift (24-hour)[a]	≤2 percent opacity
Data recorder resolution	≤0.5 percent opacity

[a] Expressed as the sum of the absolute value of the mean and the absolute value of the confidence coefficient.

[b] During the conditioning and operational test periods, the CEMS must not require any corrective maintenance, repair, replacement, or adjustment other than that clearly specified as routine and required in the operation and maintenance manuals.

6.2.6 Charge Rate

The amount of waste charged into the incinerator and the charging frequency are important operating variables for an incinerator. Some incinerators may be equipped with systems that weigh the amount of each charge and automatically record this weight, but, at most facilities, the amount charged is based on operator experience and hopper charge size and is not closely monitored. Thus, operator experience is relied upon to avoid overcharging (stuffing), which may decrease temperature, increase emissions (CO), and cause poor burnout. Undercharging will require excessive auxiliary fuel usage.

For mechanically charged systems, the charging frequency is often automatically set by the system at preselected time intervals. As long as the loader fills the charging hopper to a certain level within this time interval, the charging rate will be maintained constant by the control system, unless the charging frequency is changed by the operator. Altering the charging frequency is sometimes necessary when the characteristics or composition of the waste has changed. For example, if a charge contains large amounts of plastic or other high heating value material, temperatures may rise rapidly. Thus, the operator may decide to delay the next charge until the system can again handle another charge. For mechanical systems, a recorder can be set up to indicate the frequency of changes automatically, i.e., when a charge is fed to the incinerator.

Having a charging record available is useful for monitoring and troubleshooting problems and for determining whether adjustments to the charging procedures are necessary.

Operator judgment and experience are usually key to proper control of charging rate; pressure on the operator to increase the charging rate when the amount of accumulated waste has increased cannot be allowed to compromise proper incinerator operating conditions.

6.2.7 Scrubber Liquor pH

There are two types of pH sensors: immersion (dip-type) and flow-through. The immersion sensor is merely inserted into a tank and can be removed for maintenance and calibration. A flow-through sensor depends upon a continuous flow in the sample line. Both have advantages and disadvantages. The immersion sensor is easier to operate and maintain. Performance can also be improved by locating the sensor in a special sampling tank, by using redundant sensors, and by frequent cleaning and calibration. The flow-through pH sensor is prone to wear and abrasion. Redundant sensors are also desirable for the flow-through type but are not easy to provide.

The pH measurement probe consists of a pH measuring electrode, a reference electrode, and a high input impedance meter. The voltage of the pH electrode varies with the pH of the solution it is in contact with, while the reference electrode delivers a constant voltage. The difference between the two voltages is measured by the impedance meter, allowing pH of the system to be monitored. Such a system is susceptible to signal loss and noise, making it desirable to locate the preamp, controller, or signal conditioning unit as close to the electrodes as possible.

Calibration of a pH monitoring system is performed through the use of known pH buffer solutions. Typically, pH 7 is used for calibration, although pH 4 and pH 10 may also be used, depending upon the expected ranges of scrubber operation. For greatest accuracy, buffer solutions should be selected that are close to expected pH values.

The pH monitoring system electrodes may become fouled over time by dirt, particulate matter, and bacteria. This fouling can damage or inhibit correct electrode operation, introducing drift and inaccuracy in the unit's calibration. To maintain reliability, electrodes can be boiled in a solvent or cleaned with a built-in ultrasonic device. Calibration checks usually are necessary every few weeks.

Control systems for pH meters range in complexity from simple ON/OFF types to more sophisticated proportional controllers. In an ON/OFF type, as pH goes out of range, a valve opens and neutralizing reagent is added until the pH is corrected. Proportional controllers add an amount of neutralizing reagent in proportion to deviation of pH from the setpoint, which provides much smoother control. The exact type of controller necessary for the system is based upon individual needs, but typically a proportional controller is used.

The pH measurement probe should be placed at a representative location within the system. Turbulent flow is needed to ensure a well-mixed solution and to limit dead time (reaction time of the controller) to 30 seconds or less. Excessive dead time will cause the system to overshoot the pH setpoint continually as the controller is unable to react quickly enough and continues to add neutralizing reagent beyond the desired pH. Dead time can be reduced by locating the pH probe a short distance downstream from where the reagent is added.

6.3 References for Chapter 6

1. U. S. EPA. Continuous Air Pollution Source Monitoring Systems Handbook, EPA 625/6-79-005. June 1979.

2. Jahnke, J. APTI Course SI:476A, Transmissometer Systems Operation and Maintenance, an Advanced Course. EPA 450/2-84-004. U.S. Environmental Protection Agency, Research Triangle Park, N.C. September 1984. p. 6-9.

3. Code of Federal Regulations, Title 40 Part 60 (40 CFR 60), Appendix B, Performance Specification 1. Specifications and Test Procedures for Opacity Continuous Emission Monitoring Systems in Stationary Sources.

Chapter 7

Operational Problems and Solutions

Potential operational problems associated with hospital waste incinerators, wet scrubbers, and fabric filters are described in this chapter. The cause of the problems and possible solutions to them are discussed also. Unfortunately, some operational problems are the result of deficiencies in design, fabrication, and/or installation of the equipment. Deficiencies in incinerator design are usually the result of insufficient information on the waste characteristics and/or quantity. The assumption is made in the following paragraphs that the incinerator and its air pollution control system have been properly designed, fabricated, and installed. Therefore, no deficiencies in these areas are addressed. Purchasers of hospital waste incinerators and air pollution control systems should consult with reputable manufacturers. In many cases, these companies can provide complete turnkey service that includes evaluation of the purchaser's needs, proper design of the incinerator based on waste characteristics, proper design of the air pollution control device based on expected combustion exhaust gas characteristics, fabrication of the incinerator with appropriate quality control, installation and shakedown of the entire system, and operator training.

7.1 Operational Problems and Solutions Associated with Hospital Waste Incinerators

Incinerator operational problems include excessive stack emissions in the form of white or black smoke, smoke leakage from the charging door or other openings, excessive auxiliary fuel usage, and incomplete burnout of the waste. These operational problems can be minimized through proper operation of the incinerator together with an effective preventive maintenance program.

7.1.1 Excessive Stack Emissions – Controlled-Air Units[1,2]

The proper operation of controlled air incinerators results in relatively low emission rates. Excessive emission rates can usually be attributed to one of the following causes:

1. High setpoint for the secondary burner temperature is not high enough;
2. Excessive negative draft in the primary chamber;
3. Excessive infiltration air (from charging door);
4. Excessive underfire air in the primary chamber;
5. Operating at too high a primary chamber temperature;
6. Overcharging;
7. Problem wastes; and
8. Inadequate secondary combustion air.

7.1.1.1 Black Smoke

The appearance of black smoke indicates the presence of unburned carbonaceous material. Dense black smoke is caused because incomplete combustion is occurring. Incomplete combustion is due to insufficient amounts of combustion air for the quantity of volatiles/soot present and is usually the result of overcharging the unit, charging of a highly volatile material, or operating the primary chamber at too high a temperature. The following steps may assist in eliminating black smoke:

1. Check/increase secondary chamber combustion air;
2. Check/decrease underfire air (if necessary); an air decrease should result in reducing the primary chamber operating temperature;
3. Check/increase secondary chamber temperature.

Should these steps fail to eliminate the black smoke, evaluate the composition of the material remaining to be charged. Highly combustible materials (i.e., rubber, plastics, etc.) that are charged in too great a proportion to the other refuse will result in a combustion rate which is too rapid for the incinerator to handle. These materials may be charged in very small quantities and in relatively small pieces along with general refuse. If such materials must be burned frequently, experimentation as to the quantity that may be charged along with other materials may be necessary. Generally, highly combustible materials must be charged at less than 10 percent by weight of the total charge. If the waste contains a significant amount of plastics, then reducing the primary chamber temperature (to the 540° to 650°C [1000° to 1200°F] range) may assist in reducing emissions.

Operating the primary chamber at too high a temperature can cause the plastics to rapidly volatilize.

7.1.1.2 White Smoke

The appearance of a steady stream of white smoke from the stack indicates the presence of small aerosols in the effluent gas. There are several causes for this problem. Either excess air is entering the incinerator causing entrainment of micron-sized particles or the secondary chamber is operating at too low a temperature (i.e., too much air) causing premature cooling of the combustion gases. The following steps may assist in eliminating white smoke:

1. Check to see that the secondary burner is operating and that secondary chamber temperature is above 1200°F.
2. Check/decrease underfire air.
3. Decrease secondary air.
4. If all the secondary burner capacity is not being used, gradually increase the operating rate of the burner until full capacity is reached.

If adjustment of the combustion parameters fail to stop the issuance of white smoke, examine the material to be charged. Possibly the white smoke is the result of finely divided noncombustible mineral material present in the waste charge which is being carried out the stack. Paper sacks that contain pigments or other metallic oxides, and minerals such as calcium chloride, generate fine inorganic particulate which causes white smoke.

The appearance of a white plume (other than a condensing water vapor plume) a short distance away from the stack probably indicates that hydrogen chloride is condensing. Unfortunately, there is no incinerator adjustment that will solve this problem. One solution is to reduce the amount of chlorinated waste incinerated in each load. This option is often impractical because the waste is mixed together in packages and, therefore, cannot be separated. Probably the best solution is to eliminate chlorinated plastics from use in the hospital or to install an acid gas scrubbing system.

7.1.2 Excessive Stack Emissions – Multiple-Chamber Units

Excessive emission rates from multiple-chamber units can usually be attributed to one of the following causes:

1. High setpoint for the secondary burner temperature is not high enough;
2. Excessive draft in the primary chamber;
3. Overcharging;
4. Problem wastes;
5. Inadequate secondary combustion air; and
6. Operating at too high a primary chamber temperature.

7.1.2.1 Black Smoke

The appearance of black smoke indicates the presence of unburned carbonaceous material. Dense black smoke is caused by incomplete combustion as a result of insufficient amounts of combustion air for the quantity of volatiles/soot present. Black smoke is often the result of overcharging of the incinerator or of too large an amount of highly volatile materials in the waste charged.

Steps which can be taken to eliminate black smoke include:

1. Decrease the charging rate;
2. Increase the secondary combustion air; and
3. Reduce the percentage of highly volatile materials in the waste feed; and
4. Reduce the primary chamber operating temperature.

7.1.2.2 White Smoke

The appearance of a steady stream of white smoke from the stack indicates the presence of small aerosols in the effluent gas. Steps which can be taken to eliminate white smoke include:

1. Check to see that the secondary burner is operating. If all the secondary burner capacity is not being used, increase the operating rate of the burner to full capacity; and
2. Decrease the secondary and/or primary air in order to increase the secondary temperature.

The appearance of a white plume (other than a condensing water vapor plume) a short distance away from the stack probably indicates that hydrogen chloride is condensing. No incinerator adjustment will solve this problem.

7.1.3 Leakage of Smoke From Primary Chamber

The leakage of smoke through charging doors or other openings indicates that a positive pressure differential exists in the primary chamber. Positive pressure can be caused by excessive combustion air, by excessive charging of a highly volatile material, by too high a primary chamber operating temperature, or by too much hot ash being discharged to a wet sump all at one time. The following steps may help eliminate leakage of smoke:

1. Check/decrease underfire air (controlled-air units);
2. Decrease feed rate;

3. Adjust ash discharge ram cycle; and
4. Adjust draft control (damper or ID fan) setpoints.

If a positive pressure persists, operation of the incinerator draft control system (draft monitor, barometric damper, induced draft fan) should be checked.

7.1.4 Excessive Auxiliary Fuel Usage[1]

For controlled-air units, improper underfire air distribution, excessive air infiltration, or improper setting of the underfire and secondary combustion air levels can result in excessive fuel usage. If the underfire air distribution in the primary chamber is incorrect or if there is excessive air inleakage, even a substoichiometric air/fuel mixture, which generates combustible gases for maintaining the secondary combustion chamber temperature, will not exist in the primary chamber. Instead, the waste bed will completely burn in some areas and not burn at all in other areas. The gases conveyed to the secondary chamber will already be fully oxidized, and auxiliary fuel will be necessary to maintain the secondary chamber temperature.[2]

Another cause of excessive auxiliary fuel usage is that the incinerator is not consistently charged. If the incinerator is not receiving enough heat input in the form of waste to maintain its temperature setpoints, then the unit will supply its own heat in the form of auxiliary fuel, i.e., natural gas or oil. Consistent charging of waste at regular timed intervals at a rate near 100 percent of the incinerator's design capacity will reduce the amount of auxiliary fuel required and will enhance the incinerator's performance. It is best to charge waste in batches which are 10 to 15 percent of rated capacity. Therefore, if a unit is rated at 500 pounds of waste per hour, then the unit should be charged at 6-minute intervals with charges of approximately 50 pounds each. The following actions may assist in reducing auxiliary fuel usage:

1. Charge waste at regularly timed intervals at a rate consistent with 100 percent of the design (thermal input) capacity;
2. Check/reduce secondary combustion air levels;
3. Check primary combustion air levels and distribution;
4. Check charging door seals and other seals for air leakage (controlled-air units); and
5. Check the fuel trains and burners for fuel leakage.

7.1.5 Incomplete Burnout – Poor Ash Quality

The causes of incomplete burnout include primary burner malfunction, insufficient primary chamber combustion air or poor underfire air distribution, overcharging the incinerator with waste, and charging too much wet waste. As with other operational problems, the causes of incomplete burnout can be minimized by proper operation of the incinerator and an effective preventive maintenance program.

7.1.5.1 Primary Burner Malfunction.

Primary burner malfunction causes incomplete burnout because the primary chamber temperature will not be maintained and because the flame is insufficient to ignite the waste and keep it burning. Primary burner malfunction may arise due to burner power loss, burner pluggage, failure of the flame safeguard, or leaking fuel trains. Each of these problems can be eliminated by preventive maintenance performed on a regular basis as outlined in Section 5.1. If the primary burner should fail, the following steps are recommended:

1. Check power supply to the primary burner;
2. If power is available, check burners for pluggage and clean as required;
3. Check the operation of the burner safeguard system as outlined in the owner's manual; and
4. Check fuel trains and burner assembly for fuel leakage and repair as required.

7.1.5.2 Insufficient Underfire Air (Controlled-Air Units)

In a controlled-air incinerator, insufficient underfire air can cause the combustion process to stop completely. Primary causes of the lack of combustion air are an improper underfire air setting, clinker buildup around the underfire air ports, and air ports clogged with ash or slag from previous charges. Clinker buildup around primary chamber air ports is usually the result of too much air, resulting in local hot spots that cause the ash to soften, agglomerate, and then harden as clinker during the cool down cycle. Some manufacturers utilize steam injection into the ash bed to facilitate burnout of fixed carbon in the ash bed and at the same time help prevent hot spots and clinker formation.[3] Maintaining proper air levels and air distribution through all underfire air ports is important. Proper operation and preventive maintenance can prevent these problems. If poor burnout occurs, the following items should be checked:

1. Check underfire air ports for ash pluggage and rod out as required;
2. Check around the underfire air ports for clinker buildup and clean as required; and
3. Check underfire air setting and adjust to the proper setting (increase) as required.

7.1.5.3 Waste Charging

Charging of waste into the incinerator should be performed as described in the vendor's literature.

Two conditions to be avoided that can cause incomplete burnout are overcharging the incinerator and charging too much wet waste as part of a charge.

These problems may be encountered with the so called "stuff-and-burn" type batch units operating on a timed-cycle. When the incinerator is overcharged and tightly packed with waste, the combustion air cannot circulate freely through the compacted waste, thereby inhibiting combustion. When incinerating wet waste, the waste must first be dried by evaporating the moisture in the waste; if the batch contains a large fraction of wet waste, insufficient time for complete combustion may be a problem. Both of these conditions should be prevented by not overcharging the incinerator or by increasing the burnout cycle time.

For intermittent-duty, controlled-air, and multiple-chamber incinerators, reduction of the charge rate may improve the ash burnout quality. The burndown period also can be increased in an attempt to improve burnout.

For continuous-duty incinerators, reducing the waste feed charge rate will increase the residence time of the solids in the primary chamber and may help to improve ash burnout quality.

7.2 Operational Problems and Solutions Associated with Wet Scrubbers[4,5]

The performance of a wet scrubber system is dependent on the key operating parameters discussed in Chapter 4, on effective preventive maintenance, and on the integrity of the scrubber components. Premature failure of these components will lead to increased costs, extended downtime of the system, and/or operation in temporary noncompliance. The main problems experienced by wet scrubber systems include corrosion, scaling, and erosion. An effective preventive maintenance program can minimize these problems by correcting malfunctions, observing trends in maintenance activities and making modifications to prolong equipment life, and correcting minor problems before they become costly, time consuming repairs. The following sections describe the problems, identify affected equipment, and recommend solutions.

7.2.1 Corrosion

Corrosion of wet scrubber components is the result of absorption of sulfur dioxide, sulfur trioxide, or hydrochloric acid gas from the dirty gas to the scrubbing liquid. The resulting acidic conditions cause corrosion of the wet scrubber system if it is made of carbon steel. Wet scrubbers controlling hospital waste incinerators are likely to experience corrosion from hydrochloric acid as a result of combustion of chlorinated plastics. The types of equipment that are likely to be subject to corrosion include scrubbers, absorbers, fans, dampers, ductwork, and exhaust stack. If the scrubbing liquid is recirculated (i.e., the system does not use once-through water), the importance of maintaining the pH of the scrubbing liquid above the level at which carbon steel is attacked cannot be stressed enough. An appropriate pH of 6 or greater is usually maintained through additions of alkaline reagents such as soda ash, lime, or limestone. The operation of the pH monitor used to control the rate of alkaline addition should be checked on at least a daily basis to minimize short-term low pH excursions.

Corrosion also can be a problem in the pumps, pipes, valves, tanks, and feed preparation areas in slurry service. Slurry tanks and associated feed preparation equipment should be checked daily for leaks. Equipment temporarily removed from slurry service should be thoroughly flushed. Typically, slurry pumps are disassembled at least annually to verify lining integrity and to detect wear and corrosion or other signs of potential failure. Bearings and seals are checked but not necessarily replaced. Pipelines also must be periodically disassembled or tested in other ways (e.g., hand-held nuclear and ultrasonic devices) both for solids deposition and for wear. Valves must be serviced routinely, especially control valves.

The solution to corrosion problems in wet scrubber systems is to maintain the pH of the scrubbing liquid by the following:

1. Check the proper operation of the pH monitor that controls alkaline additions daily;
2. Check the alkaline addition system for leaks daily and repair as required; and
3. Perform regular preventive maintenance on pumps, pipes, valves, and tanks to minimize and correct corrosion problems.

7.2.2 Scaling

Scaling is a common problem that arises in scrubber components in wet service such as mist eliminators, fans, dampers, and ductwork. Scale deposits in mist eliminators can cause nonuniform flow and plugging. Fans in wet service can develop vibrations as a result of scale deposition on the fan blades. Dampers may become stuck in place.

The best solution to scaling and/or plugging is an effective preventive maintenance program. Observation of the differential pressure across the mist eliminator can alert personnel to scaling problems. Periodic cleaning of equipment can minimize scaling problems.

7.2.3 Erosion

Erosion is a common problem associated with scrubber components in dry service such as fans, dampers, and ductwork. Erosion is also a problem for scrubber spray nozzles due to the suspended solids recovered in the scrubbing liquid from the dirty gas. For fans in dry service, fan vibration may be caused by erosion of fan blades. In such cases, the fan blades may have to be replaced. Erosion may cause holes in the ductwork. These holes must be repaired to prevent air in-leakage.

Scrubber spray nozzles are extremely susceptible to erosion and pluggage problems due to the high velocities of the liquid stream and the suspended solids within the stream. Pluggage and erosion in the spray nozzles can be determined by observing the spray angle. If the spray angle has become enlarged, then the nozzle orifice probably has been enlarged by erosion. Conversely, if the spray angle has decreased or if a distinct spray pattern is no longer achieved, then the nozzle orifice probably is partially or completely plugged. The potential for erosion of the scrubber components is directly related to the percent suspended solids. The greater the recirculation flow rate relative to the makeup and purge (blowdown) flow rates, the greater the potential for buildup of solids. Infrequent purging also can cause high solids buildup.

Erosion in dry service components is to be expected. Effective preventive maintenance and equipment replacement when required are the best solutions.

Erosion in scrubber spray nozzles and other scrubber components may be prevented by proper operation and maintenance as follows:

1. Rod out spray nozzles on a regular basis to prevent plugging;
2. Purge the system frequently to prevent solids buildup; and
3. Adjust the recirculation rate as appropriate.

7.3 Operational Problems and Solutions Associated with Fabric Filters[6]

The two main operational problems associated with fabric filters are high opacity and high pressure drop. Well designed, operated, and maintained fabric filters will generally have a very low opacity (between 0 to 5 percent), and the pressure drop will fall within a general operating range for the particular fabric filter type (5 to 9 in. w.c. for pulse-jet fabric filters). Opacity and/or pressure drop deviations from the baseline values are good indicators of fabric filter performance deterioration. Higher or lower than normal inlet temperatures can cause opacity and pressure drop problems. The inlet temperature should be monitored continuously. The following sections describe each operational problem, the cause, and possible solutions.

7.3.1 Opacity

Large fabric filter installations may have an opacity monitor coupled with a strip-chart recorder. Typically, smaller installations have no opacity monitor and must rely on visible emission observations. In any event, opacity measurements are useful in determining trends in the performance of the fabric filter. Typically, the opacity plume of a properly operated and maintained filter will be very low, except when a condensable plume is present (even in this case the condensing plume should be detached). In general, high opacity is a good indicator of fabric failure. A consistently elevated opacity level relative to the baseline level is an indication of major leaks and tears in the filter bags. A puffing, intermittent opacity observed after cleaning that is higher than the baseline opacity level is a good indication of pinhole leaks in the filter bags. The factors that cause fabric failure include improper filter bag installation, high temperature, chemical degradation, and bag abrasion.

Improper installation of filter bags can result in leaks around seals, improper bag tensioning, and damage to the bags. Lack of training of maintenance personnel in filter bag replacement and poor access to the fabric filter housing are contributing factors to improper installation.

High temperatures are the result of process malfunction(s) upstream of the fabric filter. Therefore, in the fabric filter design phase, a fabric must be chosen on the basis of expected temperature range with an adequate margin for error. High temperature breaks the polymer chains in most commercially available fabrics causing loss of strength and reduced bag life. High temperature attacks the finish on fiberglass bags causing increased bag abrasions. In general, high temperatures shorten bag life considerably. High enough temperatures can cause filter bags to ignite. Some installations may have an alarm system to warn of high temperature excursions and a bypass system to prevent damage to the filter bags. Such a system may be appropriate should the cooling system prior to the fabric filter fail. Sparks may also be a problem with a combustion source such as a hospital waste incinerator. A spark arrestor can help eliminate the potential for sparks in the fabric filter.

Chemical degradation of the filter bags occurs as the result of acid gas condensation. In addition to specification of a temperature range for filter bags, a chemical resistance rating must also be specified for the fabric. In the case of hospital waste incinerators, fabric should have good chemical resistance to hydrochloric acid due to combustion of chlorinated plastics. Additionally, operation at a high enough temperature to prevent acid gas condensation will reduce chemical degradation.

Filter bag abrasion can be caused by contact between a bag and another surface (e.g., another bag or the walls of the fabric filter) or by the impact of higher-than-average gas volumes and particulate loading on the bags. Bag abrasion can also be a problem when the fabric filter experiences a high pressure drop. Usually, when bag abrasion is a problem, the greatest abrasion occurs within 18 to 24 inches from the bottom of the bags. A blast plate or diffuser will redirect the larger particles away from the bags and reduce bag abrasion.

While the only solution to the problem of high opacity is replacement of the failed filter bags, it can be prevented by the following:

1. Train maintenance personnel in the proper installation of replacement filter bags;
2. Design fabric filters for ease in bag replacement;
3. Choose filter bag fabric with an appropriate operating temperature range and chemical resistance rating;
4. Blast plates or diffusers are recommended for those facilities experiencing severe bag abrasion;
5. Monitor inlet temperature – an alarm and bypass system may be installed to prevent filter bag damage from high temperature excursions;
6. Install a spark arrestor to prevent sparks and fire inside the fabric filter; and
7. Install a bypass/alarm system to prevent damage to filter bags during high temperature excursions.

7.3.2 Pressure Drop

The pressure drop across a fabric filter is an important indicator of performance. An increase in pressure drop indicates greater resistance to flow and can be a symptom of a high air-to-cloth ratio or an increase in dust cake thickness due to condensation or cleaning system failure.

The air-to-cloth ratio is a design parameter that is determined during the fabric filter design phase. In the pulse-jet baghouses used to control emissions from hospital waste incinerators, the air-to-cloth ratio and therefore pressure drop are relatively high (5 to 9 in. w.c.). Bag abrasion and/or fugitive emissions may result if the pressure drop is too high (10 to 14 in. w.c.).

Condensation of moisture on filter bags is caused by temperatures in the fabric filter below the dewpoint. "Mudding" or blinding of the bags increases the resistance to flow and occurs because the cleaning system cannot remove the dust. Condensation can be prevented by preheating the fabric filter during the startup operation and by purging moist gases from the unit prior to shutdown. During operation it is critical to maintain the operating temperature above the dewpoint of the gas stream at all times.

Cleaning system failures in pulse-jet systems are usually the result of worn or undersized compressors, and failed solenoids and/or timers. Compressor problems are indicated by a low compressed-air pressure. Because of the low pressure the system cannot clean the bags properly and an increased pressure drop across the fabric filter results due to dust cake buildup. Compressor capacity may be a problem and should be checked against the needs of other systems the compressor serves. Routine preventive maintenance can prevent premature failure of the compressor and can prevent worn compressor seals from passing oil into the fabric filter and blinding the filter bags. Both reduced compressed-air pressure and bag blinding can cause an increase in pressure drop.

Failure of solenoids and or timers can prevent the filter bags from being cleaned at all. These systems require clean, dry mountings to operate properly. Solenoid failures affect the only row of filter bags that the solenoid services, while timer failures tend to affect most, if not all, of the fabric filter system.

An additional problem is that associated with the pulse pipe that discharges the compressed air into the bags. Pulse pipes may sometimes be damaged by the force of the compressed air causing ineffective cleaning and pressure drop increase, improper pipe alignment that may blow holes in the filter bags, or a loose pipe that may damage the interior of the fabric filter. The sound of a loose pulse pipe is unmistakable because it moves whenever compressed air is fired into the pipe.

An increase in pressure drop may indicate operation and maintenance problems that may be corrected. However, blinded bags resulting from condensation or the accidental discharge of compressor oil into the fabric filter will likely have to be replaced. An increase in pressure drop can be prevented by the following:

1. Preheat the fabric filter prior to process operation;
2. Purge the fabric filter of moist air prior to shutdown;
3. Always maintain the temperature of the gas entering the fabric filter above its dewpoint;
4. Perform preventive maintenance of the compressor system and solenoid/timer system;
5. Make necessary repairs to pulse pipes as required; and
6. Adjust the cleaning cycle to shorten the cycle between cleanings.

7.4 References for Chapter 7

1. McRee, R. Operation and Maintenance of Controlled-Air Incinerators. Ecolaire Environmental Control Products. Undated.

2. Letter from K. Wright, John Zink Company to J. Eddinger, U. S. EPA. January 25, 1989.

3. Personal conversation between R. Neulicht, MRI, and G. Swan, Ecolaire Combustion Products and J. Kidd, Cleaver Brooks. February 22, 1989.

4. Joseph, J., and D. Beachler. APTI Course SI:412C, Wet Scrubber Plan Review - Self Instructional Guidebook. EPA-450/2-82-020. U. S. Environmental Protection Agency. March 1984.

5. U. S. Environmental Protection Agency. Wet Scrubber Inspection and Evaluation Manual. EPA-340/1-83-022. (NTIS PB85-149375). September 1983.

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Chapter 8
Recordkeeping

Recordkeeping is an integral part of an equipment operation and maintenance (O&M) program. The purpose of recordkeeping is to document major O&M events and to collect historical data on key operating parameters. The objective of recordkeeping is to prevent premature failure of equipment, increase the life of the equipment, and to minimize emissions. Recordkeeping allows facility and regulatory agency personnel to track performance, to evaluate trends, to identify potential problem areas, and to determine appropriate solutions. The magnitude and scope of recordkeeping activities will depend on a combination of factors, including personnel availability and training, size and sophistication of the equipment, and the level of maintenance required. Only records of key performance parameters and activities should be maintained to avoid accumulation of unnecessary information.

The following information should be readily available to O&M personnel: (1) the manufacturer's equipment specification and instruction manuals, (2) compliance emission tests, (3) operating permits, (4) operating logs, and (5) maintenance activities log. The operating history provided by this information is useful in evaluating current and future performance, maintenance trends, and operating characteristics. A spare parts inventory also should be maintained with periodic updates so that parts can be obtained and installed in a timely manner. A recommended spare parts inventory typically is supplied with the equipment manufacturers' O&M manuals. Whether a facility maintains an extensive or minimal parts inventory is dependent on the available space for parts storage and whether the facility has a service agreement with the equipment vendor.

8.1 Manufacturer's Specifications and Literature

The manufacturer's information is the foundation of a recordkeeping program. A copy of the information and literature supplied by the incinerator and air pollution control device manufacturers should be easily accessible for use and review by personnel responsible for O&M. This literature includes the manufacturer's design specifications, performance guarantee, piping and instrumentation diagram, process flowsheet, material balance information for normal and maximum design conditions, and an instruction manual for O&M.

The O&M manuals discuss the theory and design of the equipment; operating procedures for startup, shutdown, normal operation, and troubleshooting; maintenance procedures; and a recommended spare parts list. The guarantee or warranty provisions in the contract are conditioned on the proper care and treatment of the equipment as specified in the O&M instruction manual.

8.2 Compliance Emission Test Records[1]

Records of initial compliance test results and records of incinerator process and air pollution control device operating conditions during the compliance test form the baseline information against which subsequent operating data are compared. The baseline period normally occurs soon after shakedown of new equipment and represents conditions when the control device is operating in compliance with applicable regulations. Comprehensive baseline test results and equipment operating data establish the relationship between operating conditions and emission levels for a specific process/air pollution control device combination. Once this relationship exists, operating personnel and regulatory groups can use subsequent measurements of the same parameters to compare against baseline conditions and thereby identify excursions from acceptable performance.

8.3 Operating Records[1-3]

There is a practical limit to the operating parameters that should be routinely checked and to the frequency with which the data are logged. Table 8-1 presents a list of recommended operating parameters for incinerators, wet scrubbers, fabric filters, and continuous emission monitors that should be monitored and logged on a regular basis. However, the decision on which operating parameters will be monitored and recorded and with what frequency is largely site-specific. This decision depends on the size and complexity of the equipment, the number of hours per day that it operates, and the availability of personnel. The greater the frequency of data gathering, the more sensitive the operators will be to equipment operational problems. However, as the amount of data increases, the effort required to collect and manipulate the data also increases. The optimal frequency of data gathering may be every 4 hours (twice per shift). If sudden and dramatic changes in performance occur, if the source is highly variable (such as an incinerator), or if the air pollution control device operation is extremely sensitive, shorter monitoring intervals, such as once per hour, are required.

Table 8-1. Recommended Operating Parameters that Should be Included in Operating Logs for Incinerators, Wet Scrubbers, Fabric Filters, and Continuous Emission Monitors

A. Incinerator Operating Parameters
   1. Charging rate/frequency
   2. Primary combustion chamber temperature
   3. Secondary combustion chamber temperature
   4. Incinerator draft
   5. Exhaust gas O_2 concentration
   6. Auxiliary fuel feed rate

B. Wet Scrubber Operating Parameters
   1. Gas temperature, inlet and outlet
   2. Static pressure drop, total
   3. Static pressure drop, mist eliminator
   4. Liquor feed rate
   5. Liquor pH
   6. Water makeup rate
   7. Fan(s) current, rpm
   8. Nozzle pressure
   9. Solids content of liquor

C. Fabric Filter Operating Parameters
   1. Gas temperature, inlet and outlet
   2. Static pressure drop, total
   3. Cleaning cycle frequency

D. Continuous Emission Monitors
   1. CO emission concentration, ppm
   2. Opacity of emissions, percent

In addition to the numerical values of the operating parameters, a checklist should be included to confirm operation of fans, limit switches, burners, ram feeders, pumps, nozzles, and the other general physical considerations that can adversely influence performance.

8.4 Maintenance Records[2]

Maintenance records provide an operating history of equipment. They can indicate what equipment has failed, where, when, and how often; what kinds of problems are typical; what actions were taken; and, over time, the efficacy of the remedial actions. These records can be used in conjunction with a spare parts inventory to maintain and update a current list of available parts and the costs of these parts.

The work order system is one way to keep useful maintenance records. This system would be administered by the engineer in charge of the proper O&M of the incinerator. Whenever maintenance is required, the engineer will issue a work order to the appropriate department (e.g., maintenance) detailing the work to be performed. Additionally, the work order form should include the following information to assure both good communication between departments and prompt completion of the work: a work order number, the date of the work request, the name of the person requesting the work and his/her department, the department to which the work order is sent, any special equipment required, any special precautions that should be taken, a signature block for the person performing the work, and the date of completion of the work. The format of the work order form is variable as long as it fits the needs of the particular hospital. The engineer, upon return of the completed work order, may check the satisfactory performance of the work requested. When properly designed and used, this system provides information on the suspected problem, the problem actually found, the corrective action taken, time and parts required, and any additional pertinent information. Additionally, such a system can also be used to ensure that the monthly, quarterly, and semiannual routine preventive maintenance is performed. In developing a work order maintenance log system, facility personnel should consult both the schedules in Chapter 5.0 and the manufacturer's recommended maintenance schedule. The work order system may involve the use of triplicate carbon forms or it may be computerized. Triplicate carbons provide a copy of the work order to the engineer (requestor), the department performing the work, and the hospital administration. These copies would become part of the O&M log. Daily and weekly preventive maintenance activities should be included as part of the routine operation of the incinerator and associated air pollution control device. Preventive maintenance activities and schedules for incinerators, wet scrubbers, and fabric filters are discussed more fully in Chapter 5.0.

Another approach is to use a log book in which a summary of maintenance activities is recorded. Although not as flexible as a work order system (e.g., copies of individual work orders can be sent to appropriate departments), it does provide a centralized record and is probably better suited for the small facility.

8.4.1 Retrieval of Records[2]

A computerized storage and retrieval system is ideal for recordkeeping. A computer can manipulate and retrieve data in a variety of forms and also may be useful in identifying trends. A computerized system is not for everyone, however. The larger the data set to be handled, the more likely it is that a computer can help to analyze and sort data. Sorts might include a history of maintenance activities and identification of recurring operating problems that might indicate a need for more frequent maintenance or inspections. For a small source that presents few problems and that has a manageable set of operating parameters to be monitored, a computer system may not be cost effective.

Retention time is also a site-specific variable. If records are maintained only to meet a regulatory requirement and are not used or evaluated, they can probably be disposed of at the end of the statutory limitation (typically 2 years). It can be argued that these records should not be destroyed because if the equipment fails prematurely, the data preserved in the records could be used to troubleshoot the problem. In some cases, records going back 10 to 12 years have been kept to track the performance, cost, and system response to various situations and the most effective ways to accomplish remedial actions. These records serve as a learning tool to optimize performance and minimize emissions, which is the underlying purpose of recordkeeping. Some of these records may be kept throughout the life of the equipment. After several years, however, summaries of O&M activities are more desirable than the actual records themselves. These can be created concurrently with the daily O&M records for future use. If needed, actual data can then be retrieved for further evaluation.

8.5 References for Chapter 8

1. U. S. Environmental Protection Agency. Wet Scrubber Inspection and Evaluation Manual. EPA-340/1-83-022. (NTIS PB85-149375). September 1983.

2. U. S. Environmental Protection Agency. Operation and Maintenance Manual for Electrostatic Precipitators. EPA 625/1-85/017. September 1985.

3. U. S. Environmental Protection Agency. Operation and Maintenance Manual for Fabric Filters. EPA/625/1-86/020. June 1986.

Chapter 9
Safety Guidelines

This section provides general safety guidelines in the O&M of hospital incinerators and associated air pollution control devices. The information presented here is intended to supplement safety information provided by manufacturers and/or safety standards established by individual hospitals. There are two primary concerns with respect to the operator's safety. The first concern is the potential for exposure to pathogens during handling of infectious waste. The second concern is the prevention of injury due to the general hazards normally associated with industrial equipment such as incinerators and air pollution control devices.

9.1 Prevention of Infection During Waste Handling[1]

The major risk of infection to an operator is from puncture wounds caused by contaminated objects such as surgical instruments, needles, and broken glass. Most, if not all, hospitals are using special rigid, secure containers to prevent injury from infected sharp objects. Nonetheless, to prevent possible injury which could result in infection, safety rules which should be followed include:

1. Minimize the handling of red bag waste;
2. Keep red bag wastes in a secure location prior to incineration;
3. **Never** open red bags to inspect the contents;
4. Follow procedures which maintain the integrity of the red bag waste. If breakage/spillage of red bag waste occurs, then handling procedures must be changed. The use of double bags, stronger bags, rigid carts, or cardboard containers to contain the red bag waste should be instituted. The hospital administration should be contacted if continued problems with bag integrity occur;
5. Wear thick rubber gloves when handling red bag wastes;
6. Wear hard-soled rubber shoes when handling waste and working in the area around the incinerator; and
7. Wear safety glasses.

9.2 Equipment Safety Procedures[2-5]

General safety procedures to prevent injury when working around the incinerator and air pollution control equipment include:

1. Containers of flammable liquids or explosives should never be fed into the incinerator;
2. The incinerator charging door should not be opened if the incinerator is under positive pressure, if the ignition burner is on, or if other conditions recommended by the manufacturer are not met (i.e., minimum time between charges). Always exercise caution when opening the charging door. Wearing safety glasses, the operator should stand behind the door, open the door several inches and pause, then open the door fully;
3. Never open cleanout ports to view into the incinerator during operation;
4. **Never** enter the chambers of mechanical ram feeders, ash conveyors, or the incinerator without first turning off all power sources and assuring that the units are "locked out." If a chamber must be entered, after locking the unit out, make sure a second person is standing by;
5. Observe caution around all moving belts, hydraulic cylinders, and doors;
6. For systems requiring manual ash removal, exercise extreme caution when removing the ash. Do not enter the incineration chamber to remove the ash. Instead, use the mechanical ash ram or conveyor (if available) or rakes or shovels with handles of sufficient length to reach the back of the incinerator ash compartment. When using rakes or shovels, use caution so as not to damage the incinerator refractory;
7. Wear proper personal safety equipment when operating the incinerator and removing/handling the ash to prevent burns, cuts, punctures, or eye injury. Proper safety equipment includes gloves, hard-soled rubber shoes, and safety glasses;

8. Avoid direct contact with the hot surfaces of the incinerator chamber, heat recovery equipment, ductwork, and stack;

9. The scrubber liquor from wet scrubbers likely will be caustic. Avoid contact with the liquid and wear eye protection near and around the scrubber;

10. Venturi scrubbers operate at high positive pressures. Be cautious of leaks in the scrubber vessel, ductwork, or piping;

11. Entry into fabric filters other than for maintenance should be avoided. Only persons who have been properly trained should enter fabric filters, and they should be alert to the following hazards and necessary precautions.

    (a) Before personnel enter the unit, the filter bags should be thoroughly cleaned and dust dislodged and discharged from the hopper by mechanical vibration to prevent fugitive emissions and dust inhalation. Hopper doors should only be opened when the unit (including fan and hopper evacuation systems such as screws and drag chains) has been shut down.

    (b) Oxygen deficiency as is common in incinerator combustion gases makes fabric filter entry especially dangerous. Purging of the unit does not always replace the exhaust gases with ambient air. Inspectors should know the dangers associated with oxygen deficiency.

    (c) Explosion is possible in a confined space such as a fabric filter. Ventilation/purging prior to entry is recommended.

    (d) Exposure to toxic chemicals in the collected dust is another danger of fabric filter entry. A quantitative assessment of the expected compounds in the dust and threshold dose levels should be made prior to entry. Proper personnel protection equipment such as respirators should be worn.

12. Eye protection, hearing protection, long sleeved shirts, and gloves should be worn during fabric filter inspection. Inspectors also should be cognizant of heat/thermal stress associated with the length of time required for inspection/repairs. Because of the dusty, humid conditions and limited access, thermal effects may be severe.

9.3 Fire Safety[6]

Fire safety is particularly important when working around incinerators due to the nature of the high temperature combustion process. The areas in which the operator should exercise caution include: waste storage, waste charging to the incinerator, and ash removal.

The location of the waste storage area relative to the incinerator is an important consideration regarding fire safety. Waste should be stored away from the incinerator and ash storage areas such that access to the unit is not blocked and premature ignition of the stored waste from stray sparks or burning flyash is eliminated.

Charging of the waste into the incinerator has a particularly high fire hazard associated with it because of the potential exposure of high temperature and flaming conditions to the operator and surrounding building areas. When charging manually charged incinerators, the operator should exercise extreme caution. A fire safety feature that should be included on manually loaded incinerators is an interlock system that shuts off the primary chamber burner(s) when the charging door is opened. Some systems shut off the underfire air when the charge door opens. The charge door should operate freely and be free of any sharp edges or projections that could catch or hang up waste materials and cause spillage. When charging automatically charged incinerators, a potential fire hazard exists when waste material (particularly plastics) adheres to the hot charging ram. If these materials do not drop from the ram during its loading cycle, they may ignite and be carried back into the charging hopper where the remaining waste will become ignited. Automatic loading systems usually have automatic safety systems activated by a flame scanner that spray water to quench the hot ram face and any flames and/or automatic systems that reinitiate a loading sequence to charge the burning waste into the incinerator.

Handling of ash is another area where the operator should exercise extreme caution regarding fire safety. Manual ash removal involves removing ash with rakes and shovels followed by a water quench. Because the ash may contain hot spots, the operator should wear proper personal safety equipment including gloves, hard-soled rubber shoes, and safety glasses. Water quenching should occur only after removing the ash from the incinerator to prevent damage to the incinerator refractory. Automatic ash removal systems quench the ash as it is removed from the incinerator and dump the quenched ash into ash carts. Quenched ash should be stored in a fire rated area in a location isolated from stored waste materials.

9.4 References for Chapter 9

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3. U. S. Environmental Protection Agency. Wet Scrubber Inspection and Evaluation Manual. EPA 340/1-83-022. (NTIS PB85-149375). September 1983.

4. Richards Engineering. Air Pollution Source Field Inspection Notebook; Revision 2. Prepared for the U. S. Environmental Protection Agency, Air Pollution Training Institute. June 1988.

5. U. S. Environmental Protection Agency. Air Pollution Source Inspection Safety Procedures: Student Manual, EPA-340/1-85-002a. September 1985.

6. Doucet, L. Fire Protection Handbook, National Fire Protection Association Waste Handling Systems and Equipment. Chapter 12. 1986

Chapter 10
Glossary

ABSORPTION[3]	The process by which gas molecules are transferred to (dissolved in) a liquid phase.
ACID GASES[4]	Corrosive gases formed during combustion of chlorinated or halogenated compounds and sulfur-containing compounds, e.g., hydrogen chloride (HCl), or sulfur oxides (SO_x).
ACTUAL CUBIC FEET PER MINUTE (acfm)[3]	A gas flow rate expressed with respect to temperature and pressure conditions.
AERODYNAMIC DIAMETER[4]	The diameter of a unit density sphere having the same aerodynamic properties as an actual particle. It is related to the physical diameter according to the equation: $d_{pa} = d_p (\rho C)^{1/2}$ where: d_{pa} = aerodynamic diameter d_p = physical diameter ρ = particle density C = Cunningham correction factor
AIR, DRY[4]	Air containing no water vapor.
ASH[5]	The noncombustible inorganic residue remaining after the ignition of combustible substances.
ATOMIZATION[4]	The reduction of liquid to a fine spray.
BAG BLINDING	The loading, or accumulation, of filter cake on the bag fabric to the point where capacity air flow rate is diminished.
BAROMETRIC SEAL[1]	A column of liquid used to hydraulically seal a scrubber, or any component thereof, from the atmosphere or any other part of the system.
BOTTOM ASH[5]	The solid material that remains on a hearth or falls through the grate after incineration is completed.
BURN RATE[4]	The total quantity of waste that is burned per unit of time that is usually expressed in pounds of waste per hour.
BURNDOWN PERIOD	The period of time in an incinerator's operating cycle during which no additional waste is charged to the incinerator and the primary combustion chamber temperature is maintained above a minimum temperature (using auxiliary burners as necessary) to facilitate the solid phase combustion of the waste bed.
CEMS	Continuous Emission Monitoring System (CEMS). The total equipment required for the determination of opacity or an emission rate for stack gases.

CHARGE RATE[4]	Quantity of waste material loaded into an incinerator over a unit of time but which is not necessarily burned. Usually expressed in pounds of waste per hour.
CLINKERS[5]	Hard, sintered, or fused pieces of residue formed in an incinerator by the agglomeration of ash, metals, glass, and ceramics.
COCURRENT OR CONCURRENT[4]	Flow of scrubbing liquid in the same direction as the gas stream.
COLLECTION EFFICIENCY[1]	The ratio of the weight of pollutant collected to the total weight of pollutant entering the collector.
COMBUSTION[4]	A thermal process in which organic compounds are broken down into carbon dioxide (CO_2) and water (H_2O).
CONDENSATION[1]	The physical process of converting a substance from the gaseous phase to the liquid phase via the removal of heat and/or the application of pressure.
CONTROLLED AIR INCINERATION[5]	Incineration utilizing two or more combustion chambers in which the amounts and distribution of air to each chamber are controlled. Partial combustion takes place in the first zone (chamber) and subsequent zones are used to complete combustion of the volatilization gases.
COOLDOWN PERIOD	The period of time at the end of an incinerator's operating cycle during which the incinerator is allowed to cool down. The cooldown period follows the burndown period.
CROSSFLOW[4]	Flow of scrubbing liquid normal (perpendicular) to the gas stream.
CYCLONE[4]	A device in which the velocity of an inlet gas stream is transformed into a confined vortex from which inertial forces tend to drive particles to the wall.
DAMPER[2]	An adjustable plate installed in a duct to regulate gas flow.
DEHUMIDIFY[1]	To remove water vapor from a gas stream.
DEMISTER[4]	A mechanical device used to remove entrained water droplets from a scrubbed gas stream.
DENSITY[2]	The ratio of the mass of an object to the volume of the object.
DIFFUSION (AEROSOL)[4]	Random motion of particles caused by repeated collisions of gas molecules.
DRAFT[1]	A gas flow resulting from pressure difference; for example, the pressure difference between an incinerator and the atmosphere, which moves the products of combustion from the incinerator to the atmosphere. (1) Natural draft: the negative pressure created by the difference in density between the hot flue gases and the atmosphere. (2) Induced draft: the negative pressure created by the vacuum action of a fan or blower between the incinerator and the stack. (3) Forced draft: the positive pressure created by the fan or blower, which supplies the primary or secondary air.
DUST[2]	Solid particles less than 100 micrometers created by the breakdown of larger particles.
DUST LOADING[2]	The weight of solid particulate suspended in an airstream (gas). Usually expressed in terms of grains per cubic foot, grams per cubic meter, or pounds per thousand pounds of gas.

ENDOTHERMIC[4]	A chemical reaction that absorbs heat from its surroundings. For example: $C + H_2O + \text{heat} \rightarrow CO + H_2$.
ENTRAINMENT[3]	The suspension of solids, liquid droplets, or mist in a gas stream.
EXOTHERMIC[4]	A chemical reaction that liberates heat to its surroundings. Combustion is an exothermic reaction. For example: $C + O_2 \rightarrow CO_2 + \text{heat}$
FEEDBACK CONTROL[3]	An automatic control system in which information about the controlled parameter is fed back and used for control of another parameter.
FIXED CARBON[4]	The nonvolatile organic portion of waste.
GRID[1]	A stationary support or retainer for a bed of packing in a packed bed scrubber.
HEADER[1]	A pipe used to supply and distribute liquid to downstream outlets.
HEAT RELEASE RATE[4]	The energy released over a unit of time during combustion. Calculated as the heating value (Btu/pound) × burn rate (pound/hour). Usually expressed as Btu/hour (Btu/h).
HEATING VALUE[4]	The amount of heat that is released when a material is combusted, usually expressed as Btu/lb.
HUMIDITY, ABSOLUTE[2]	The weight of water vapor carried by a unit weight of dry air or gas.
HUMIDITY, RELATIVE[2]	The ratio of the absolute humidity in a gas to the absolute humidity of a saturated gas at the same temperature.
INCINERATOR[4]	A thermal device which combusts organic compounds using heat and oxygen.
INDUCED DRAFT FAN[3]	A fan used to move a gas stream by creating a negative pressure.
INERTIA[4]	Tendency of a particle to remain in a fixed direction, proportional to mass and velocity.
LIQUID-TO-GAS RATIO[3]	The ratio of the liquid (in gallons per minute) to the inlet gas flow rate (in acfm).
LIQUOR[1]	A solution of dissolved substance in a liquid (as opposed to a slurry, in which the materials are insoluble).
MAKEUP WATER[3]	Water added to compensate for water losses resulting from evaporation and water disposal.
MIST ELIMINATOR[3]	Equipment that removes entrained water droplets downstream from a scrubber.
OPACITY[4]	Measure of the fraction of light attenuated by suspended particulate.
PACKED-BED SCRUBBER[3]	Equipment using small plastic or ceramic pieces, with high surface area to volume ratios for intimate gas/liquid contact for mass transfer.
PARTICLE[4]	Small discrete mass of solid or liquid matter.
PARTICLE SIZE[4]	An expression for the size of a liquid or solid particle, usually expressed in microns (or micrometers).

PARTICULATE EMISSION[4]	Fine solid matter suspended in combustion gases carried to the atmosphere. The emission rate is usually expressed as a concentration such as grains per dry standard cubic feet (gr/dscf) corrected to a common base, usually 12 percent CO_2 or 7% oxygen.
PARTICULATE MATTER[4]	As related to control technology, any material except uncombined water that exists as a solid or liquid in the atmosphere or in a gas stream as measured by a standard (reference) method at specified conditions. The standard method of measurement and the specified conditions should be implied in or included with the particulate matter definition.
PATHOGENIC	Waste material capable of causing disease.
PATHOLOGICAL WASTE	Waste material consisting of anatomical parts.
PENETRATION[4]	Fraction of suspended particulate that passes through a collection device.
pH[1]	A measure of acidity-alkalinity of a solution.
PRESSURE DROP[3]	The difference in static pressure between two points due to energy losses in a gas stream.
PRESSURE, STATIC[4]	The pressure exerted in all directions by a fluid; measured in a direction normal (perpendicular) to the direction of flow.
PROXIMATE ANALYSIS[4]	The determination of the amounts of volatile matter, fixed carbon, moisture, and noncombustible (ash) matter in any given waste material, usually expressed in percentages by weight.
PYROLYSIS	The chemical destruction of organic materials in the presence of heat and the absence of oxygen.
QUENCH[1]	Cooling of hot gases by rapid evaporation of water.
REAGENT[3]	The material used in a scrubbing system to react with the gaseous pollutants.
RED BAG WASTE	As used in this document, red bag waste refers to infectious waste; the name comes from the use of red plastic bags to contain the waste and to clearly identify that the waste should be handled as infectious.
RESIDENCE TIME	Amount of time the combustion gases are exposed to mixing, temperature, and excess air for final combustion.
SATURATED GAS[1]	A mixture of gas and vapor to which no additional vapor can be added at specified conditions.
SIZE DISTRIBUTION[4]	Distribution of particles of different sizes within a matrix of aerosols; numbers of particles of specified sizes or size ranges, usually in micrometers (μm).
SLURRY[1]	A mixture of liquid and finely divided insoluble solid materials.
SMOKE[4]	Small gasborne particles resulting from incomplete combustion; particles consist predominantly of carbon and other combustible material; present in sufficient quantity to be observable independently of other solids.
SPECIFIC GRAVITY[1]	The ratio between the density of a substance at a given temperature and the density of water at 4°C.
SPRAY NOZZLE[1]	A device used for the controlled introduction of scrubbing liquid at predetermined rates, distribution patterns, pressures, and droplet sizes.

STANDARD CUBIC FEET PER MINUTE (scfm)[3]	A gas flow rate expressed with respect to standard temperature and pressure conditions (20°C [68°F] and 29.92 in. Hg [760 mm]).
STARVED-AIR INCINERATION	Controlled air incineration in which the primary chamber is maintained at less than stoichiometric air conditions.
STOICHIOMETRIC AIR	The theoretical amount of air required for complete combustion of waste to CO_2 and H_2O vapor.
STUFF AND BURN	A situation in which the charging rate is greater than the burning rate of the incinerator.
ULTIMATE ANALYSIS	A determination of the quantities of the various elements (i.e., carbon, hydrogen, sulfur, nitrogen, and oxygen) and ash of which a substance is composed, usually expressed in percentages by weight.
VAPOR[4]	The gaseous form of substances that are normally in the solid or liquid state and whose states can be changed either by increasing the pressure or by decreasing the temperature.
VOLATILE MATTER	That portion of waste material which can be liberated with the application of heat only.

10.1 References for Chapter 10

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2. Industrial Gas Cleaning Institute. Fundamentals of Fabric Collectors and Glossary of Terms. Publication F-2, August 1972.
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4. U. S. Environmental Protection Agency, Control Techniques for Particulate Emissions from Stationary Sources. Volume I. EPA-450/3-81-005a. September 1982.
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