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Multiple-Hearth and Fluid Bed Sludge Incinerators:

Design and Operational Considerations

MULTIPLE-HEARTH AND FLUID BED SLUDGE INCINERATORS: DESIGN AND OPERATIONAL CONSIDERATIONS

by

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This document is condensed from an EPA research report entitled "Improving Design and Operation of Multiple-Hearth and Fluid Bed Sludge Incinerators", which will be available in late 1985. That report has been subjected to the United States Environmental Protection Agency's peer review. This document has undergone an EPA administrative review and has been found to be consistent with the EPA research report referenced above. The information in this document is made available for the use of the technical community. The information contained herein does not constitute EPA policy, guidance or directive. Design engineers, municipal officials, and others are cautioned to exercise care in applying this general information to particular circumstances of individual wastewater treatment facilities. EPA assumes no responsibility for use of this information in a particular situation. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The construction of more wastewater treatment facilities with higher levels of treatment has resulted in the need to treat and dispose of larger amounts of sewage sludge. In recent years, sludge incinerators have been frequently considered and often installed as a final disposal alternative. Many of these were constructed using financial assistance from the construction grants program of the U.S. Environmental Protection Agency.

Many municipal sludge incinerators have experienced a variety of design and operational problems. In addition, the increased cost of energy during the past decade, as well as an increasing awareness of possible air pollution problems from incinerator emissions, has raised serious concerns over the suitability of incinerators for sludge disposal. EPA's Water Engineering Research Laboratory in Cincinnati, Ohio has studied sludge incinerators to identify the nature and extent of design and operational problems, to identify possible problem solutions, and to determine the applicability of the technology for use as part of municipal sludge treatment systems.

This summary document is based on that EPA study and is intended to provide a basic understanding of sludge incineration, as well as concise information on design considerations, operational characteristics, and process and equipment problems and possible solutions. The document will be useful to design engineers, governmental agency review personnel, municipal officials, operators, and others who are considering using sludge incineration in a sludge treatment train, or who are concerned with optimizing performance of an existing sludge incinerator. The information in this summary supplements detailed guidance available elsewhere, which should be considered when making design or operating decisions. Improvements in the technology, the ability to integrate the technology into the total treatment process, and the compatibility of the process with the plant environment must be considered along with associated costs in comparing this technology with other treatment alternatives.

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SECTION 1

INTRODUCTION

Improvements in wastewater treatment technology and in the design and operation of wastewater treatment plants are resulting in higher-quality effluents with increased sludge production. Concurrently, the problem of sludge disposal has become more difficult because many disposal methods have been found to present risks to public health and safety. Sludge processing and disposal methods that have received only cursory attention in the past are now being reevaluated.

PURPOSE

This design information summary report presents data and best practices relating to the design and operation of multiple-hearth and fluid bed furnace incineration systems for combustion of sludges in municipal wastewater treatment plants in the United States. It is based on an investigation which evaluated the causes of operations and maintenance problems experienced with multiple-hearth and fluid bed furnace systems. The data contained in the report were obtained from technical literature, discussions with manufacturers, and telephone inquiries and site visits to municipal wastewater treatment plants. This document presents process and equipment descriptions, operational characteristics, process selection and application information, common problems and solutions, and design and operational considerations related to incineration of sludge.

The emphasis of this report is on multiple-hearth and fluid bed furnace incineration systems, not just on the furnace itself. In incineration, as in sludge handling in general, the performance and success of each step in the process flow train depends upon the previous step. Cost-effective operation and efficient performance of an incinerator depends upon a properly dewatered and prepared feed sludge. Ease of operation and low maintenance needs for ash handling systems depend upon the design and operation of the incinerator that produces the ash. The performance of the entire sludge handling system, not just the incinerator, will determine the success of the incineration process.

The purpose of this report is to summarize concisely the available design and operational information on multiple-hearth and fluid bed furnaces, thereby providing a general understanding of the incineration process as well as its proper application in a sludge handling system. It is not intended as a detailed design guide or as a replacement for other design guides available from manufacturers or for technical information contained in published literature. This report should be regarded as a summary of technical design and operational information. Detailed discussions on particular topics are contained in the original investigation document (1) and in the references cited within the text.

BACKGROUND

Combustion of sludge provides maximum volume reduction, destroys or reduces most toxic materials, and offers the potential for energy recovery. Multiple-hearth furnace (MHF) and fluid bed furnace (FBF) systems have been the most prominent types of incinerators used in sludge combustion in the United States for many years. Multiple-hearth furnace incineration has been widely used for over 40 years. Use of fluid bed furnace incineration has increased steadily over the last 15 years. Most of the sludge incineration facilities currently operating in the United States are MHFs, which outnumber FBFs about eight to one.

Other types of sludge incinerators include the electric furnace and single hearth cyclonic furnace. The electric furnace is relatively new and has been used since 1979 in a limited number of plants. The cyclonic furnace is limited to industrial applications in the United States.

Multiple-Hearth Furnace

The MHF is durable and simple to operate if sludge feed quality and rate are reasonably constant. This furnace can handle variations in sludge characteristics and loading rates if such changes are experienced over the long range, such as month-to-month, but hour-to-hour variations present combustion and operational difficulties. The MHF is best suited to continuous operation. Because of the time and fuel required to bring the hearths and internal equipment from a completely cold condition to operating temperatures between 1,400°F and 1,800°F, intermittent MHF operation is inadvisable.

The MHF was first used more than 100 years ago by the mining industry to dry and roast ore concentrates. These early furnaces were constructed of refractory brick, with hearths, a central shaft, and a rabble system like today's furnace. Wood and coal were used as heat sources. By 1910, the furnace was being constructed with a steel shell, which permitted a larger diameter and more hearths, and oil and gas fuel systems were added. The use of stainless steel alloys for high temperature applications of the furnace, including sludge incineration, grew out of technology developed during the 1940s.

Approximately 350 wastewater treatment plants in the United States have MHF systems. Of these facilities, 271 were reported to be operating at least intermittently. Available data on operating MHF facilities indicate that the majority use vacuum filters to dewater the sludge prior to incineration. Data on 64 operating facilities indicate that sludge feed characteristics range from 4 to 50 percent solids and from 61 to 42,000 dry pounds per hour, with averages of 28.2 percent solids and 3,850 dry pounds per hour (1).

<u>Fluid Bed Furnace</u>

The use of the FBF for wastewater sludge disposal has increased in recent years. These furnaces are characterized by a combustion process taking place in a fluidized sand bed and operating in a temperature range between 1,400°F and 1,500°F. All combustion gases and ash leave the bed and exit at the top of the pressurized furnace. Heat recovery from furnace off-gases by means of a gas-to-air heat exchanger is a desirable and common practice. The characteristic feature of the FBF is a constantly available heat sink in the sand bed, which aids in attaining steady combustion.

The first municipal application of a FBF incinerator was in Lynnwood, Washington in 1965. Today, approximately 60 municipal wastewater treatment plants have FBF facilities. Improvements in the FBF include the development of an air preheating unit (a hot windbox) in the mid-1960s, and use of waste heat boilers for energy recovery in 1968.

Approximately 29 FBF facilities in the United States are reported to be operating. The data indicate that the majority of the facilities use vacuum filters to dewater sludge prior to incineration. Reported sludge feed characteristics range from 21 to 40 percent solids and from 300 to 6,040 dry pounds per hour. Average sludge feed is 2,270 dry pounds per hour at approximately 30 percent solids (1).

PROCESS PROBLEMS

Although incineration systems are a very effective method of sludge disposal, these systems have had problems in the areas of design and operation that have limited successful and cost-effective operation. Design problems have related primarily to sizing of the furnaces and to variable sludge feed rates and characteristics. Equipment problems have included the selection, design, and layout of furnace components and support systems. Operations and maintenance (O&M) problems have involved the handling of slag, clinkers, screenings, grit, and scum.

Administrative problems in management and training of staff and in system optimization procedures have also plagued these facilities.

In some cases, these problems have been so serious that the process has been abandoned. In general, incineration systems have been shut down as a result of high energy costs making other sludge disposal methods more economically desirable. Although these costs are often attributed to improper design or to improper operation of the incineration system, in a number of cases poorly dewatered sludge has caused increased fuel consumption or fuel costs have exceeded those anticipated when the furnace was designed.

The potential for operational problems, the ability to minimize or avoid these problems through proper design features or operational controls, and a careful analysis of the operation and maintenance costs associated with an incineration system should all be considered before the process is selected over other sludge disposal alternatives. Both the benefits and the potential problems attributed to these systems, as well as side benefits such as the potential for waste heat recovery, should be included in such considerations.

SECTION 2

PROCESS AND EQUIPMENT

The incineration process reduces sludge volume by evaporating the water and burning the volatile matter contained in sludge. The efficiency of this process depends upon the performance of the preceding dewatering process and the operation of support systems such as ash handling. The combustion process, MHF and FBF incinerators, support equipment, operating characteristics, and guidelines for MHF and FBF selection and application are discussed in this section.

COMBUSTION PROCESS DESCRIPTION

Incineration is a two-step oxidation process involving drying and then combustion or burning in the presence of oxygen. Drying and combustion may be accomplished in separate units or successively in one unit, depending upon temperature constraints and control parameters. The steps are the same in both MHF and FBF incinerators. The temperature of the feed sludge is raised to 212°F to evaporate water from the sludge. Then the temperature of the water vapor and air are increased. When the sludge solids content reaches approximately 40 percent, the temperature of the dried sludge volatiles is increased to the ignition point, which is less than 1,000°F. Complete combustion of all organic material occurs at furnace operating temperatures that are in excess of 1,400°F. The sludge solids are converted to a relatively inert ash. Moisture, particulates, and inert gases are released through the furnace exhaust system during the process.

The primary combustible elements in sludge and in most supplemental fuels are fixed carbon, hydrogen, and sulfur. Because free sulfur is rarely present in sludge to any significant extent and is being limited in fuels, sulfur content can be neglected in determining the fuel value of a sludge. The fuel value of sludge is based on its carbon and hydrogen (volatile) content. In conventional solid fuels, volatile solids content is determined by heating the fuel in the absence of air, and the combustible content is determined by ignition at 1,336°F. The difference in weight loss between these two procedures is the fixed carbon content of the fuel. In sanitary engineering, the volatile content of a fuel, such as sludge, is determined by heating the sludge in the presence of air at

1,021°F; this temperature is higher than that used for volatile solids measurement for solid fuels and includes a portion of the fixed carbon. The terms volatiles and combustibles will be used interchangeably in this report in accordance with wastewater industry practice.

Solids with a high percentage of volatiles, such as grease and scum, have ~~high~~ fuel values. Grit or chemical precipitates do not have high fuel values because of the large percentage of inert material in them, and they require auxiliary fuel to burn.

Incinerator operations require air in excess of theoretical requirements to achieve complete combustion. The excess air increases the opportunity for contact between the oxygen contained in the air and the fuel. To ensure complete combustion, air volumes of 50 to 150 percent in excess of theoretical requirements must be provided in the combustion zone. When the amount of excess air is inadequate, only partial combustion of carbon occurs, and carbon monoxide, soot, and odorous hydrocarbons are produced.

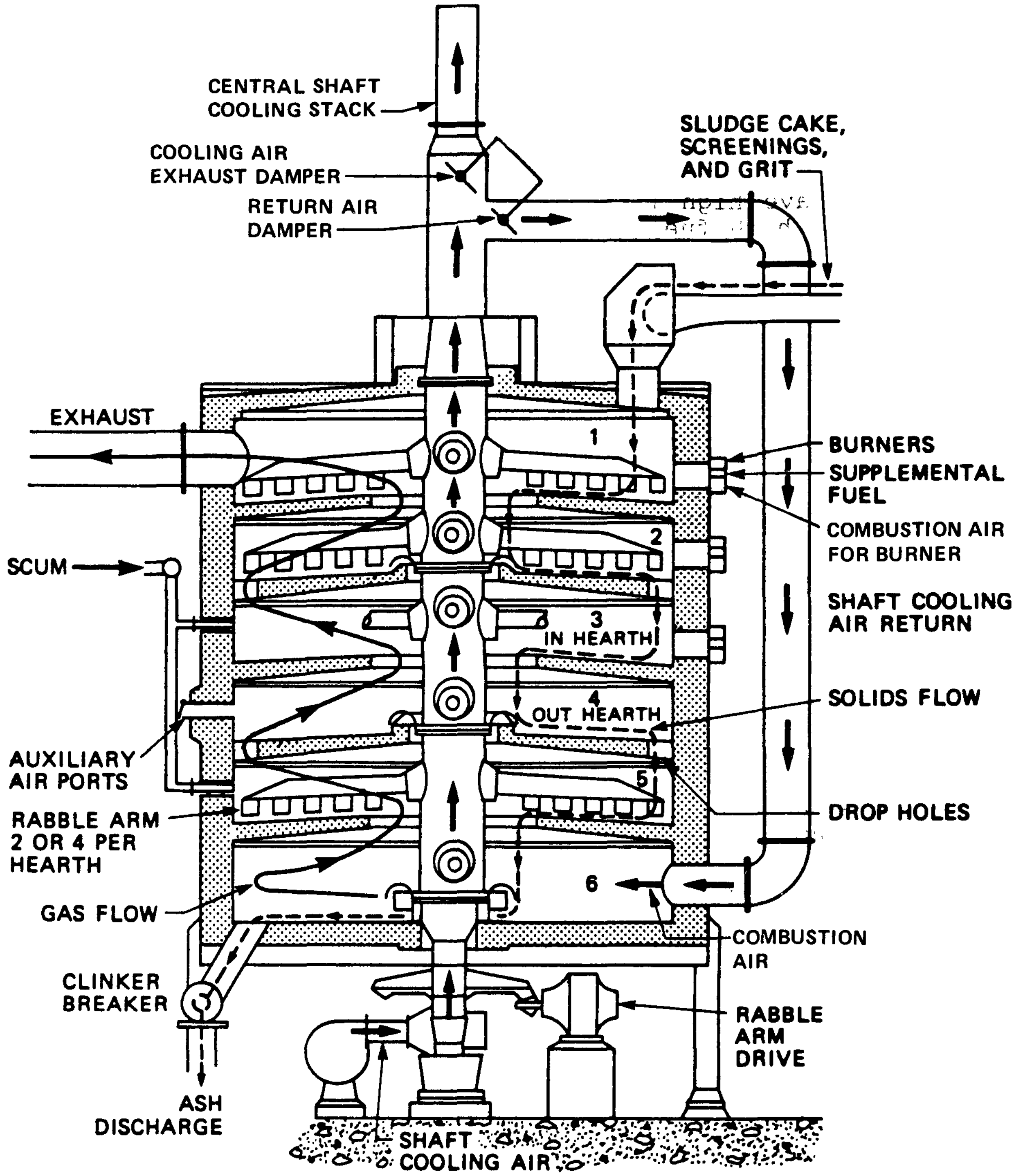
The amount of excess air required varies with the type of incinerator, characteristics of the sludge, and the disposition of the stack gases. Cost-effective operation requires that excess air be minimized to reduce energy consumption while still achieving complete combustion. Energy will be consumed by the operation of air blowers and by using supplemental fuel to raise the temperature of the combustion products and excess air from ambient to that of the combustion zone.

The amount of supplemental fuel required is not only dependent upon the amount of excess air needed for complete combustion, but also on the water content of the sludge, radiation losses, and the heating of gas streams and sludge feed solids. The heat released by the burning sludge must be sufficient to raise the temperatures of the air and all substances in the incoming sludge from ambient levels to those of the exhaust and ash and to compensate for any radiant heat loss from the incinerator. If the available heat from sludge burning is sufficient to maintain combustion without the addition of supplemental fuel, the process is termed autogenous.

Details of combustion theory and procedures to determine heat balances and fuel requirements are presented in the EPA publication entitled "Process Design Manual for Sludge Treatment and Disposal" (2).

Multiple-Hearth Furnace

A cross-section of a MHF is shown in Figure 1. The furnace consists of a circular steel shell with a series of horizontal hearths made of fire bricks. MHFs are available in



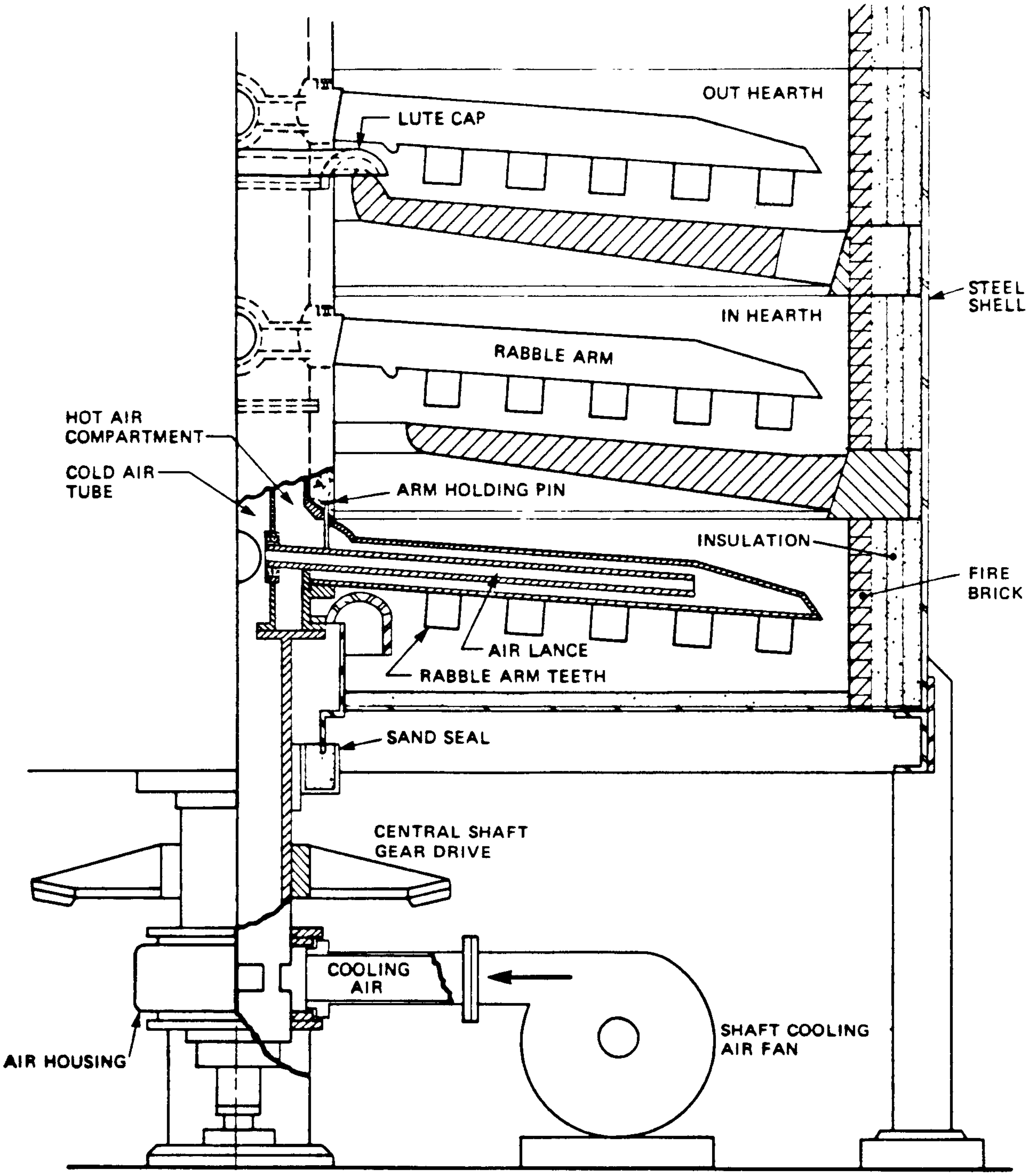
SOURCE: U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011

FIGURE 1. CROSS SECTION OF A MULTIPLE-HEARTH FURNACE

diameters ranging from 4.5 feet to 29 feet and can have 4 to 14 hearths. Two access doors with observation ports are generally provided at each hearth. The rotating central shaft is a hollow iron column cast in sections. The shaft is normally insulated with castable refractory, which is a mixture of heat-resistant aggregate and cement. Insulation renders the shaft suitable for temperatures of about 800°F for continuous operation and 1,100°F for short term operation. Shaft speed is adjustable between 1/2 and 2 revolutions per minute (rpm). Dewatered sludge is fed into the furnace at the top hearth and proceeds downward through the furnace from hearth to hearth, moved by rotating rabble arms with rabble teeth or plows attached to the central shaft. The arms are normally 25 percent chrome, 12 percent nickel alloy castings. The rabble arms constantly move the sludge in the hearths, aiding drying and burning. Ash is discharged from the bottom of the furnace, and the exhaust gases are discharged from the top of the furnace.

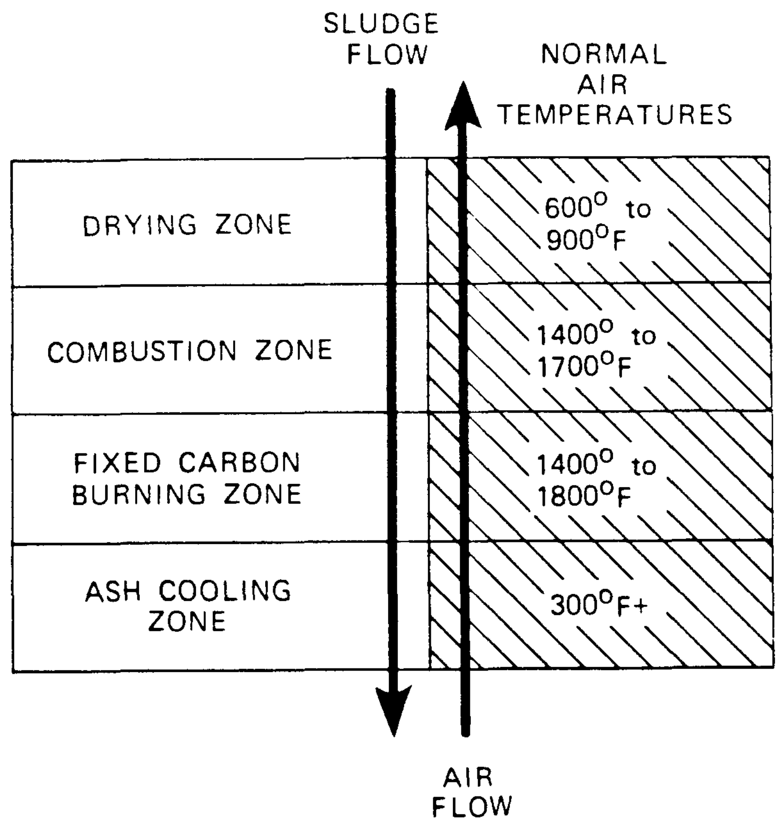
Air for combustion and cooling of the shaft and rabble arms is supplied by a fan. A cold air tube from the fan runs up the center of the shaft; air lances extend from the tube to the end of each rabble arm as seen in Figure 2. Ambient air is blown through the cold air tube and lances. The cold air exits from the lance tips, flowing back to the annular space in the shaft through the space between the lances and the rabble arm wall. This flow of air cools the shaft and rabble arms by convection. The central shaft cooling air is returned to the bottom hearth of the furnace to be used as sludge combustion air. If all the air is not needed for combustion, it is discharged to the atmosphere through the central shaft cooling stack. Because the heated central shaft cooling air is not contaminated with combustion air, it may also be used for direct forced warm air heating of the furnace area. An MHF can also have a combustion air blower which supplies auxiliary air to the combustion hearth.

The functions of drying the wet feed, combusting sludge volatiles, complete burning of fixed carbon, and cooling ash are performed in distinct zones of the furnace from top to bottom as seen in Figure 3. The first zone (drying zone) consists of the upper hearths where heated combustion gases flow upward countercurrent to the descending sludge, thereby drying and heating the sludge. The second zone (combustion zone) generally consists of the central hearths. In this zone, the majority of volatile organics are burned and some of the fixed carbon in the sludge begins combustion; temperatures reach between 1,400°F and 1,700°F. In the third zone (fixed carbon burning zone), the burning of the fixed carbon continues and is completed. Ash is cooled and discharged from the fourth zone, utilizing returned central shaft air for cooling. The sequence of these zones is always the same, but the number of hearths employed in each zone is dependent on the characteristics of the feed sludge and the



SOURCE: U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011

FIGURE 2. INTERIOR CUTAWAY VIEW OF A MULTIPLE-HEARTH FURNACE



SOURCE. U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011 (MODIFIED)

FIGURE 3. PROCESS ZONES IN A MULTIPLE-HEARTH FURNANCE

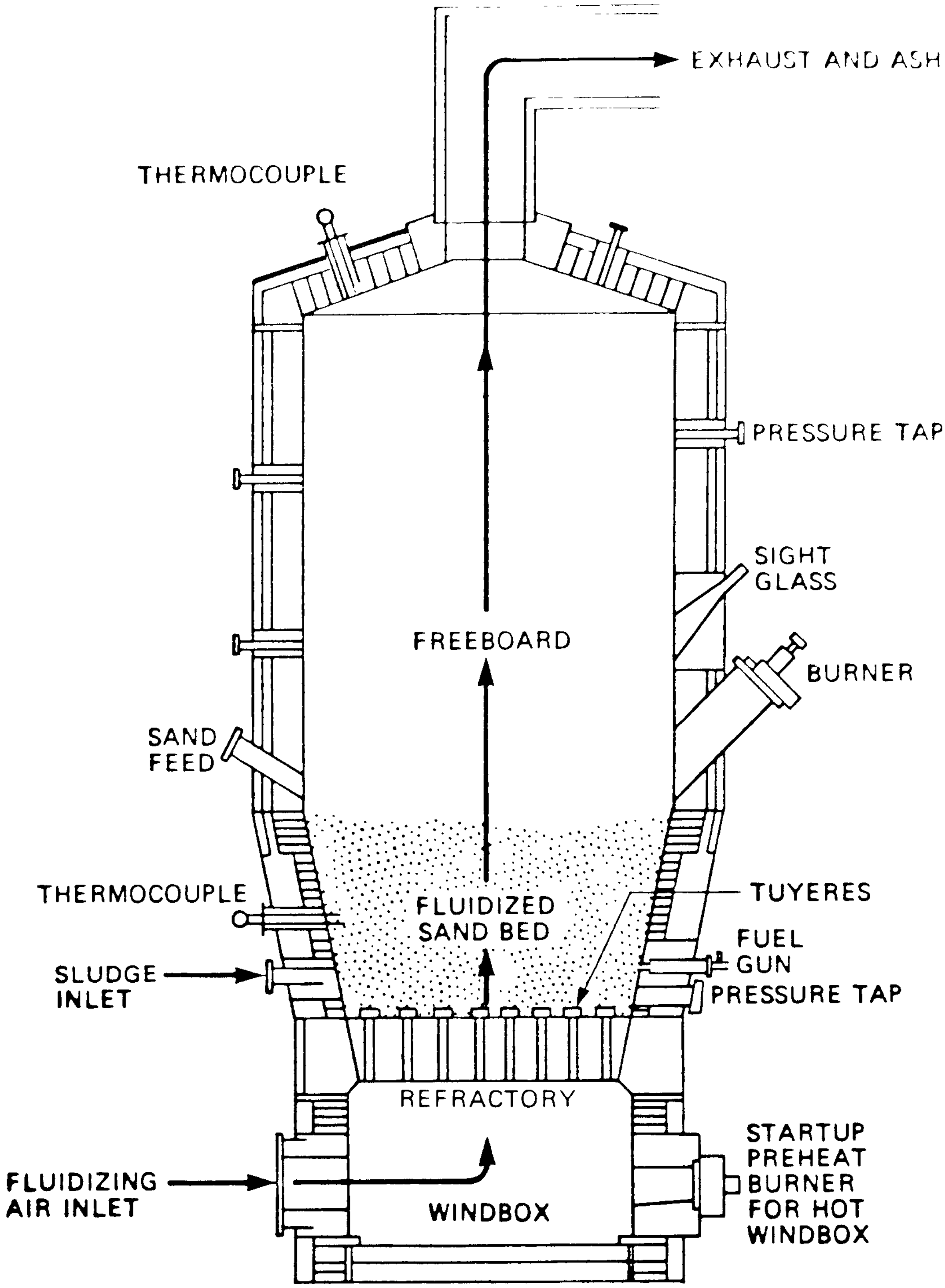
design of the furnace and burner system. Drying and combustion may occur on the same hearth in some instances.

Furnace gases exit from the MHF at temperatures ranging between 600°F and 900°F in normal operation without afterburning. At some sites, air emissions standards and sludge characteristics require an afterburner to raise the temperature of the exhaust gases to 1,400°F or higher to destroy odor-causing constituents and to burn hydrocarbons. Afterburners may either be inside the top of the furnace or outside the furnace.

Generally, the heating value of the sludge is insufficient to sustain autogenous combustion, and additional heat is provided by adding supplemental fossil fuel to the MHF. Auxiliary fuel burners for supplemental fuel and combustion air ports are located at selected hearth levels in the furnace, normally below the combustion zone hearth in the fixed carbon burning zone. The position of the combustion zone can be modified or changed depending upon the sludge feed rate, solids content, auxiliary heat input, and central shaft speed. Burners may operate either continuously or intermittently on selected hearths to maintain temperatures best suited to the sludge feed.

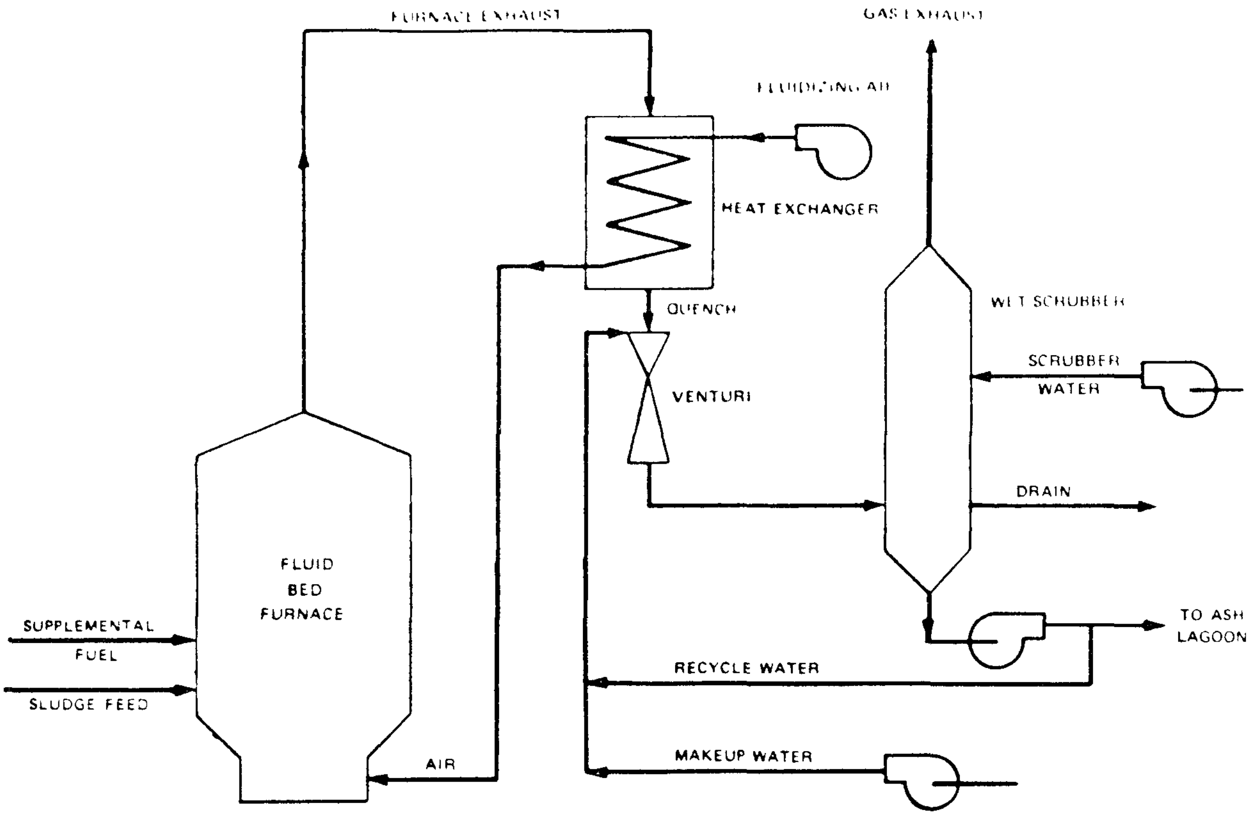
Fluid Bed Furnace

The FBF, seen in Figure 4, is a vertical cylindrically-shaped, refractory-lined steel shell that contains a sand bed (media), fluidizing air orifices, and auxiliary burners to produce and sustain combustion. The FBF is normally available from 9 to 25 feet in diameter. The sand bed is approximately 2.5 feet thick when quiescent, resting on a brick dome or refractory-lined grid. The sand bed support area contains orifices, commonly known as tuyeres, through which air is injected into the furnace at a pressure between 3 psig and 5 psig to fluidize the bed. The tuyeres are installed at an angle to the bed to prevent media from flowing back into the windbox. The structure of the bed support varies depending upon the operating temperature of fluidizing air. Dewatered sludge is either pumped or carried by screw conveyors into the sand bed. Sludge may also be pumped or conveyed into the top of the furnace, but this practice is not recommended for municipal sludge. When the sand bed is active and at operating temperature it expands to approximately double the at-rest volume. Sludge is quickly mixed within the fluid bed by the turbulent action of the bed. Evaporation of the water and combustion of the volatile solids within the sludge rapidly takes place. Combustion gases and ash leave the bed and are transported through the freeboard area to the gas outlet at the top of the furnace. Combustion gases and entrained ash are normally scrubbed in a venturi scrubber. In some designs, the exhaust gases pass through a gas-to-air heat exchanger to preheat the fluidizing air. A flow sheet for a FBF system is shown in Figure 5.



SOURCE. U. S. EPA PROCESS DESIGN MANUAL FOR SLUDGE TREATMENT & DISPOSAL EPA 625/1-79-011

FIGURE 4. CROSS SECTION OF A FLUID BED FURNACE



SOURCE U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011

FIGURE 5. FLOW SHEET FOR SLUDGE INCINERATION IN A FLUID BED FURNACE

The water and volatile solids content of the sludge normally establishes the heat demand in the bed once air flow is set. Fuel is injected into the sand bed as required to maintain bed temperature or to heat the fluidizing air. Auxiliary burners may be located either above or below the sand bed. In some installations, a water spray in the freeboard area or a heat-removal system in the bed controls furnace temperature.

Both drying and combustion of sludge occur primarily within the fluidized sand bed. The minimum temperature needed in the sand bed prior to injection of sludge is approximately 1,300°F. The temperature of the sand bed is controlled between 1,400°F and 1,500°F. Gas residence time is between 5 seconds and 10 seconds.

The freeboard space above the expanded sand bed is designed to allow disengagement of entrained sand particles. Sand or other bed media not disengaged in the freeboard zone leaves the furnace with the ash and must be replaced periodically. Media losses are approximately 5 percent of the design bed volume for every 300 hours of operation. Replacement media are introduced to the furnace either above or directly into the bed.

Combustion of gases and entrained sludge solids will continue in the freeboard area after their separation from the bed, and adequate detention time and volume must be provided to complete this combustion prior to exhaust. Freeboard combustion is evidenced by an increase in temperature between the bed and freeboard as measured by thermocouples. Temperature increases across the freeboard section must be monitored to control furnace operation. The amount of increase that may be expected is unique to each facility and must be controlled to keep furnace temperatures below 1,600°F. Increases in the order of 100°F are considered normal, and considerably higher increases are not uncommon, but must be limited. Up to 5 percent of the combustion in the FBF may occur in the freeboard area. Freeboard combustion in excess of 5 percent may result in incompletely burned organics passing through the exhaust system.

Effective destruction of organic substances that might cause odorous exhaust gases occurs when (1) the combustion within the expanded sand bed is 90 to 98 percent complete, (2) overall residence time is 5 to 10 seconds with adequate freeboard volume, and (3) a temperature range between 1,400°F and 1,600°F is maintained. In normal FBF operation, because the exhaust gases are maintained at temperatures of 1,400°F to 1,500°F for the stated time period, unburned hydrocarbon emissions are minimal and strict hydrocarbon regulations can be met without using an afterburner. However, operating conditions must be proper and steady to ensure a continuous low level of emissions.

In a FBF, sufficient air is provided for combustion by allowing for 15 percent excess air. To account for imperfect mixing in the combustion zone and to ensure that adequate oxygen is available, the FBF is typically designed with 30 to 45 percent excess air capacity. Less excess air capacity may result in incomplete combustion.

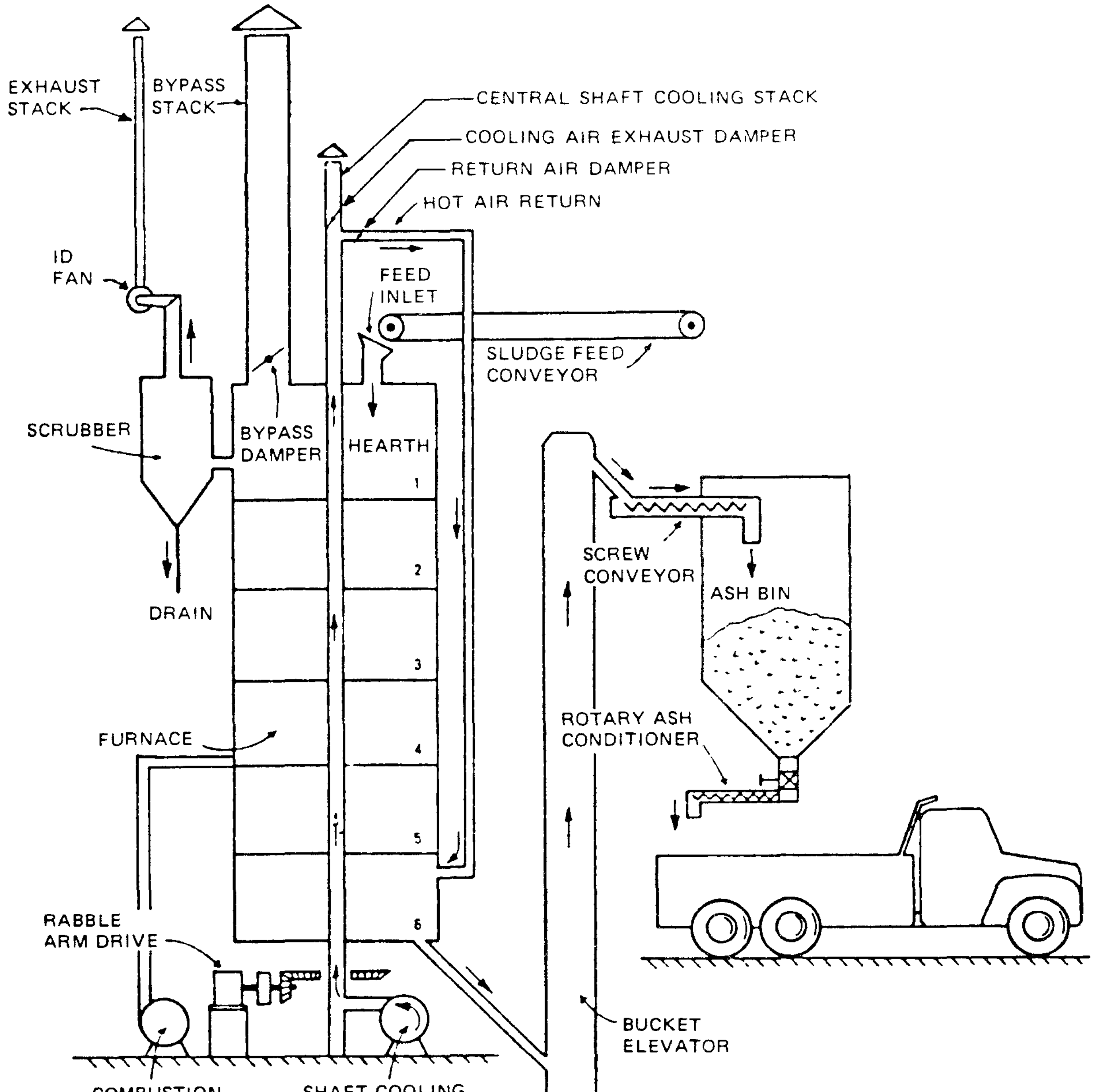
Air supplied to a FBF may either be at ambient temperature (cold windbox) or heated (hot windbox). In cold windbox design, the support beneath the sand bed serves as the air distribution plate. Because this plate is not subject to the same temperature conditions as that of the hot windbox, it can be constructed of metal. This metal plate is air cooled, which prevents excessive expansion, and designed for temperatures up to 1,000°F or slightly higher. Provisions for plate expansion at much higher temperatures require greater design attention and cost.

In hot windbox design, seen in Figure 4, the air is heated by burners within the windbox or by a heat exchanger that captures heat from the high-temperature exhaust of the furnace. The hot windbox unit utilizes a refractory brick dome bed beneath the sand. This construction is somewhat similar to the refractory hearths of MHFs. The brick domes are often twice as thick as MHF hearth cross-sections, however, since they support the sand bed and the air pressure for fluidization. Large, specially shaped bricks in the dome are pierced by holes 1 to 3 inches in diameter, through which metal air nozzles are placed, forming the tuyeres for injecting the fluidizing air.

The fluid bed acts as a thermal sink providing substantial heat storage capacity. This capacity dampens temperature fluctuations (thermal cycling) that may result from short term variations in sludge feed properties and feed rates. To indicate the heat storage characteristics of a FBF, a sand bed suitable for combustion at a rate of 6,000,000 Btu per hour would absorb or release about 1,000 Btu to change the expanded bed area temperature by 20°F. This heat storage capacity also enables relatively quick startups if the furnace shutdown period has been short, e.g., overnight, and protects the refractory dome and support arches from cracking by dampening out temperature fluctuations.

SUPPORT SYSTEM EQUIPMENT DESCRIPTION

The performance of either a MHF or a FBF incinerator is dependent upon the provision of proper support system equipment. This includes ash handling equipment, scrubbers, and other equipment directly associated with the furnace. A typical MHF system, including most of the support equipment, is illustrated in Figure 6.



SOURCE: U.S. EPA OPERATIONS MANUAL
SLUDGE HANDLING AND CONDITIONING
EPA 430/9-78-002.

FIGURE 6. SCHEMATIC OF MHF INCINERATION SYSTEM

Ash Handling System

There are two types of ash handling systems, hydraulic (wet) and mechanical (dry). The MHF can use either the hydraulic or mechanical type; the FBF can only use a hydraulic ash system because wet ash is discharged from the FBF scrubber. The hydraulic ash system, seen in Figure 7, has a steel ash hopper, pump, discharge pipeline, and water supply. The ash drops into the hopper, which is filled with water. The wetted ash settles and the resultant ash slurry is pumped to a lagoon or fill area for further settling.

The mechanical ash system, shown in Figure 8, consists of screw conveyors, a bucket elevator, an ash bin, and a rotary ash conditioner. The dry ash is discharged from the furnace to a bucket elevator, which lifts the ash to a screw conveyor and into a storage bin. From the bin, the dry ash is conditioned or wetted by a conditioning screw or rotary drum mixer with internal water sprays prior to disposal to reduce dust. The conditioned ash is normally disposed by truck at a landfill.

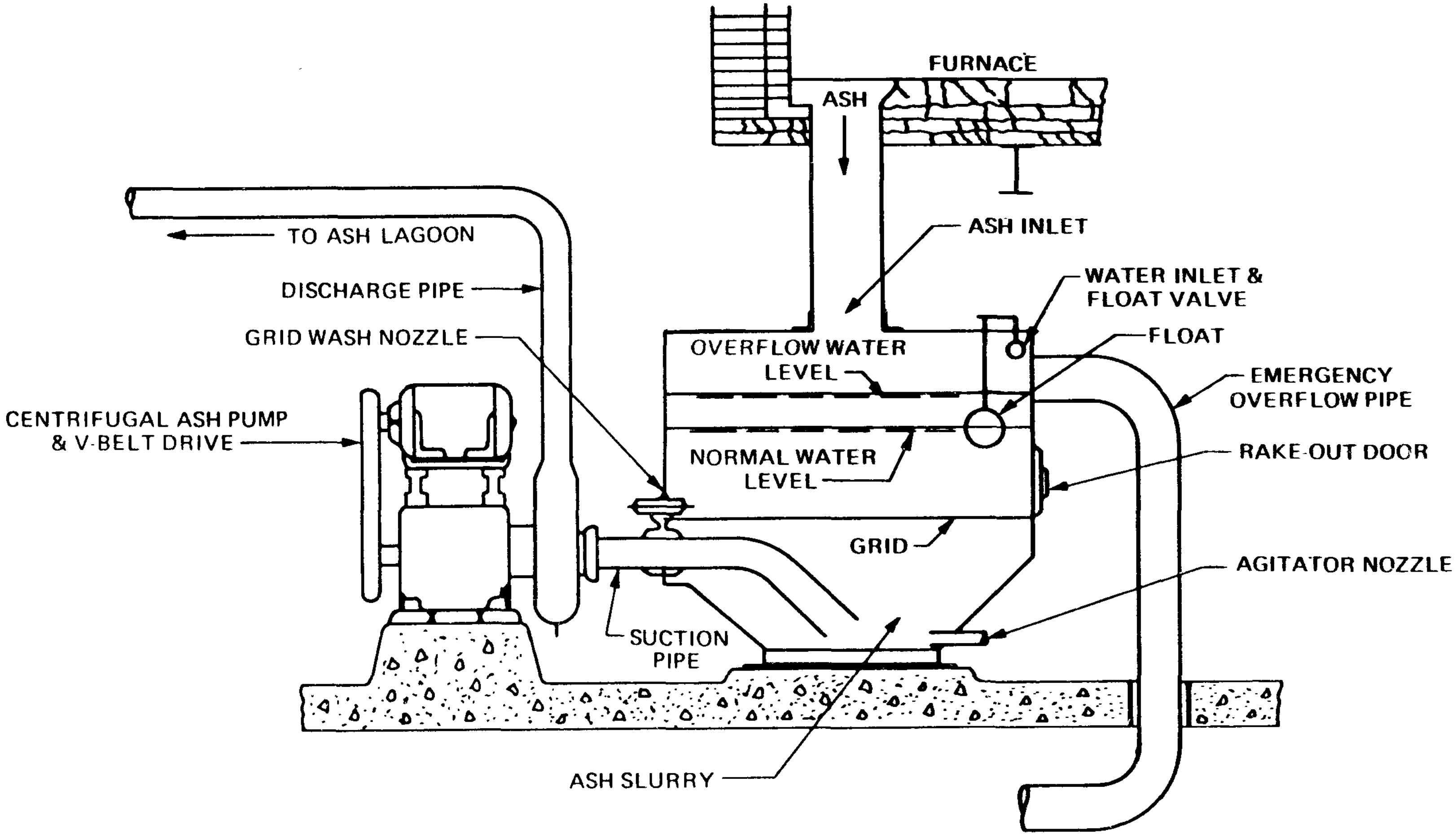
Scrubber System

The venturi scrubber with an impingement tray separator is the most commonly used exhaust gas scrubber in municipal incinerator facilities. As seen in Figure 9, the exhaust gas leaves the furnace, passing into a precooler section with water sprays, and then into a quench section in which water flows over the metal walls, forming a water seal. After quenching, the gas passes into a venturi section where its velocity increases. This increases particle collisions, promoting droplet formation. The gas and liquid pass into a flooded elbow, after which the clean gas passes through an impingement tray separator that disengages the liquid from the gas. Following this, any remaining mist is separated from the gas in the demister section. The clean gas then passes through an induced draft (ID) fan and out through an exhaust stack. Scrubbing water can be recycled and/or supplied by make-up water. Waste scrubbing water from an MHF is normally recycled into the main process train in a wastewater treatment plant. With a FBF, the scrubbing water contains the ash from the furnace and is normally treated and sent to an ash lagoon.

Other Support Equipment

Other equipment directly related to efficient operation of the MHF includes a well-sealed ash discharge outlet from the furnace to prevent the infiltration of ash into the furnace and lance or poke holes at perimeter drop hole locations in the hearths to allow access for control of slagging.

Additional support system equipment for a MHF includes the following:



SOURCE BEAUMONT BIRCH COMPANY, NJ
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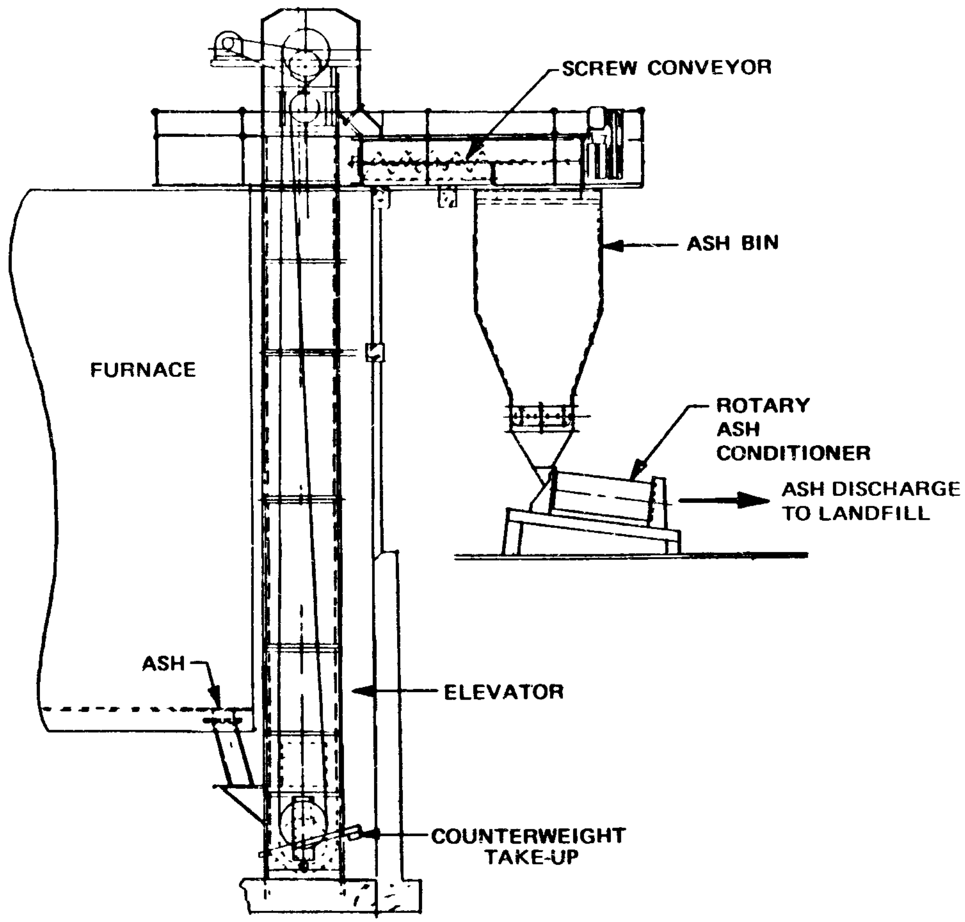
FIGURE 7. EXAMPLE OF HYDRAULIC ASH HANDLING SYSTEM



SOURCE: BEAUMONT BIRCH COMPANY, NJ
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FIGURE 8. EXAMPLE OF MECHANICAL ASH HANDLING SYSTEM

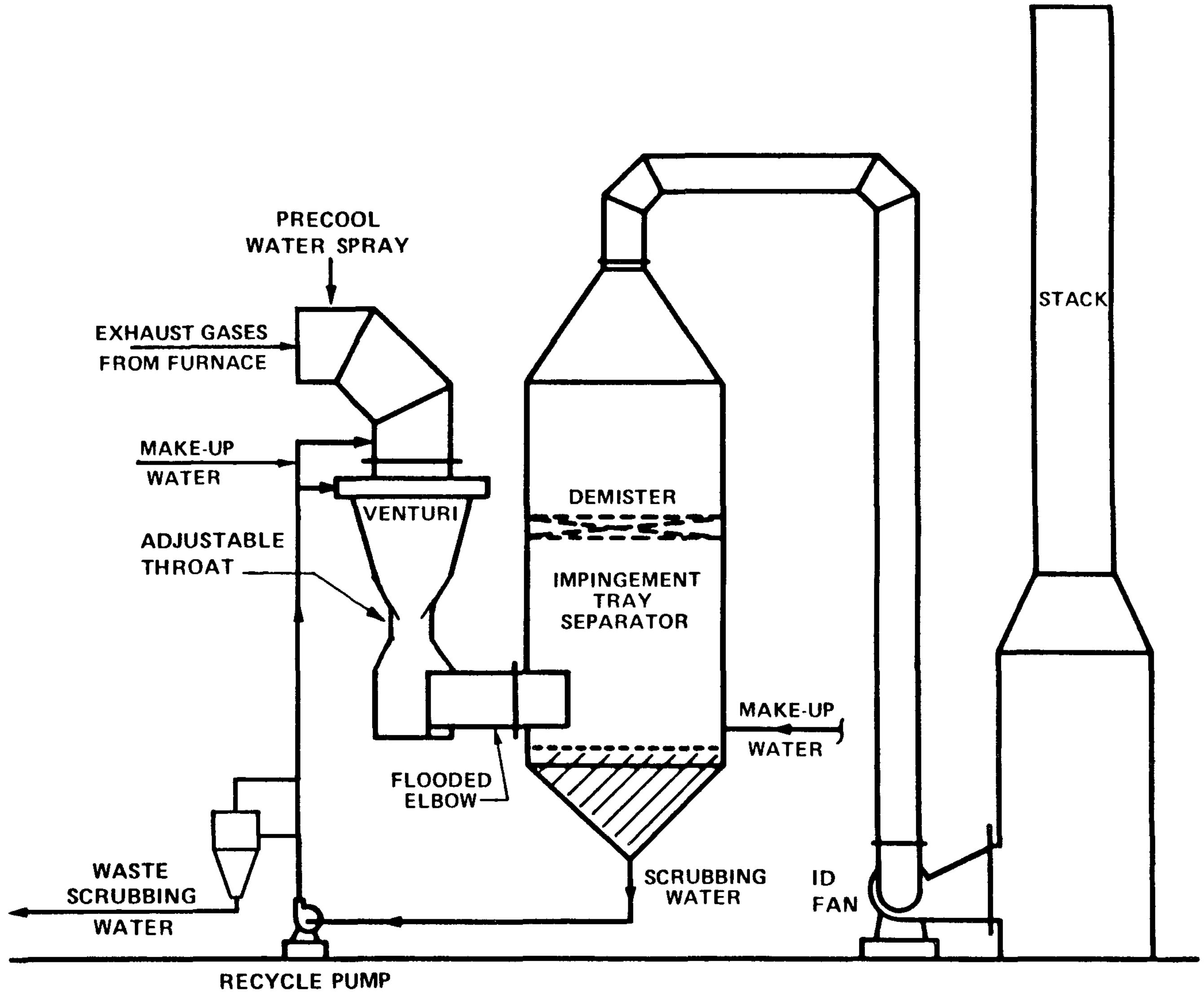

FIGURE 9. EXAMPLE OF A VENTURI SCRUBBER

- A sludge cake feed conveyor system and feeder that provides a steady, nonvariable input to the furnace.

- A live bottom bin that regulates the dewatered sludge feed to the incinerator. This type of bin has a series of augers or screws at the sludge discharge point to facilitate sludge discharge and to prevent sludge from bridging.

- Auxiliary fuel burners that are sealed at the furnace entry to prevent air infiltration into the furnace.

- Burner system blowers and central shaft cooling air fan.

- Central shaft cooling air return ductwork to hearths below the combustion zone.

- An induced draft fan designed with an adequate capacity range to satisfy the desired excess air levels in the furnace. The fan sizing should make allowances for anticipated infiltration and variations in air requirements.

- An oxygen analyzer to sample flue gases in the exhaust gas outlet from the top hearth of the furnace.

- Temperature measurement in all hearths and draft measurement in the top hearth and at selected points.

- Automatic damper-operated air and gas ducts.

- A heat recovery system consisting of a convective waste heat boiler ahead of the venturi scrubber.

Additional support system equipment for a FBF includes:

- Progressive cavity pumps, piston pumps, or screw feeders for feeding sludge beneath the surface of the bed.

- A multi-staged fluidizing air blower.

- A preheat burner mounted in the furnace to raise the temperature of the inert bed for ignition of auxiliary fuel and sludge during furnace startup.

- Fuel injectors for feeding auxiliary fuel directly into the bed.

- An auxiliary fuel system incorporating flame safeguard controls for burners and a separate furnace fuel injector system.

- A furnace freeboard temperature control system, consisting of a high pressure water pump and sprays.

- A gas-to-air heat exchanger for hot windbox FBFs.

- A heat recovery system consisting of a convective waste heat boiler ahead of the venturi scrubber.

DESIGN IMPROVEMENTS

Contemporary design and operation of MHF and FBF systems incorporates procedures that conserve auxiliary fuel. These diverse fuel-saving procedures range from improved sludge dewatering to modifications of the furnace itself. Because the focus of this document is on improvements to incinerator systems, this discussion includes a brief summary of operating variables that affect fuel consumption and a description of two installations where fuel-saving designs and procedures have been undertaken.

Multiple-Hearth Furnace

The primary factors that affect fuel consumption in the MHF are the sludge feed rate and its fuel value. Although these factors are often not subject to control, the sludge combustion air flowrate, the auxiliary fuel and sludge combustion rate, and the rotational speed of the rabble arms are operating variables that can be controlled. Manipulation of these variables will directly affect the following:

- Exhaust temperature (temperature of the uppermost hearth)

- Excess air in the exhaust gas

- Temperature of the gas in the combustion zone.

In order to conserve auxiliary fuel consumption in the MHF, these variables should be controlled. If not, the following operating conditions can result, leading to high fuel consumption:

- High incinerator exhaust temperatures

- High combustion zone location in the incinerator

- Greater draft than necessary

- Underutilization of heated cooling return air

- Unsatisfactory burner use patterns.

A new MHF system at San Mateo, California has incorporated fuel-efficient design features for that type of furnace. The feed sludge to the MHF has a dry solids content of 25 percent. The furnace itself has an oversized combustion hearth located approximately in the middle of the furnace. The exhaust gases exit the furnace from this combustion hearth, not from the top of the furnace, at temperatures between 1,400°F and 1,600°F. The furnace does not have auxiliary burners mounted on the walls; rather there is a separate combustion chamber mounted externally on the furnace. This chamber contains the only auxiliary fuel burner in the system. All fuel burning occurs in it, providing more precise control of fuel and air combustion. Flue gases from the drying zone of the furnace are recirculated into this chamber and then pass into the fixed carbon zone. Excellent design features include:

- Use of moisture in the sludge to absorb excess heat in the combustion zone and oxygen in the dry recirculated off-gases.

- A variable gas recirculation rate. For example, to accommodate variations in sludge feed solids content, a decrease in sludge solids can be offset by a corresponding increase in gas flow through the drying zone, ensuring that the sludge reaches the combustion zone with the solids content required for combustion.

- Control of excess air.

- An external combustion chamber that can burn a variety of available fuels, including waste fuels, without flame impingement on the rabble arms or on the central shaft because no burners are mounted in the furnace.

- A suitable residence time and temperature (between 1,400°F and 1,600°F) for exhaust gases to achieve deodorization, making afterburning unnecessary.

- Return air temperature is maintained without the use of fossil fuel.

Fluid Bed Furnace

As with the MHF, the sludge feed rate and its fuel value are the primary factors affecting fuel consumption in an FBF. Because the FBF is designed with specific fluidizing air requirements, the air flowrate is more or less fixed. The sludge feed rate is matched to the air flowrate and is therefore limited to a narrow design range. Auxiliary fuel consumption is dependent upon the fuel value of the sludge and the required bed temperature.

While bed temperature is a function of the sludge characteristics and feed rate, the furnace exhaust temperature can be directly controlled by a temperature control system, consisting of a series of high pressure water sprays that cool the exhaust gases.

Improvements in fuel efficiency of FBF systems primarily depend on revisions to support systems and changes in modes of operation. This is illustrated by modifications to a FBF system at a wastewater treatment plant in Norwalk, Connecticut, as seen in Figure 10. The FBF system, installed in 1973, utilized a cold windbox without heat recovery. Sludge was dewatered by centrifuge prior to incineration.

The system was revised by replacing the centrifuge with a belt filter press for dewatering and installing a FBF to act as a dryer in series with a FBF acting as a combustor. Sludge from the belt filter press, at approximately 25 percent solids, is fed directly to the dryer FBF. The dried sludge and sand from the dryer FBF flow by gravity down to the combustor FBF where the sludge is burned. A sand lift blower circulates the hot sand from the combustor FBF to the dryer FBF, providing a constantly hot bed for drying. Hot exhaust gas (approximately 1,500°F) is routed from the combustor FBF through two heat exchangers in series and then through a scrubber. These heat exchangers preheat fluidizing air to approximately 1,200°F for the combustor and 230°F for the dryer FBF. The key to fuel saving operation is the use of a low temperature FBF as a dryer. With less fuel required for evaporating moisture, more air is available to burn sludge.

These improvements have resulted in reductions in operating crew, hours of daily operation, and fuel oil use while doubling sludge capacity. Annual cost savings have been estimated at between $300,000 and $400,000 (1984 dollars).

PROCESS SELECTION AND APPLICATION

Selection of the incineration process for municipal sludge is generally based on the results of a technical and economic evaluation and a comparison with other sludge handling alternatives. Because the incineration process can handle nearly all types of sludge, the primary factors in the selection of incineration are plant size and economics. An economic comparison of incineration with other sludge handling alternatives is beyond the intent of this report and is discussed in other technical literature (2). The major advantages and disadvantages of incineration are summarized in Table 1.

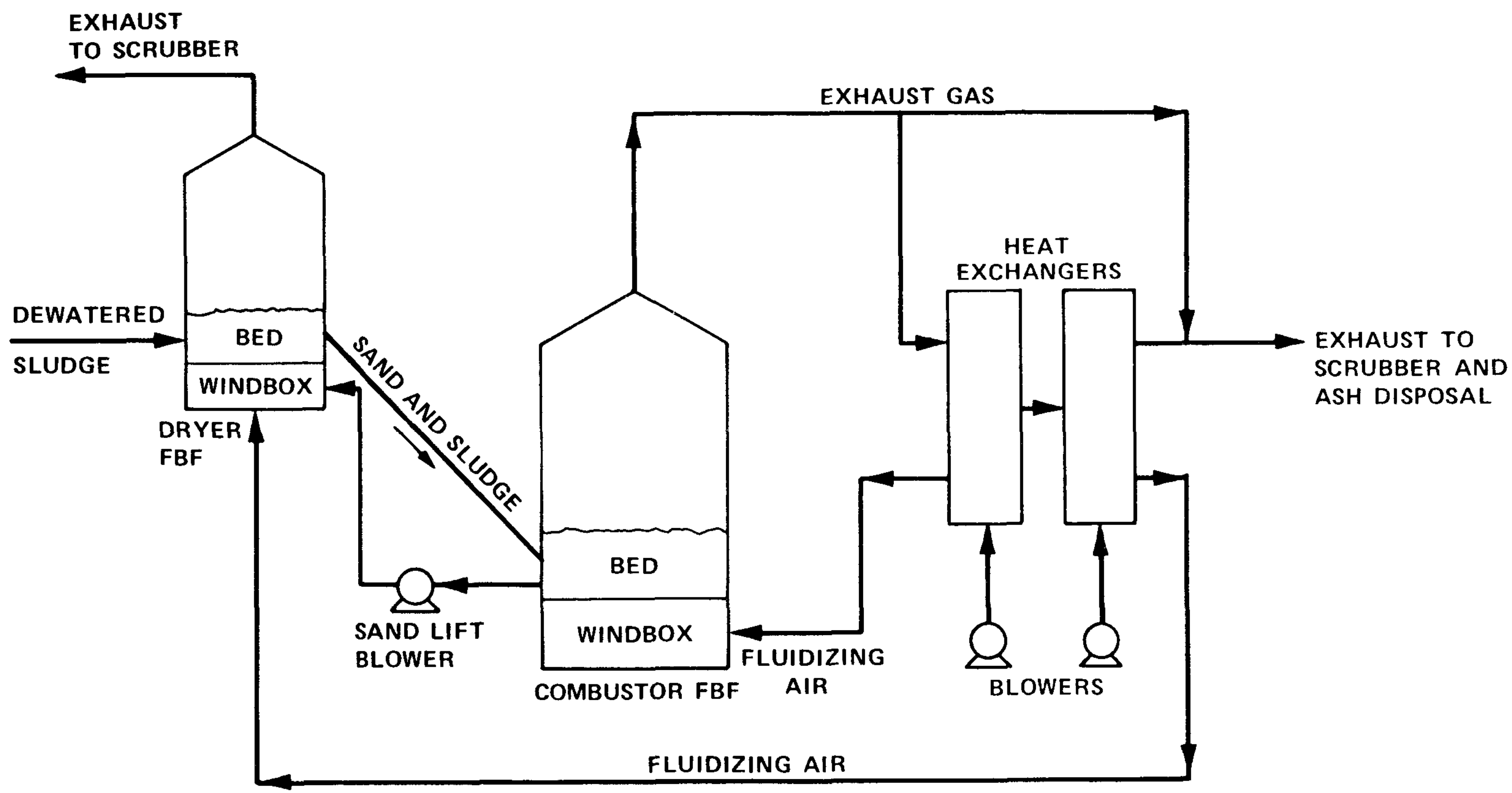

FIGURE 10. SCHEMATIC OF FBF SYSTEM AT NORWALK, CONNECTICUT

TABLE 1. ADVANTAGES AND DISADVANTAGES OF INCINERATION

Advantages
Reduction of volume and weight of wet sludge cake by approximately 95 percent, reducing volume for disposal
Destruction or reduction of toxics
Potential for recovery of energy from waste heat
Disadvantages
Generally higher capital and O&M costs than for alternative disposal methods, especially if energy recovery and fuel efficient operation are not considered
High maintenance requirements due to high temperature operations
Highly skilled and experienced operators required
Discharges to atmosphere that may require extensive treatment

Factors that affect selection of both the incineration process and the type of incinerator are plant size and process flow train, furnace design differences, emissions levels, fuel requirements, maintenance, power, labor, and chemical sludge conditioning.

Plant Size

Practical wastewater treatment plant size for incineration of sludge is primarily dictated by the feasibility of other volume reduction and stabilization processes at the site, and the availability of other, lower-cost disposal methods such as landfilling, land application, or composting. Generally, smaller plants (less than 10 million gallons per day, mgd) have options such as these that are viable and less costly for the volume of sludge they produce. Other factors influencing this choice include the location of the plant and the availability of the land for alternative, more economical disposal methods. Smaller plants in urban areas may find incineration the best method, whereas plants of equal size in less industrial, more rural areas may not. Sludge characteristics, such as volatile solids contents, also affect the decision to incinerate.

In general, incineration is cost-effective in larger installations where the support facilities discussed below are readily available and alternative disposal options are limited. An approximate plant size at which incineration becomes feasible is about 20 mgd for a MHF system and 10 mgd for a FBF system. Other factors that dictate practical plant size are:

- The opportunity to incorporate energy saving features into the overall treatment process by waste heat recovery, steam generation, use of the incinerator for odor control of off-gases from other processes, and the use of digester gas for auxiliary fuel.

- The availability of O&M personnel with the comparatively sophisticated training required to operate and maintain incineration units. Maintenance and instrumentation personnel with the necessary skills are not normally present at smaller plants, and service contracts are usually quite costly.

- The ability to finance the considerable spare parts inventories and preventive maintenance programs needed to minimize downtime, which may not be feasible in small plants.

For smaller facilities, the FBF is available in smaller units than the MHF, and the FBF has the flexibility to be shutdown for short periods without using significant amounts of auxiliary fuel to restart or maintain heat. This allows small plants to operate with one shift per day.

Design Comparison

Differences in design between the MHF and the FBF are primarily in the areas of ash handling, incinerator construction, feed solids content, and level of instrumentation.

- The MHF can use a dry ash handling system; its dry ash is lighter and therfore cheaper to haul and landfill than is wet ash from a FBF.

- The MHF does not require a regular supply of bed media (sand) and is not likely to incur as much erosion damage in the exhaust gas system as is the FBF.

- The FBF system requires gas tight construction. MHFs are under negative pressure and must be designed to minimize air infiltration to maintain thermal efficiency, but they are not necessarily gas tight.

- Both incinerator systems must have properly designed furnace refractories and flues.

- Slagging and clinkering may be more easily handled in a MHF because of the accessibility provided by furnace doors. Although this advantage is marginal, slagging in a FBF may cause defluidization or shutdowns for long periods to remove the slag.

- FBFs can better accommodate grease and scum, using it as auxiliary fuel in sludge burning. These materials can burn in the fluidized bed, which supplies good contact with combustion air.

- The FBF is more easily controlled than the MHF because it has a simpler burning process. MHF control can be simplified by low excess air operation and a longer sludge drying period.

Emissions

Both types of furnaces can meet present federal emission standards when fitted with appropriate emission control devices. In many cases, pollutant emission levels may be decreased through improved combustion control. In the future, increasingly stringent requirements on emissions may influence furnace selection.

Under normal operation, FBFs have exhaust temperatures between 1,400°F and 1,500°F, which destroy odors and hydrocarbons, and reduce particulates. Because MHF exhaust temperatures are below this range, it may be necessary to incorporate afterburning in some MHF installations to destroy odors and to burn out hydrocarbons. Present afterburning methods use considerable amounts of auxiliary fuel, raising operating costs. Given the present use of the MHF, the FBF has an advantage where afterburning is necessary. If an exhaust temperature of 1,600°F is required for emission control, the FBF can be operated at this level without afterburning.

Operational Flexibility

Based on current use in municipal plants and available manufacturers' products, the FBF provides more flexibility in furnace operation than does the MHF. The primary advantage of the FBF is its ability to be operated for less than 24 hours a day. The FBF can accommodate shorter periods of sludge feed by operating fewer hours a day and can be placed on standby overnight without experiencing appreciable heat loss in the bed. The MHF cannot be operated intermittently for short periods without maintaining furnace temperatures at the expense of auxiliary fuel. The FBF is also more responsive to variations in feed characteristics and rate than is the MHF. In addition, the FBF is better able to handle scum, grit, and screenings than is the MHF. The main disadvantage of the FBF is that it has minimum air requirements to fluidize the bed media that cannot be reduced. Therefore, the FBF should be operated near design sludge loading rates even for short periods.

Fuel Requirements

A comparison of the fuel requirements of the MHF and the FBF must be based on the characteristics and type of sludge feed to the furnaces. These characteristics include volatile content and odor potential. FBFs perform better than MHFs where high volatile content sludges are incinerated. The typical 50/50 mix of polymer conditioned raw primary/waste activated sludge is in this category.

The FBF has better fuel efficiency than the MHF if afterburning is required. In the FBF, all exhaust gases pass through a zone between 1,400°F and 1,500°F before exiting from the furnace. Odor causing components of the exhaust gas usually have ignition temperatures under 1,420°F and are therefore destroyed.

In the MHF, furnace exhaust gas temperatures range from 600°F to 900°F when maintaining correct operating temperatures in the combustion zone without afterburning. For sludge with odor causing exhaust gas constituents, afterburning may be required in the MHF. However, MHFs may operate with reduced fuel requirements with less odorous sludges, such as primary and trickling filter sludges conditioned with lime and ferric chloride. With these types of sludges, odor causing constituents are minimal and afterburning would not normally be required.

Conventional auxiliary fuels for both furnaces are oil and gas. In some cases, digester gas can replace or supplement these fuels. The FBF can also operate on nonconventional types of fuel such as coal or refuse derived fuel.

Maintenance

Maintenance and replacement requirements for major components of the MHF and FBF systems show no distinct advantages of one system over the other.

- Both MHF rabble arms and FBF air distribution systems are durable, and neither requires replacement for many years with ordinary maintenance. Although rabble arms are more exposed to abrasion and differential heating than are FBF orifices, long service is attainable if they are properly designed and maintained.

- Hearths in the MHF and refractory domes in the FBF are subject to cyclical temperature swings which can cause damage. The MHF has a greater potential for damage because it has more frequent temperature fluctuations than the FBF and more hearths that must be repaired and replaced. However, with a steady sludge feed and a minimum of shutdowns and startups, maintenance requirements in these refractory areas are reduced.

- If both types of furnaces use hydraulic ash handling systems, the general opinion is that there is no outstanding difference in maintenance between the two. Dry ash handling for the MHF requires a considerable degree of maintenance.

- Because the exhaust gases of the FBF carry both ash and bed media, there is a significant problem of erosion in flues from the point at which gas exits the furnace to the scrubber entrance.

- The exhaust gas systems for the FBF, including the heat exchanger and expansion joints, often require serious maintenance and must normally be given more maintenance attention than the MHF exhaust system. Corrosive attack is reported more often for the FBF exhaust system. However, the induced draft fan in the MHF has high maintenance requirements that do not exist for the FBF.

Electric Power

Under normal operating conditions, electric power requirements are not significantly different for the MHF and the FBF systems. In the MHF, the major electrical equipment is air blowers for the auxiliary fuel system, the induced draft fan, and the furnace drive. Fluidizing blowers and burners are the major electrical equipment in the FBFs. Despite the considerably higher pressure required for the FBF fluidizing blower, it must supply only half the air volume of a comparably sized MHF.

Labor Cost

For either type of furnace, a full-time operator is required when one furnace is operating. If two furnaces are operating, operator attention will increase similarly for either type of furnace, requiring supplemental part-time help. The required skills for operators of either furnace are considered to be equal.

The FBF is more advantageous where operating with one or two shifts per day is preferred to 24-hour operation. The MHF performs more economically under continuous operation. If furnace capacity exceeds sludge production or sludge dewatering is not continuous, labor costs are more favorable for the FBF system.

Maintenance labor for MHF and FBF systems is approximately equal.

Inorganic Chemical Conditioning

Lime, metal salts, and polymers are frequently used as chemical aids in wastewater treatment processes and in sludge conditioning. The burning of sludges containing metal salts from these processes has caused severe slagging and clinkering. Some FBFs that have burned municipal sludge containing ferric chloride have had slagging so severe as to plug the gas outlet from the furnace. Burning sludge containing polymers has caused clinkering in some MHFs.

In both types of furnaces, sludges containing lime or metal salts increase O&M costs, fuel consumption, and corrosion. Higher operating and maintenance costs result from the added ash and clinkers produced when using these chemicals. The additional inert materials from chemicals fed into the furnace also increase fuel consumption. If calcining temperatures are reached, the endothermic reaction of lime will require additional energy. At high temperatures the chlorides carried in ferric chloride sludges will result in accelerated corrosion of metal parts.

SECTION 3

COMMON PROBLEMS AND SOLUTIONS

Problems involving design, equipment, operation, and administration of MHF and FBF systems, summarized in Table 2, are common at many municipal wastewater treatment plants. These problems increase the unit cost of incinerator operation, reduce its operational efficiency, and/or cause equipment or system failures. Solutions to these problems exist and have been successfully implemented. The solutions presented can be used as guidelines for designing and operating MHF and FBF systems, keeping in mind that specific solutions may have to be modified to suit a particular plant.

This information, gathered as part of a research study conducted for EPA, is drawn from a number of sources, including discussions with manufacturers and consultants, and telephone inquires and site visits to municipal wastewater treatment plants with MHF and FBF facilities.

PROCESS DESIGN PROBLEMS

Process design problems relate to selection and application of the type of incinerator, as well as the equipment for the incinerator and its support systems. These support systems include sludge dewatering and sludge feed facilities. Problems that relate more specifically to the design and use of other equipment components are discussed as equipment problems.

Dewatering

Regardless of the type of incinerator, the extent to which feed sludge is dewatered has a major impact on incineration efficiency and costs. The low solids content of sludges dewatered by vacuum filters or centrifuges is a common problem at plants completed prior to 1979. Sludge having a high moisture content reduces the equivalent dry solids throughput capacity of furnaces and requires larger amounts of auxiliary fuel to evaporate the water prior to or during combustion.

TABLE 2. SUMMARY OF MAJOR PROBLEMS WITH MHF AND FBF SYSTEMS

Process Design Problems
Inefficient sludge dewatering
Oversizing of incinerators
Variable sludge composition and feed rate
Equipment Problems
Failure of hearths
Overheating and failure of rabble arms
Cracks in central shafts
Design, draft control, vibration, noise, and corrosion of induced draft fans
Failure of poorly fitted bypass dampers
Failure of thermocouples
Failure of refractory domes
Sand leakage into air distribution piping
Corrosion in flues
Wear, dust control, and abrasion in ash handling systems
Wear and maintenance of conveyors
Misalignment of off-gas system
Improper sizing, design, and corrosion of boilers
Improper design and corrosion of scrubbers
Operation and Maintenance Problems
Slag and clinkers
Improperly adjusted burners
Screenings, grit, and scum handling
Administrative Problems
Lack of system understanding by senior management personnel
Poorly qualified O&M staff
Insufficient operator training
Lack of process optimization

Drier sludge cakes are achieved at plants that use more efficient belt presses or recessed plate filter presses. In some cases, incinerator fuel consumption has been reduced by more than 50 percent as a result. In multiple incinerator systems, drier feed sludge has also eliminated the use of one or more incinerators. Other savings occur in labor, power, and maintenance costs due to the higher solids content and lower volume of sludge to be incinerated. The cost for supplementing or replacing dewatering equipment would be expected to be recovered from O&M savings in three months to two years.

Equipment Sizing

Incineration systems are often oversized. Their selection and sizing is frequently based only on projected design loads that either are never realized or are so much higher than the sludge volumes provided in the initial years of plant operation that furnace operation cannot be efficiently reduced to match production. An oversized incinerator must be operated intermittently, which leads to very high auxiliary fuel costs associated with reheating the furnace to operating temperature after cooling down or maintaining the furnace in a "hot" standby condition. Oversizing is the result of a compounding of the following factors:

- Use of peaking factors of 1.5 to 2.0 times average sludge production to define maximum weekly loading conditions

- Use of overly conservative criteria (i.e., design for the highest probable moisture content of the dewatered cake at the highest solids loading)

- Adoption of excessive safety factors for such parameters as sludge cake loading on MHF hearths or FBF fluidizing and freeboard velocities.

Excess MHF capacity increases capital and sludge disposal costs. The unit costs of MHF operation and maintenance will increase for the following reasons:

- Total labor costs will remain nearly the same whether operating at full or partial incinerator capacity because staffing for both cases will be approximately the same.

- Total electric power costs for units operating at partial capacity will be nearly equal to costs at full capacity due to operation of electrical motors at inefficient levels.

- Unit fuel costs will be higher due to frequent startups or a need for standby heating for long periods. Additionally, extended sludge storage can reduce dewaterability, increasing sludge cake moisture and the fuel required for evaporation.

- Total maintenance costs will increase because cycling of the incinerator for intermittent use decreases refractory life, requiring more frequent replacement of brickwork.

The impacts of oversizing the FBF are similar to those for the MHF. The most significant impact is the added capital cost for larger FBF unit(s). Labor costs for operation of a FBF are not significantly affected by oversizing, and may be reduced if sludge can be processed during one or two shifts per day. As with the MHF, unit electric power costs will be higher due to inefficient operation of motors. Maintenance costs for an oversized FBF will be increased by cyclic operation and increased needs for repair or replacement of the refractory.

The first and most important step for the design of a municipal sludge incineration system is to define the sludge feed characteristics and to establish the operating parameters required for the furnace and support systems. Two basic criteria are required:

- Sludge feed rate: pounds of wet cake per hour

- Properties of the sludge feed:

  . Percent solids (preferable to moisture content)

  . Percent combustibles in the solids (total volatiles)

  . Gross heating value of combustibles

  . Analysis of total, or ultimate, combustibles

  . Presence of chemicals that react endothermically.

The softening and fusion points of the ash, determined by ASTM Method D-1857-68, are also highly desirable. These criteria can be determined if a valid specimen of the sludge or ash can be obtained.

In many instances, the above criteria are not known with precision before specifications are prepared. The designer depends upon the accumulation of in-house data on sludge feed characteristics. Ranges of expected values are inspected to ensure that the furnace will meet the needs of the wastewater treatment plant.

An effective alternative to specifying wide ranges in these criteria is to develop plant operating mode scenarios. This will not only facilitate the development of the above criteria and heat and material balances, but will also provide a more realistic picture of operation of the solids handling train. Once these criteria are developed, minimum and maximum furnace exhaust temperatures and minimum and maximum percentages of oxygen (excess air) in the exhaust gas can be determined.

Before specifications are finalized, heat and material balances should be revised and finalized for each operating scenario and a table prepared indicating the following:

- Sludge combustion air required, as both mass flowrate and volume rate, in pounds per hour and standard cubic feet per minute, respectively
- Shaft cooling air recycle (if a MHF is considered), in pounds per hour
- Ambient air temperature, in ^{o}F
- Auxiliary fuel required, in Btu per hour, or in fuel volume terms, including fuel analysis and characteristics
- Auxiliary fuel combustion air required, in pounds per hour and standard cubic feet per minute
- Furnace exhaust flue gas volume, in actual cubic feet per minute.

After this table of values is completed, a summary table indicating the minimum and maximum values for each parameter should be prepared. The summary table should then be examined to determine whether the desired capacity range of individual equipment items is within the useful and feasible operating range of available equipment.

The problem of excess furnace capacity in the initial years of operation may be addressed by two design approaches. One approach is to install furnaces that can be incrementally modified to activate the use of more hearths and/or combustion volume as sludge quantities increase. An alternative approach is to use smaller multiple units to achieve incremental increases in plant furnace capacity. Although multiple units increase the capital cost of the plant, they provide considerable flexibility and increased reliability. If all of the projected furnace capacity is not initially installed, benefits derived from advanced technology and onsite system improvements may be realized when the additional units are installed in the future. The applicability of either approach is dependent on the projected growth rate of the sludge load as well as other factors unique to each individual treatment facility.

In existing MHFs, modifications are possible to minimize the impact of oversizing. Modifications can be made to the MHF to reduce the number of sludge processing hearths by cutting holes in the upper hearths to allow sludge to be fed two or three hearths lower. The burners on the upper hearths may be sealed off or used as afterburners if required. Reduced gas flows to scrubbers can be appropriately handled by variable venturi throats and/or variable speed fans.

The MHF can also be modified to handle low sludge feed rates by allowing the sludge to burn on a higher hearth than normal and permitting the lower hearths to simply transport ash. For prolonged low solids throughput, revising the operation to the higher hearths and discontinuing heating of the lower hearths could be practiced. The entry of excess air could be sealed off in the lower part of the furnace. Combustion air and gas would also be proportionately reduced.

Variable Sludge Composition and Feed Rate

Variations in feed rate, heating value, and solids content of sludges result in unsteady conditions in MHFs and difficulty in maintaining regular operation at low excess air in FBFs. The inability to operate at planned excess air levels seriously affects fuel economy, capacity, and power consumption.

The combustion air requirements of a furnace are directly related to the combustible solids feed rate of the feed sludge. The combustible content of the sludge is directly related to its dry solids content and to the particular constituents of the sludge, such as volatile solids, scum, grease, and inert solids content. For a particular sludge, a 50 percent increase in dry solids content will equal a 50 percent increase in combustible material. Under steady sludge feed conditions, this represents a 50 percent increase in combustion air requirements. Similarly, a decrease in the inert solids content of feed sludge will produce a proportionate increase in the combustible content of the sludge. Finally, an increase in sludge feed rate to the incinerator will increase the rate of feed of combustible material. If all of these changes occur simultaneously, as they frequently do in municipal installations, they can produce a radical change in the heat input to the furnace and in combustion air requirements, resulting in extreme demands on air and fuel supply systems. Where those demands are beyond the capacity of installed equipment, excessive temperatures will result.

An increase in the solids content of the sludge feed can also place additional demands on the MHF. Increasing the solids content decreases the quantity of water to be evaporated, decreasing the hearth drying area required. If the solids content of feed sludge is increased suddenly, it could be dried to the point where it could ignite while still on an upper drying hearth. The preceding lower solids content sludge, still burning at its normal rate on the lower hearths, would contribute heat to further raise the temperature on the upper hearths, increasing the combustion rate on the upper hearths. This burning in two zones of the furnace is termed double burning and results in a very large increase in combustion air needs. Once the upper hearth ignites, temperatures on that hearth and all hearths above may rise, causing burning on yet a third hearth.

These conditions result in unstable combustion in a MHF due to high temperatures and a lack of sufficient air for complete combustion. Without this air, the furnace may produce smoke or exceed safe temperature limits, depending on furnace control setting and operating conditions prior to the change. When combustion occurs on the upper hearths, combustion space is inadequate, and the lower hearths are rendered useless. These conditions are extremely serious and result in flue damage and severe smoking, in addition to limiting MHF capacity to a level far below the design rating.

On a long term basis, if feed sludge is dryer than anticipated during furnace design, the upper hearths of existing MHFs may be bypassed by cutting drop holes in the hearths. This would improve control of the furnace to eliminate double burning, reducing fuel requirements. However, the previously noted increase in combustion air needs would not be changed and sufficient air would have to be supplied.

Because dewatering and incineration operations within a treatment facility are often separate, the incinerator operator may not be aware that short term sludge feed rate or quality changes have occurred until temperature readouts indicate a markedly changed furnace condition. This effect may not be apparent in the MHF until the sludge has passed through several hearths. MHF response to new burner settings and central shaft speed changes is very slow, and these changes usually are best made slowly. Because of this sensitivity to changes in sludge characteristics, the ability to measure temperature and excess air in the burning zone of a MHF is the key to furnace control.

The effects of variable sludge feed rates on the operation of FBF units are different from those in the MHF. Generally, the FBF requires a forced feed injection system to overcome the pressure in the furnace. Feed rate surges do not occur because the screw or the progressive cavity pump used to feed the furnace operates at a set speed or rate. A sludge with an unusually high solids content may cause "over pressure" stoppage of the feeder or plugging due to the increased viscosity of the sludge.

The effects of varying the solids content of feed sludge on a FBF are similar to those for a MHF. If the solids content of feed sludge is increased from 27 to 30 percent and the sludge feed rate and combustible content remain unchanged, the feed rate of combustibles is increased by 10 percent. If the FBF was operating at 25 percent excess air originally, this same air flowrate would be equivalent to 15 percent excess air with the higher solids content sludge. At this lower excess air level, the chance for smoking is greater. In the FBF, the time needed to sense increasing bed temperature is shorter than in the MHF, which permits the operator to reduce auxiliary fuel flow more quickly, restoring the excess air to the safer 25 percent level. Under autogenous burning conditions, water sprays or a reduction of the sludge feed rate would be necessary to reduce bed temperature.

If sludge solids content were to change in the opposite direction, from 30 to 27 percent solids, combustibles would decrease by 12 percent. If original operation were at 25 percent excess air, the new condition would be at 37 percent excess air. This condition could be maintained until dryer sludge was available or adjustments to fuel or sludge feed rates could be made.

Ideally, sludge storage should be provided before dewatering to level out variations in daily sludge feed quantities and characteristics. The use of sludge blending tanks will help minimize variations in moisture, chemical, and grease content in the liquid sludge feed to dewatering. Multiple dewatering units will also even out variations in the sludge dewatering process and provide a constant sludge feed rate to the incinerator. Minimizing these variations over short periods (minute-to-minute and hour-to-hour) will help establish steady and fuel-efficient incineration.

EQUIPMENT PROBLEMS

Major equipment problems in MHFs occur with hearths, rabble arms, central shafts, induced draft fans, dampers, and thermocouples. FBF components that experience frequent problems include refractory domes, air distribution piping, and flues. Components common to both types of incinerators that experience problems include ash handling systems, sludge conveyors, off-gas systems, waste heat boilers, and scrubbers.

Failure of Hearths

MHF hearth failures can result from lack of feed rate control as well as frequent, rapid temperature cycling; but hearths primarily fail as a result of sudden changes[8] in temperature. Frequent cycling between 1,300°F and 1,800°F can be worse than controlled shutdowns. In normal operation where sludge feed is steady, properly constructed hearths should not fail in less than ten years, even with weekend or nightly standby cooling[6] as long as temperature changes are controlled to less than 50°F per hour.

Proper record keeping can be helpful in predicting hearth failure. During internal inspections of the furnace, the high point on each hearth should be measured from a common benchmark, such as the bottom of an inspection door, and recorded. An increase in the rate of arch settlement indicates an impending problem. Refractory behavior is relatively unpredictable, however, and hearths that started out almost flat or even slightly negative in slope from perimeter to center have been known to last a year or more. If the hearths rise on initial heating, they will generally have a normal service life.

Rabble Arms, Teeth, and Central Shaft

Rabble arms are subject to overheating and accumulating sludge on top of them. A steady sludge feed and adequate cooling air flow can prevent overheating of the rabble arms and are vital to rabble arm life. Sufficient cooling air is dependent upon the design and size of the furnace and central shaft. The temperature of the cooling air at the central shaft cooling air stack should be maintained between 250°F and 350°F. Castable refractory insulation can also protect rabble arms from overheating and appears to be effective. By placing the rabble arms for each hearth at an angle to those on adjacent hearths, accumulation of sludge on the rabble arms of the lower hearths is avoided.

Rabble teeth may bend if exposed to short term high temperatures. The solution is to control temperatures by maintaining a steady sludge feed. Corrosion of the teeth is generally caused by chlorides and can be minimized by careful control of ferric chloride use in liquid and solids treatment. In addition, use of a two-part tooth avoids replacement of the tooth holder.

Central shaft problems include insulation anchoring and cracks. Various means have been used to anchor the castable refractory insulation to the shaft. None have been entirely effective due to the difference in coefficients of expansion for the cast iron shaft and the insulation material. Cracks in the insulation can be repaired with patches, but proper selection and application of the patch material are required.

Minor expansion cracks in the cast iron shaft should not be a major concern. The cast iron can be exposed to the fire as long as the area receiving the radiation is small and the surrounding cooling wall area is large.

Induced Draft Fans

Serious problems with improperly selected induced draft fans may be correctable, but often at considerable cost. The long term effect of operation with a deficient fan can be extremely costly in terms of reduced sludge disposal capacity, limited furnace operating time, and excessive power consumption. Major problems with ID fans are mainly attributable to the physical layout and orientation of the fan and ductwork, draft control, vibration, sizing, noise, corrosion, and drainage.

Fan inlet conditions may not permit the ID fan to meet its rated capacity and pressure. Sharp, short radius bends in the inlet duct and the resulting change in direction of the inlet gas stream upstream of the fan impeller can cause an unbalanced, nonuniform flow condition that reduces fan performance. Adequate space for fan and duct layout is the solution. Where space is limited, modification of inlet ductwork and use of straightening vanes with short radii can avoid many flow problems.

Draft control and scrubber pressure drop are usually obtained by modulating the flow using an automated damper. In almost all cases, an inlet damper to the fan is preferable to a discharge damper. Either parallel or radial leaf dampers may be used. Parallel leaf dampers resemble louvers or venetian blinds mounted either vertically or horizontally. The louver segments of radial dampers are mounted radially to the centerline of the fan shaft. Butterfly-type dampers mounted too close to the fan inlet can cause flow unbalance and a higher pressure loss than radial or parallel leaf dampers.

Induced draft fan vibration can be minimized by a structural analysis of the fan foundation block and by provision of vibration isolators on the foundation. Where the ID fan is located high in a steel frame structure, a careful analysis is required to avoid harmful vibration. Impeller imbalance caused by the accumulation of particulates, tars, soot, grease, and water with subsequent loss of part of the build-up, is common in wastewater treatment plants. Vibration switches that permit quick fan shutdown are mandatory in a fan subject to accumulation of grease and solids to prevent damage from excessive vibrations.

In many instances, improper sizing of the ID fan has considerably limited furnace capacity and resulted in severe noise generation. An ID fan must be sized in accordance with air flow and pressure requirements, and fan tip speed. Selecting a fan that is too small and operating it at a speed higher than its normal operating range will cause high noise levels. If properly sized and selected, the fan capacity will be adequate for the furnace and the noise level can be maintained within acceptable limits.

ID fan corrosion is a result of using improper materials of construction. Because scrubbers do not absorb all the acid gases produced in combustion, these gases and the mist droplets carried through the scrubber can produce some high concentrations of acid. Chloride corrosion of ID fans following wet scrubbers can be avoided by selection of special stainless steel alloys for fan parts. Depending on chloride concentrations, a variety of materials including 316L stainless steel, Iconel 600 series, and Hastelloy C276, increasing in corrosion resistance, can be used. Corrosion can also occur on exhaust stacks and other parts following induced draft fans. The ID fan drains and the stack drains must be kept clear to allow the corrosive liquids to drain away. Drains of corrosion-resistant material have been found to be necessary in many plants.

The combustible materials built-up in the ID fan can be ignited under certain circumstances. With a loss of scrubber water, the bypass dampers in a MHF system should open to protect the ID fan and scrubber from excessive temperature. If the bypass does not open, the hot gases passing through the exhaust system can ignite the fan deposits. A combination of water sprays in the fan and mechanical cleaning are mandatory to reduce the rate of material build-up in the fans and to protect against fan fires.

Emergency Bypass Damper

In a MHF system, one of the most common problems is poorly fitted bypass dampers. Seating of the damper disc is normally imperfect in the large refractory-lined stacks. As seat areas deteriorate and become worn, gases that have not been scrubbed can leak from the stack. Although an inflow of air to a lower pressure area below the damper disc should occur, untreated gases can flow from this area. Alternatively, failure of the bypass stack damper to close reasonably tightly at high furnace draft can result in major in-leakage of air adding to the gas flow that the scrubber and the ID fan must handle. The solutions are provision of a refractory seat with closer seating tolerances and routine checking by maintenance personnel.

Damper bearings installed on the bypass stack can overheat and seize, rendering the damper inoperable. The bearings should be offset from the stack with an intervening heat shield.

Thermocouples

Ceramic protective shields for thermocouples are prone to shattering. They have had satisfactory service life in MHFs when special refractory shapes are provided above the shields to protect the thermocouple from falling sludge. However, when the ceramic type shield is placed unprotected and in the path of dropping sludge, the thermocouple tends to shatter very easily.

Most ceramic shields for thermocouples in MHFs have been replaced with Inconel 601 shields, eliminating the shattering problem. Thermocouples with 304 stainless steel shields are usually not suitable for service in MHF combustion hearths.

Ceramic type thermocouples are used in FBFs because the frequency of shatter is much lower. The thermocouples are suspended from the furnace wall in the freeboard and fluidizing sand bed areas and are less subject to physical impact.

Refractory Dome

In FBFs, failure of the refractory dome beneath the sand bed has been as severe a problem as hearth failure in MHFs. Just as some MHFs have had long hearth life and others have had frequent failures, the FBF refractory dome experiences are also varied. Maintaining constant temperatures or heating and cooling slowly are normally the key factors in avoiding problems.

An improved practice for FBFs is to introduce the fluidizing air into a recessed chamber with a burner that heats the air to prevent localized hot and cold areas in the brick arch. This practice is probably more important when oil is used as the auxiliary fuel than with natural gas because of the luminosity of oil flames. In all cases, consideration should be given to uniform temperatures on brick domes or arches during heating.

During startup of a hot windbox FBF, a preheat burner is used to heat fluidizing air and bring the sand bed to operating temperatures. Once operating temperatures are reached, they are maintained by auxiliary burners in the furnace, and the fluidizing air is heated using waste heat. At this point, the preheat burner is turned off. When this is done, the burner should be shut down slowly, allowing the windbox temperature to gradually reach equilibrium with that of the fluidizing air. The windbox temperature should not be allowed to drop more than 50°F per hour to avoid damage to the refractory dome.

FBF Air Distribution Pipes

Maintenance of FBF air distribution pipes can be difficult. Keeping the pipes locked in place in brick hearths and sufficiently tight to prevent sand from leaking into the windbox during shutdown periods is a problem because the metal pipes have a coefficient of expansion three times that of the brick hearth. Proper design of the arch in the hearth, which results in air pipes of different bends and lengths, permits controlled expansion of piping without allowing sand to leak.

Exhaust Flue Corrosion

Chlorides and sulfur in dewatered sludge cake are transformed during the combustion process into corrosive constituents that damage metal components in the furnace and flue gas system.

At incinerator temperatures, most chloride salts react with water vapor to produce hydrochloric acid (HCl). Many metallic chlorides first vaporize, then react with water vapor in the gas phase, leaving an extremely fine metallic oxide dust plus hydrochloric acid vapor. Hydrochloric acid is corrosive in the hot dry state, as well as upon condensation. At metal temperatures above 800°F, alloys of the type used in MHF rabble arms and teeth are subject to dry corrosion by HCl. This corrosion is not generally a noticeable problem but can contribute to shortened rabble tooth life.

Sources of chloride include sludge conditioning with ferric chloride, industrial contributions, and saltwater intrusion into the sewer system. Where ferric chloride is used to coagulate sludge solids, the ferric chloride will contribute chloride to the water. The water retained in the dewatered cake contains the same chloride concentration. The chloride in the wet cake will be present in the exhaust gas.

Unlike HCl, SO_2/SO_3 is corrosive only upon condensation with water or absorption in water. The most critical corrosion conditions occur when the temperature of the steel scrubber shell and flue drop momentarily below the dew point of the furnace combustion gas, causing condensation to occur. This absorbs HCl and SO_2/SO_3 to create acidic solutions. When the temperature rises or the partial pressure of water diminishes within the flue duct or vessel shell, the water evaporates, leaving concentrated acid on the steel. Repeated occurrences of these conditions will produce concentrations of hydrochloric, sulphuric, and sulphurous acids, which attack the metal surface on which they concentrate. These conditions are considerably lessened in areas where in-leakage of air occurs, diluting the concentration of corrosive gases near the steel surface.

FBFs are constructed to operate under positive pressure. The higher pressure reduces the temperature at which the acids in the exhaust gases condense, causing corrosion in exhaust ducts and at expansion joints. Although MHFs are not immune to the same phenomenon, the situation is mitigated because MHFs are not pressurized and are subject to air infiltration.

Heat exchangers and waste heat boilers located ahead of the scrubber frequently have not been designed with consideration for local cold spots (e.g., first tubes contacted by the entering cold fluid) where metal temperatures are below the acid vapor dew points. A general rule for waste heat boilers is to generate saturated steam greater than 300 psi to maintain boiler metal temperatures safely above 400°F and to raise steam generation pressures before acid bearing gases are allowed into the boiler, unless other specific anti-corrosion measures are taken.

If the boiler is to be bypassed, recognizing that the dampers cannot make positive gas-tight closure, the boiler casing can be pressurized such that sufficient clean air forces leakage across the dampers from the boiler into the bypass duct.

The solutions to the problems raised by chlorides and sulfur in sludge begin with recognition and consideration of the problem. Improved dewatering will help chloride removal. Twenty percent solids sludge contains 4 pounds of water per pound of solids; 33 percent solids sludge, contains 2 pounds of water per pound of solids. This increase in solids reduces the inorganic chloride content by half since all inorganic chlorides are water soluble. Using polymer or ferric sulfate instead of ferric chloride in solids coagulation may be preferable to further reduce the chloride content of sludge.

Proper handling of exhaust gas for either type of incinerator will minimize corrosion problems. Transition from hot dry gas conditions to wet scrubber conditions must be accomplished without an interfacial zone subject to alternate wetting and drying conditions. The exhaust gas should be kept hot enough to keep all metal parts well above the temperature at which sulfuric acid condenses. The gas should pass into the throat of the venturi scrubber, where the flow of water covers metal parts and is sufficient to absorb the acidic gases without a significant change in water pH.

Corrosion problems for all equipment in contact with incinerator off-gases can be minimized by process temperature control, insulation for temperature control, and selection of proper materials. Materials selection can be based on historical data or on actual testing of samples in an existing installation. The equipment involved includes heat exchangers, waste heat boilers, ID fans, stacks, duct work, and drains.

Ash Handling

Ash handling problems have been experienced with both mechanical and hydraulic ash systems.

Mechanical Type. The mechanical (dry) ash system is only applicable to MHF systems. The dust from non-tight dry ash systems and the abrasive ash create severe maintenance problems. The inability to keep the plant clean causes operator morale problems that further detract from performance. Common problems include the following:

- The ash drop hole and chute at the bottom of the MHF can become plugged with large clinkers or loose brick. This problem can be reduced by adding a diversion chute and coarse screen. The fine ash will pass through the screen, but larger objects will be diverted to the other chute for removal. This solution helps to protect ash conveying screws and bucket elevators.

- Chains and sprockets must be made of materials with high hardness to protect against the abrasive ash. The sprockets should be harder than the chain to prolong sprocket life.

- Bucket elevators should never be loaded greater than 80 percent of capacity and loading should be considerably less.

- Most bucket elevators have two chains, one on each side of the bucket. One chain is driven, and the other chain is on idler sprockets and used to maintain bucket alignment. Both chains should be used to avoid misalignment.

- Helical screws in covered troughs move ash horizontally or on an incline. Hard iron bearings support the screw and increase the bearing life against the abrasive ash. Hard iron bearings can be very noisy, generating a screeching sound. Grease lubrication may reduce the noise problem, but will reduce bearing life as ash becomes entrained in the grease. Wooden bearings can be used to solve the problem.

- The covers on screw conveyors are very difficult to keep dust tight. If all the gaskets, screws and clips on the cover are used, the dust is reduced. After maintenance, the covers should be put back with all fasteners in place.

- Ash conditioning screws and rotary drum ash conditioners require proper maintenance to wet the ash sufficiently to minimize landfill dust problems, and generally are only moderately successful.

- Conditioning screws must be equipped with adequate horsepower drives for moving the wet ash.

- Control of the water for wetting requires frequent operator attention due to changing ash characteristics and feed rates.

- The ash conveyors should have a vacuum dust removal system at the transfer points to minimize fugitive dust.

Hydraulic Ash Handling. Wet ash systems can be used with either the MHF or FBF. Problems with hydraulic ash systems are abrasion and wear in the pump and piping due to the ash slurry. The slurry, consisting of bottom ash and fly ash, is abrasive and accelerates wear in the piping and pump, especially in pipe elbows. Abrasion-resistant heavy walled pipe and rubber-lined pumps should be used for this service.

The ash slurry is generally disposed in a lagoon, which will require cleanup and disposal after a period of time. This clean-up and long-term disposal is difficult because of abrasion and accelerated wear on cleanup equipment due to the ash and retention of water by the ash slurry.

Sludge Conveyors

Sludge cake conveyor systems, normally belts that deliver sludge to more than one incinerator, may restrict operation of the incinerator at full capacity. Common practice is to divide the feed on a conveyor belt with a plow, which is a metal plate that diverts part of the sludge to an incinerator or another conveyor. However, precise division cannot be obtained. The result is that incinerators may not be equally loaded. A uniform feed rate to more than one incinerator may be maintained by dedication of a sludge hopper or bunker with a controlled discharge system to each incinerator. To obtain a fairly uniform sludge distribution, the bunkers can be fed by a conveyor system in which automatically-operated plows divide the sludge feed. These plows alternately divide all sludge on the conveyor to each bunker at frequently timed intervals. The bunkers would either be placed directly below the main feed conveyor or would be fed by individual feed conveyors.

There are two ways to feed sludge into a MHF. The sludge cake can be directly dropped into the top of the MHF from a conveyor over the furnace or from a chute or screw conveyor that receives sludge from a conveyor on the side of the furnace. Conveyors located over the top of the incinerator have more maintenance problems because of the high temperature environment. Sludge cake should be cleaned off these belts prior to shutdown because the sludge will become baked on and difficult to remove. Elastomer and rubber conveyors have reduced life in this hot environment.

Although conveyors located to the side rather than over the top of the incinerator have reduced maintenance, the side conveyors require a chute or screw conveyor to feed the sludge. To avoid bridging of the sludge at the transfer point, and to ensure free flow of the sludge, the chute angle should be between 70 degrees and 80 degrees. Water sprays to help keep the sticky sludge moving at the transfer points are not recommended because of the increased evaporative load to the furnace.

Off-Gas System

Air leakage into the furnace off-gas system may prevent furnace operation at design conditions and reduce efficiency. For example, misalignment of the precooler to a venturi scrubber may not permit closing of the water seal. The air introduced into the off-gas system at this point will reduce furnace capacity. Air in-leakage from dampers in interconnecting duct work may also be sufficient to reduce furnace capacity. A check for misaligned equipment should be performed in both new and older plants, and equipment should be properly aligned to avoid this problem.

Waste Heat Recovery Boilers

The design loading factors for dust, which are solid particles in the exhaust gas, are critical in sizing a waste heat recovery boiler. The values in Table 3 are typically used by manufacturers in the waste heat recovery boiler industry. As dust loads increase, gas velocity must decrease to reduce erosion. Reduction of gas velocity increases boiler size and cost. Tube wall thickness should be increased for erosion protection where required.

TABLE 3. TYPICAL DUST LOAD FACTORS

Percent Dust by Weight in Flue Gas	Maximum Gas Velocity (ft/sec)
10.2	32
0.32	54
0	66.5

Control dampers must be carefully located to avoid dead spots where dust can build up when the dampers are modulated. Modulation changes the velocity distribution profile.

Unburned carbon in the exhaust gas can also be a problem, coating waste heat boilers with soot and reducing heat transfer efficiency. The soot is removed by steam cleaning. If steam availability is a problem, a high pressure air cleaning system may be used.

An auxiliary heating system may be required to protect the boiler against condensation and corrosion during long standby periods.

Air Pollution Control/Scrubbers

Approximately 20 pounds of uncontrolled particulates per ton of sludge and 0.0038 pounds of particulates per gallon of fuel oil fired (3) are generated in MHFs. The Federal New Source Performance Standard of 1.3 pounds of particulates per dry ton of sludge can be met with modern high energy wet scrubbers, such as the venturi.

Removal efficiency is a direct function of particle size and the amount of energy (or pressure drop) designed into the scrubber system. Typical published values (3) for percent removal and size distribution data from literature (3) for sludge incineration of different particle sizes are in Table 4.

TABLE 4. SIZE DISTRIBUTION AND REMOVAL EFFICIENCIES OF PARTICULATES

Particulate Size Range (microns)	Distribution Percent by Weight	Removal Efficiency (percent)
<0.5	1.6	75
0.5-1.0	2.2	96
1.0-5.0	8.2	99.9
>5.0	88.0	100

Problems in meeting air pollution requirements have resulted from excessive submicron particles with a high percentage of unburned organics, primarily hydrocarbons.Improved combustion control of the incinerator usually corrects the problem of unburned organics.

A constant flow of water over the walls of the venturi scrubber must be maintained to ensure scrubber performance and to minimize corrosion in the exhaust gas system. Variation in scrubber water flow may be caused by a plugged strainer in the supply line or inadequate flow and pressure control in the supply system.

Venturi scrubbers are generally constructed of high hardness stainless steel. However, should abrasion of the venturi throat become a problem, greater wear-resistant material, such as silicon carbide, can be used.

The impingement tray separator section of a venturi is also usually constructed of stainless steel. Corrosion at the liquid gas interface above the tray sections can be avoided by making the wall thicker at these points or by constructing the separator in a more corrosion-resistant material, such as silicon carbide.

Because the control actuator on variable throat venturis may tend to stick and cause erratic operation, the actuator must be properly sized and an adequate control system provided.

Excessive water carryover from the exhaust stack results from an inadequately designed demister section in the scrubber. Proper baffling and drains within the scrubber avoid this problem.

OPERATION AND MAINTENANCE PROBLEMS

Improved operation of an incinerator system is heavily dependent on the ability to deal with common operation and maintenance problems of slag and clinkers; improperly adjusted burners; and screenings, grit, and scum disposal.

Slag and Clinkers

Clinkers are free lumps occurring in the burning bed of MHFs that are carried to the cooling hearths. Slag, which can occur in a MHF or FBF, is the accumulation of fused material on walls and dropholes, rabble arms, etc. Failure to recognize the ash melting temperature under both oxidizing and reducing conditions and failure to make proper tests has resulted in severe operational problems and increased maintenance costs due to slag and clinker formation.

Slag and clinkers result from high temperatures (above 1,650°F) in the combustion zone. These temperatures are caused primarily by variable sludge feed and, to a lesser extent, by poor burner control. Observations indicate that the highest temperatures occur in the upper portion of the combustion hearth in a MHF where the sludge volatiles mix with air when they are passing through drop holes in a MHF. The greatest slagging potential is observed to occur at the drop holes, particularly in the outer drop hole area. The intense heat from combustion heats the refractory at the drop hole; when fine ash particles contact the drop hole, they adhere and build up. Eventually, the drop holes can plug entirely. To minimize this problem, lance ports should be located in this area.

The problem of clinkers deserves more extensive treatment than can be addressed in this report. Operators with these problems should seek expert advice to:

- Determine where and how much air enters the furnace, and quantify and adjust burner excess air as necessary

- Readjust rabble teeth to break up lumps and to retain lumps longer in the fixed carbon hearths

- Change chemical conditioning, if necessary

- Shred very dry sludge cakes.

Slagging occurs in several forms. Oil and dust can create slag on burner tiles. Grease burned on a hearth may create local hot spots or a local area of ash melting, causing slag. Sludge left on rabble arms can be carried through the burner flame zone and held at the junction with the central shaft, producing a roaring volatile flame that turns sludge to slag. Lastly, dust carried in the gases from the lower hearths can pass through burner or volatile flames, become molten while in suspension, and then stick to the first contacted surface. If the surface is cool enough, the molten droplets freeze and drop away. If the surface is sufficiently hot, alternating strata of cinder and glass deposit on the surface. At still hotter surface temperatures, the molten droplets become glass-like and penetrate the refractory until the deposit can only be removed by breaking away the brick surface. The slag is taffy-like while hot, and if heated another 100 to 400°F, will become fluid and slowly dissolve the brick.

In general, if the combustion zone temperatures are below 1,650°F, slag and clinkers are not a problem in a MHF. Problems occur, however, because bed temperatures and hot spots frequently exceed this value in localized areas.

Solutions to slagging, as well as clinkering, involve control of air infiltration and oxygen supply. The slagging problem is usually better understood and correctable where the analysis is not only based on oxygen measurement in the top hearth, but also on excess air leakage into the furnace above the fixed carbon burning hearth.

In the MHF, one solution to slagging may be to reduce the fixed carbon burning rate by decreasing the oxygen concentration over the bed. This solution reduces overheating on the combustion hearth above. Another solution may be to increase the air flow into the volatile burning hearth after reducing the air on the fixed carbon burning hearth. Slagging problems with thermally conditioned sludges can be minimized by sizing burners for 100 percent excess air. Slagging caused by ash melting when passing through the burner flame can be eliminated by reducing flame temperature through use of higher burner excess air. Other alternatives to alleviate slagging problems include:

- Providing lance or poke holes at perimeter drop hole locations

- Enlarging drop holes in the combustion zone

- Increasing turbulent mixing of gases to provide a uniformity of the fire from one side of the furnace to the other

- Adding air below the fire, not above the volatile burning hearths.

Burners

Carbon build-up around burner tiles is an indication of an improperly adjusted burner. Other problems caused by maladjusted burners are slag, clinkers, refractory damage, and furnace shell damage from buildup of molten material around burners. Typical reasons for lack of proper adjustment are failure to use the proper orifice plates in making adjustments and setting the excess air so low that high flame temperatures cause the ash to slag. Excess air in MHFs must be high enough to reduce slagging around the burner.

Screenings, Grit, and Scum Disposal

Screenings, grit, and scum demand special handling if processed in an incinerator system. The impact on the incinerator, particularly the MHF, has been adverse, and relatively few such furnaces have performed satisfactorily. Screenings can clog feed mechanisms and require constant attention. Operation costs are expensive due to the high moisture content of the screenings. Grit is abrasive and may be high in organic matter and relatively dry. Burning grit causes a deficiency in combustion air and generation of black smoke. Whether grease and scum are burned separately or in a high proportioned scum-sludge mixture, burning them results in uncontrolled burning, slag, and unburned carbon due to lack of combustion air. Grease and scum have a high heat value and require combustion air commensurate with heat release. The air volume for a high proportioned scum-sludge mixture is not normally available in the air distribution system of a MHF.

The experience of plants utilizing MHFs adapted to burn screenings, grit, and scum demonstrate that these furnaces have been largely inadequate for this service. In addition, there is considerable risk to furnaces and to emission violations caused by incomplete combustion.

The FBF is much more adaptable to burning grease, oils, and other materials of high calorific value. Pumping and extruding fuels directly into the media bed are the normal feeding methods in the FBF. Within the last 10 years, 10 FBFs have been designed and put into service to burn both sludge and grease.

ADMINISTRATIVE PROBLEMS

Problems in the administration of MHF and FBF systems are in the areas of operations management, staffing, and training.

Management personnel should be aware of the technical complexities of MHF and FBF systems and should have a knowledge of system O&M needs, including expected results, methods to evaluate performance, and a system of personnel accountability.

Many of the problems discussed in this section, although related to the design of the system and the equipment provided, can often be eliminated or at least mitigated by proper operations managment. In many instances, properly designed systems have functioned poorly due to lack of proper management procedures. Areas in which operations management can be improved to enhance incinerator system performance include:

- Control of sludge dewatering operation to maintain a steady, uniform sludge feed to the incinerator

- Control of energy consumption through efficient sludge dewatering

- Control of sludge feed and ash disposal through scheduled, thorough maintenance of these systems.

Because of the complexity of the incineration process, having an O&M staff with the right qualifications is an absolute necessity. This staff must have a working knowledge of the process, the ability to troubleshoot process problems, and be motivated to learn. Salaries commensurate with these qualifications are also needed to attract and retain highly skilled personnel.

Quality training is required for personnel who operate, maintain, and manage these systems. The training normally provided by the manufacturer during startup is, in most cases, insufficient to ensure that long-term training needs are met. Specialized training is required and should include:

- Basic knowledge of routine system startup, shutdown and standby procedures

- Preventive maintenance requirements and procedures

- System process control theory and testing procedures

- Process troubleshooting techniques

- System economic considerations

- Process data collection, documentation, and evaluation

- Support system O&M, control, fine tuning, and troubleshooting.

TECHNICAL INVESTIGATIONS OF MULTIPLE-HEARTH FURNACE PROBLEMS

Although the problems and solutions in this section have been catagorized into design, operation, and administrative areas, problems overlap and system improvements must be made in all three categories. Successful operation of an incinerator system is dependent upon the integration and implementation of all necessary and required improvements. Technical investigations of conventional MHF systems in three major cities illustrate this approach.

The investigation of conventional MHF operating modes in Indianapolis, Indiana (4); Nashville, Tennessee (5); and Hartford, Connecticut (6); and consequent changes in these modes are fully documented in EPA reports on the respective municipal facilities. The operational modes recommended and adopted resulted in remarkable savings in auxiliary fuel consumption for the plants in these cities. In the case of one plant, the operational changes resulted in a large decrease in particulate loading to the scrubbers and the avoidance of retrofitting with new, energy-intensive scrubbers at high capital cost.

The changes in operation modes for all of these plants include:

- Maximum use of central shaft cooling air return to minimize hot air heat loss

- Reduced draft to minimize air in-leakage

- Slow central shaft speed to increase sludge drying time concurrent with sludge combustion at a selected lower hearth

- Elimination of air flow to and operation of top burners resulting in provision of more hearths for drying at reduced temperatures

- Burner operation under the combustion zone hearths

- Maintenance of excess air at no greater than 50 percent

- Instrumentation and, in some cases, control changes to measure and regulate sludge, air, and fuel flows and to control fuel and air flow remotely.

The main thrust of the work performed at the plants in Indianapolis, Nashville, and Hartford is the establishment of operating procedures suited to the sludge feed rate and sludge volatiles, which utilize the MHF volume for combustion in the most appropriate zone and for drying in a far more efficient manner than has been practiced. To achieve fuel savings, the operation has to be performed with greatly reduced excess air. The incinerator upgrading work, resulting from pilot project findings and subsequent recommendations by the Indianapolis Center for Advanced Research (ICFAR) (4), is estimated to have cost $20,000 per incinerator in 1980 to 1981 dollars, which includes operator training. This cost is normally recovered in fuel savings within a 3- to 6-month operating period, since the average savings per furnace is estimated at $180,000 per year.

This approach to incinerator upgrading relies mainly on well trained, informed operators. The inherent strength of the approach is transmitting knowledge of the full performance capabilities of the furnace to the staff.

SECTION 4

SUMMARY OF DESIGN AND OPERATIONAL CONSIDERATIONS

The selection, design, and operation of a MHF or FBF incineration system must take into account the integration of the system into the overall treatment process and the complexities of the system. Failure to do this has led to many of the past and current problems that have plagued MHF and FBF incineration processes. Under proper conditions, these processes can be an effective part of the sludge processing train.

This section summarizes the more important design and operational factors to review when considering MHF or FBF incineration as part of a new or upgraded treatment facility, or when optimizing the performance of an existing facility.

IMPROVING SYSTEM DESIGN

When planning a MHF or FBF system, the following process and support system equipment design factors should be considered:

- The selection of an incineration system should be carefully considered in recognition of plant size and anticipated sludge production. As a general guideline, FBF systems are most applicable at plants of 10 mgd or more, and MHF systems at plants of 20 mgd or more.

- The design of an incineration process should integrate the incineration and support systems into one design by developing operating scenarios, calculating heat and material balances, and defining operating ranges. One overall system safety factor should be applied to the estimated quantities of sludge.

- Incineration and support system equipment selection and sizing should be carefully matched to the rate and characteristics of sludge production expected from the mainstream process. Either units that can be incrementally modified or multiple units should be provided, where needed, to avoid inefficient operation of oversized component parts.

- Incinerator feed characteristics should include a uniform sludge mixture with a high volatile content, low grit content, and be greater than 20 to 25 percent solids to maintain steady operation of the incinerator and to conserve auxiliary fuel.

- Blending tanks and multiple dewatering units should be provided to minimize variations in solids content and feed rate to the incinerator.

- The ferric chloride dosage for sludge conditioning should be optimized or eliminated to prevent corrosion problems. If necessary, corrosion-resistant metals should be considered for ID fans, drains, and exhaust flues.
- An energy recovery system to reduce plant-wide energy consumption should be incorporated into the solids handling design.

- MHF support systems should include:

  . sludge storage system with live bottom bins

  . an ash handling system with a sealed ash discharge outlet from the MHF

  . an ID fan with adequate capacity range

  . central shaft cooling air fan and ductwork

  . a venturi scrubber with an impingement tray section

  . instrumentation to measure oxygen in the flue gas, temperatures on all hearths, and draft in the top hearth.

- FBF support systems should include:

  . sludge feed pumps or screw conveyors with adjustable speed drives

  . an external firebox with a windbox burner and fluidizing air entry for heating the air

  . an auxiliary fuel system with flame safeguards and direct feed of fuel into the bed

  . fluidizing air blowers with multiple impellers

  . a venturi scrubber with an impingement tray and demister section

- a freeboard temperature control system with high pressure water pump and sprays.

IMPROVING EXISTING SYSTEMS

Although recent technical investigations have primarily focused on operational improvements to MHFs, improvements to the support systems, greater efficiency in sludge dewatering, and the principle of more efficient sludge drying are applicable to both types of furnaces. The design factors discussed above and the following key factors from technical investigations should be used as guides for determining needed modifications to improve operation and increase the efficiency of an existing MHF or FBF incinerator system.

- Incorporation of sludge dewatering systems that will produce dryer sludge with an increased volatile solids content and a more homogeneous product.

- Development of sludge feed systems that will provide a more constant, continuous, and controllable feed rate to furnaces.

- Utilization of sludge conditioning chemicals, such as polymers, that will not produce the slagging and corrosion problems associated with the use of ferric chloride.

- Installation and proper maintenance of sludge and ash conveyance systems to reduce abrasion and to improve performance.

- Maintenance of design furnace capacity by repair of all equipment-related air-leakage into an MHF and minimization of the draft in the top hearth of the furnace.

- Minimization of hot air heat loss by maximization of central shaft cooling air return.

- Improvements in sludge drying by reducing central shaft speed or by reducing or eliminating active burners above the combustion zone in a MHF and by using one FBF for sludge drying in a multiple FBF installation.

- Control of excess air rates and reduction of heat loss by using an oxygen analyzer to indicate the type of combustion in a MHF (high/low excess air).

DESIRABLE OPERATING CHARACTERISTICS

The key parameters for efficient performance of MHF and FBF systems include feed sludge characteristics, furnace operation, air rates, and, for the MHF system, temperature. These parameters are important considerations in designing a new system or in optimizing the performance of an operating facility.

- A uniform and constant sludge feed is needed to maintain steady furnace temperatures and air rates and to minimize energy consumption. Screenings, grit, and scum should not be fed directly into a MHF to avoid uncontrolled burning, slagging, and air deficiencies. Grit and scum should only be burned in a FBF when the feed is under manual control and with the required excess air.

- Furnace startups and shutdowns should be minimized to avoid temperature fluctuations, which result in high auxiliary fuel consumption. Continuous 24-hour operation of both types of furnaces is preferable.

- The rotational speed of the rabble arms in a MHF should be less than 2 rpm to increase sludge drying time and to maximize the use of the hot exhaust air to dry the sludge.

- Sludge loading rates to the FBF should be maintained at design values at all times due to minimum fluidizing air requirements that must be met in order to conserve auxiliary fuel and energy consumption by the fluidizing air blowers.

- The temperature in the MHF combustion zone should be kept below 1,650°F to prevent slag and clinker formation. This is accomplished either by decreasing the oxygen in the fixed carbon burning zone or by increasing the air flow into the combustion zone.

IMPROVING PLANT OPERATIONS AND MAINTENANCE

The efficient, safe, and cost-effective operation of an incineration system is dependent upon having well-qualified, trained personnel, working within a well-managed system with adequate budget support. The complexity of the incineration process and specialized equipment of MHF and FBF systems require that special attention be given to the management, training, and staffing for these systems to ensure safe and efficient operation.

- Each incinerator facility should have a detailed management plan that includes procedures to collect, review, and analyze process data for trend analyses and process optimization; communication channels between operators of solids handling processes; and procedures to evaluate system and personnel performance.

- Training should be provided for operations, maintenance, and management personnel with emphasis on "hands-on" training. This training should be routinely updated to reinforce process control, troubleshooting techniques, and preventive maintenance procedures.

- A skilled and qualified staff must be present to monitor and optimize the incineration process. Management must support this staff by maintaining adequate spare parts and supplies and by providing training and commensurate pay.

REFERENCES

1. U.S. Environmental Protection Agency, "Improving Design and Operation of Multiple-Hearth and Fluid Bed Sludge Incinerators," EPA Contract No. 68-03-3208, in preparation.

2. Environmental Protection Agency, "Process Design Manual for Sludge Treatment and Disposal," EPA 625/1-79-011, September 1979.

3. Brown and Caldwell, "Central Contra Costa Sanitary District - Solid Waste Resource Recovery, Full Scale Test Report," March 1977.

4. U.S. Environmental Protection Agency, Indianapolis Center for Advanced Research, "Plant Scale Demonstration of Sludge Incinerator Fuel Reduction," EPA 600/2-83-083, March 1983.

5. U.S. Environmental Protection Agency, "Sewage Sludge Incinerator Fuel Reduction at Nashville, Tennessee," EPA 600/2-83-105, December 1981.

6. U.S. Environmental Protection Agency, "Sewage Sludge Incinerator Fuel Reduction, Hartford, Connecticut," EPA 600/2-84-146, March 1982.

ENGLISH TO METRIC UNITS CONVERSION TABLE

English	Conversion Factor	Metric Equivalent
British Thermal Unit, Btu	1.055	Kilojoule, kJ
Cubic feet per minute, cfm	0.472	Liters per second, L/s
Degrees Fahrenheit, °F	0.555 (F-32)	Degrees Centigrade, °C
Feet per second, ft/sec	0.305	Meters per second, m/s
Foot, ft	0.305	Meter, m
Million gallons per day, mgd	43,800	Milliliters per second, mL/s
Pounds per gallon, lb/gal	0.120	Kilograms per liter, Kg/L
Pound per pound, lb/lb	1000	Gram per kilogram, g/kg
Pounds per square inch, psi	6895	Pascals, Pa
Pounds per ton, lb/T	0.500	Gram per kilogram, g/kg

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