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The Conversion of Existing Municipal Sludge Incinerators for Codisposal

THE CONVERSION OF EXISTING MUNICIPAL SLUDGE INCINERATORS FOR CODISPOSAL

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Dick Richards and Harvey W. Gershman

1. INTRODUCTION

As a result of the U.S. Environmental Protection Agency's St. Louis/ Union Electric demonstration, the use of refuse-derived fuel (RDF) type resource recovery systems is receiving wide consideration. A crucial factor in the implementation of an energy/resource recovery project is the existence of locally available energy user(s) for the various forms of refuse-derived energy products available from municipal solid waste. One such energy product, refuse-derived fuel, offers users the advantage of being able to utilize existing combustion equipment and thus possibly avoid additional investments in associated equipment.

Because of the capabilities of their existing facilities, electric utilities have been identified as the primary market for RDF products to date. However, marketing experience, a number of studies, and an electric utility survey all indicate that these utilities have no present economic incentive to undertake such projects.[1] Therefore, a need exists to identify other users that could consume large quantities of RDF.

With passage of the Federal Water Pollution Control Act (P.L. 92-500) and its subsequent amendments, the quantities of sludge generated by municipal wastewater treatment plants have increased and will continue to increase dramatically. A 1976 EPA report[2] estimated a current municipal sludge generation rate of 6.21 M dry metric tons/year and predicted an 8.40 M dry tons/year generation rate by 1986. In addition, the <u>National Needs Survey</u>, the primary source of quantitative information of a national scope correlating quantities of sludge with disposal techniques, provided the information regarding sludge disposal found in Table 1. Although these data indicate that incineration will be the primary method employed for sludge disposal, EPA's current policy "vigorously encourages...land treatment processes..."[3]

As a result of P.L. 92-500, municipalities are faced with finding environmentally sound methods for disposing of these sludges. As stated above, incineration is the most common method for sludge disposal and will no doubt continue to be for the next 25 years. Through combustion processes, the high moisture content sludges are reduced to an inert ash residue. In almost all sludge incinerators, large quantities of fuel oil and/or natural gas are consumed in order to complete the reduction of

Table 1

SLUDGE QUANTITIES

(MILLION DRY METRIC TONS PER YEAR)

Disposal Technique	1976	Projected 1990
Incineration	2.27	3.33
Recalcination	.81	.80
Landfill	1.21	.81
Landspreading	.31	.45
Ocean Dumping	.29	0
Total	4.89	5.39

these sludges (Table 2). The equivalent of more than one million barrels of oil per year is currently being consumed in these incinerators. As both fuel prices and sludge generation increase, the cost of sludge incineration to municipalities is expected to rise sharply.

The ability to use RDF as a fuel in municipal sludge incinerators (SIs) could offer the following benefits:

- significant reduction in fuel consumption by municipal sewage treatment sludge incinerators,
- provision of a hedge against large increases in future solid waste disposal and sludge incineration costs, and
- significant reduction in solid waste disposal process steps, such as hauling and landfilling.

Although the application of RDF in SIs is receiving much attention and is technically feasible,[4] no information exists relating to the extent to which this disposal technique may apply in the many U.S. municipalities with municipal sludge incinerators. In order to assess the applicability of RDF as a fuel in municipal sludge incinerators, EPA's Office of Solid Waste contracted with Gordian Associates Inc. (EPA Contract Number 68-01-4427) to undertake this study. The purpose of this study is to investigate the potential for using RDF in existing sludge incinerators only. There are several other techniques for the combined disposal of municipal solid waste and sewage sludge (codisposal) that merit attention but which are beyond the scope of this study.[5]

Table 2

ANNUAL FUEL CONSUMPTION IN CURRENTLY OPERATING

AND PLANNED MUNICIPAL SLUDGE INCINERATORS*

	Present Sludge Incinerators		Planned Sludge Incinerators		Total	
		x 1000 BBLS Fuel Oil		x 1000 BBLS Fuel Oil		x 1000 BBLS Fuel Oil
Gas	4696+	765.4	1368+	223.0	6064+	988.4
Oil	15358‡	365.7	24684‡	587.7	40042‡	953.4
Electricity	2458§	1.5	2612§	1.6	5070§	3.1
Total	-	1132.6	-	812.3	-	1944.9

* Source: U.S. EPA, A. Hais, personal communication, 1977.
\+ Gas: million cu. ft/yr
‡ Oil: thousand gal/yr
§ Electricity: thousand KWH/yr

2. REFUSE-DERIVED FUEL SYSTEMS

Refuse-derived fuel (RDF) is produced in the following manner: incoming municipal solid waste (MSW) is first processed through shredding and air-classification and/or screening to separate the non-combustible from the combustible portion. The percentage of each material in the RDF produced from MSW is shown in Table 3. The non-combustible portion may be used for landfilling, etc., while the combustible portion may be burned as is, or re-shredded into a smaller, more homogeneous particle size (fluff RDF). Once shredded, the RDF may be modified chemically so that it can be disintegrated into a powder (dust RDF); or the RDF may be densified into briquettes or pellets (densified RDF, or d-RDF). These two modifications facilitate storage, transportation, and handling of the fuel. The characteristics of fluff RDF and dust RDF are compared to those of coal for heat value, particle size, moisture, ash. and sulfur content in Table 4.

Table 3

RDF COMPOSITION*

Material	% Composition
Paper	63.3
Plastic	6.5
Wood	2.4
Glass	1.0
Metal	0.7
Organics	0.6
Miscellaneous	25.4

* Source: U.S. EPA Resource Recovery Seminar, Chicago, Illinois, June 1977.

Several RDF processing systems are currently offered by private system vendors. Figure 1 depicts a simplified diagram of one such RDF production system. In addition, a number of RDF facilities have been designed and constructed by municipalities through the services of architects

Table 4

CHARACTERISTICS OF RDF AND COAL*

	Fluff	Dust	Coal
Heat Value (Btu/Lb.)	5,000-6,000	7,800	11,000-14,000
Particle Size (In.)	3/4-1½	<0.015	-
Moisture (%)	20-30	2.0	3-12
Ash (%)	15-21	9.4	3-11
Sulfur (%)	0.1-0.4	0.1-0.6	0.5-4.3

* Source: U.S. EPA Resource Recovery Seminar, Chicago, Illinois, June 1977.

and engineers, such as those in Ames, Iowa and Chicago, Illinois. However, the production of RDF cannot be considered a proven technology since the reliability of the processing equipment has not been demonstrated over extended periods of operation.

Examples of the cost for RDF production facilities are shown in Table 5. This listing cites capital costs for RDF production, materials recovery (usually only for ferrous metals), and storage only; costs for feeding and firing are not included here. The wide variation in cost is due to differences in project design, date of construction, location, process redundancy, equipment selection, etc. In order to make more accurate deductions from these figures, more specific cost estimates would be necessary. A recent analysis by Gordian[6] normalized several 1975 RDF project capital costs versus peak capacity. This information is presented graphically in Figure 2, which provides a "rule of thumb" measure for RDF plant capital costs. Since 1975 the construction cost index has escalated 8.6 percent in 1976, 7.2 percent in 1977, and is forecast to increase another 7.1 percent in 1978.[7]

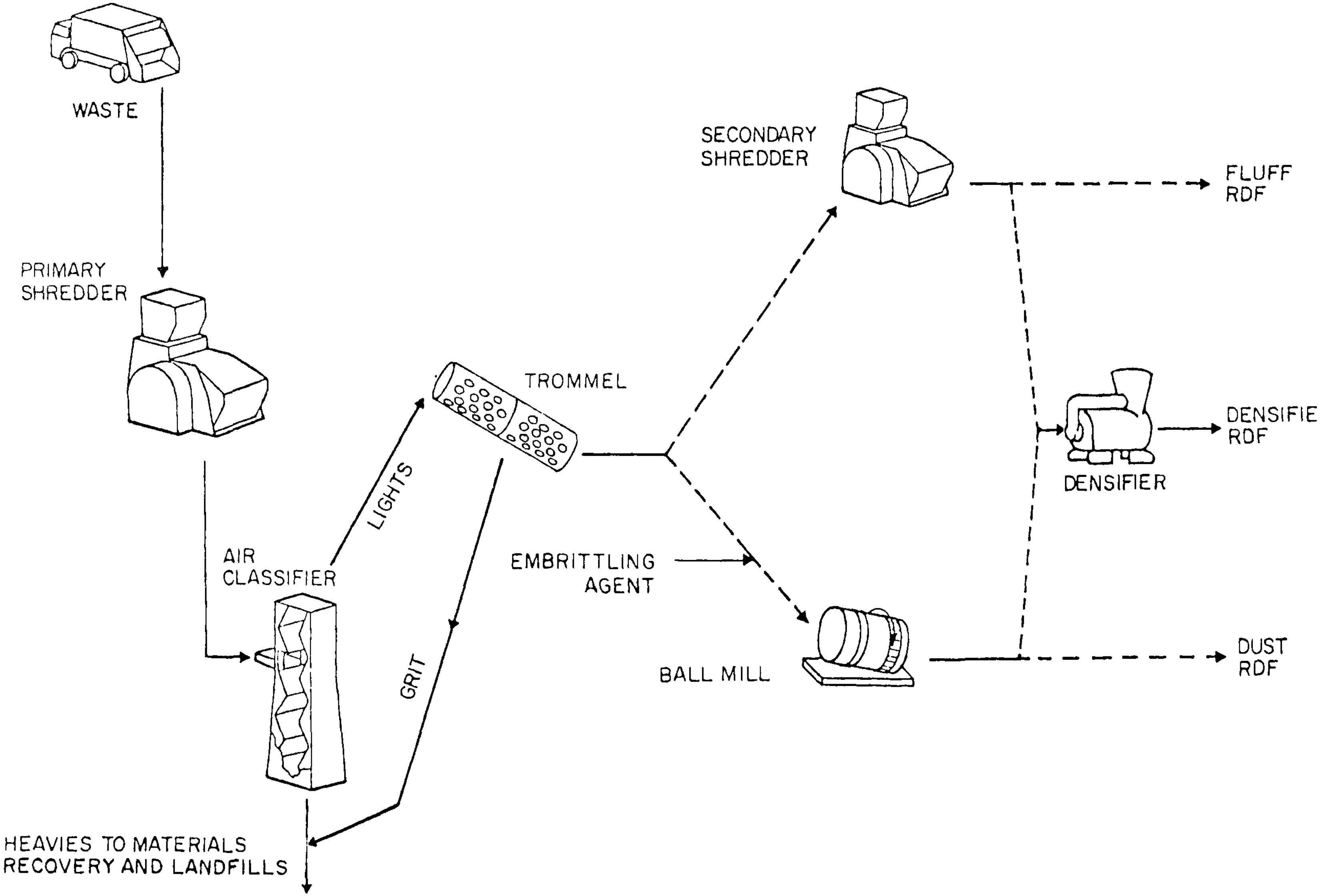

Figure 1. A typical RDF process. Source: U.S. EPA.

Table 5

RDF PRODUCTION FACILITY COSTS*

Location	Capacity (tons/day)	Type RDF	Capital Cost and Year of Estimate
Monroe County, NY	2,000	Fluff RDF	$30 million (1976)
Milwaukee, Wis.	1,000	Fluff RDF	$14 million (1975)
New Orleans, La.+	650	Fluff RDF	$5.7 million (1975)
Chicago, Illinois	1,000	Fluff RDF	$16 million (1975)
Ames, Iowa	400	Fluff RDF	$5.6 million (1974)
East Bridgewater, Mass.	160	Dust RDF	Not Known
Bridgeport, Conn.	1,800	Fluff RDF	$52 million (1975)
Hempstead, NY	2,000	Wet-Pulped Fiber	$73 million (1976)‡
Baltimore County, MD	1,500	Fluff-RDF	$10 million (1975)

* Source: Gordian Associates Inc. and L. B. McEwen, A Nationwide Survey of Waste Reduction and Resource Recovery Activities (Washington, D.C.: U.S. EPA Office of Solid Waste, 1976).

\+ RDF is produced here. It is not currently sold, but is suitable for use in applications such as codisposal.

‡ Cost includes waterwall combustion system.

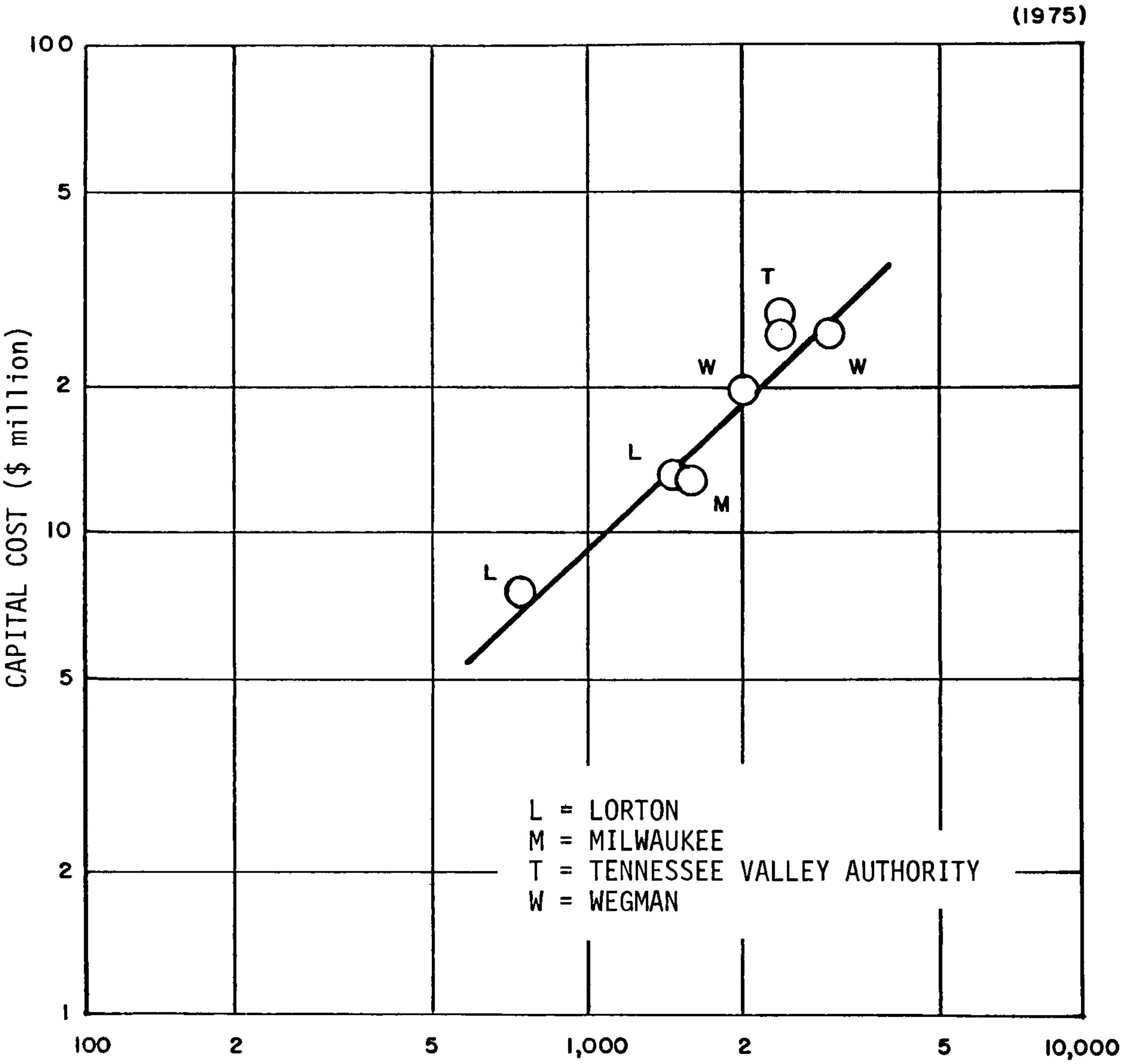

Figure 2. Capital cost/plant capacity correlation for selected RDF manufacturing projects (ferrous and aluminum separation). Source; Gordian Associates Incorporated.

3. MUNICIPAL SLUDGE INCINERATORS*

The combustion of municipal sewage sludge in an incinerator provides for its maximum volume reduction and leaves an inert ash which is suitable for landfilling. Although the heat value of sludge is fairly high (5,000 to 10,000 Btu/lb dry solids), the water content of most sludges requires the addition of an auxiliary fuel to maintain combustion in the furnace. The fuel cost is the major operational cost of incineration. The reduction of this cost can be achieved either by raising the solids content of the sludge, thereby increasing the net heat value, or by lowering the amount of inert material in the sludge prior to incineration.

Many processes which reduce the moisture content of sludge also lower its heating value, as the proportion of inert material increases at the expense of the volatile fraction. This is most apparent in anaerobic digestion where bacteria convert much of the volatile matter to methane. The methane is given off as a digester gas which is frequently used a fuel in the treatment plant. Physical-chemical sludges have a high content of inert material, but tend to dewater better than biological sludges. When incineration is the final step in sludge processing, the benefits and penalties of the conditioning steps on the furnace's fuel consumption must be evaluated. Pretreatment of sludge to decrease the water content prior to incineration may actually increase overall plant energy requirements.

Sludge incineration is a process which involves drying the sludge prior to its actual combustion. Drying and combustion may be performed in separate units, or both processes can be accomplished in the furnace. Sludge incineration occurs in four steps:

- the temperature of the sludge is raised to 212 F;
- the water is evaporated from the sludge;
- the water vapor temperature and air temperature are increased; and
- the temperature of the sludge is raised to the ignition point of the volatiles.

* The discussion presented here is derived from Brown Caldwell's Incineration-Pyrolysis of Wastewater Treatment Plant Sludge, presented at the U.S. EPA Technology Transfer Design Seminar, 1977.

The heat evolved by sludge incineration can be utilized in many ways: heating and drying of incoming sludge, production of steam for space heating, powering mechanical equipment, or generating electricity. Autogenous or self-sustained combustion is possible with some sludge feeds, but is dependent on the net heat value of the sludge. Because of the relatively high temperature of the combustion gases (approximately 1300 to 1700 F), a large amount of the heat evolved is used to raise the temperature of the incoming combustion air and fuel mixture. For successful incineration, proper mixing of the combustion gases, the fuel mixture, and the volatile solids in the sludge are important.

There are two types of furnaces generally used for sludge incineration in the United States, the multiple hearth and the fluidized bed. A third type, the single rotary hearth cyclonic furnace, has several installations in Great Britain and Europe, but is not as widely used in the U.S. as the other two furnaces. It too, has a potential for sludge incineration. All three furnaces provide an adequate mixing of sludge with the combustion gases and a residence time which ensures complete combustion. Since U.S.-installed sludge incinerators are almost always of the first two types, the discussion in this report has been limited to multiple hearth and fluidized bed installations.

Multiple Hearth Furnaces

The multiple hearth furnace (MHF) is the most widely used sludge incinerator in the United States. It is durable, relatively simple to operate, and can successfully handle a wide variety of sludges and loading rates. However, smooth operation of an MHF requires that the quality of the feed, particularly its moisture content, remain relatively constant.

The MHF is a vertically oriented, cylindrically shaped, refractory lined, steel shell containing a series of horizontal refractory hearths, one above the other. MHFs are available with diameters ranging from 54 inches to 25 feet, and contain 4 to 13 hearths. A typical cross-section of an MHF is given in Figure 3. A central shaft runs the height of the furnace and supports rabble arms above each hearth. There are either two or four rabble arms per hearth. Each arm contains several rabble teeth or plows which rake the sludge spirally across the hearth as the arm rotates above each hearth. The sewage sludge is fed at the periphery of the top hearth and is raked toward the center where it drops to the hearth below. On the second hearth, the sludge is raked outward to holes at the periphery of the bed where the sludge then drops to the next hearth. The hot gases rise counter-current to the sludge. This flow and the alternative drop hole locations on each hearth provide good contact between the hot combustion gases and the sludge feed to ensure complete combustion.

The central shaft, which serves as an exhaust passageway for the cooling air, is normally cast iron and has an inner tube called the cold

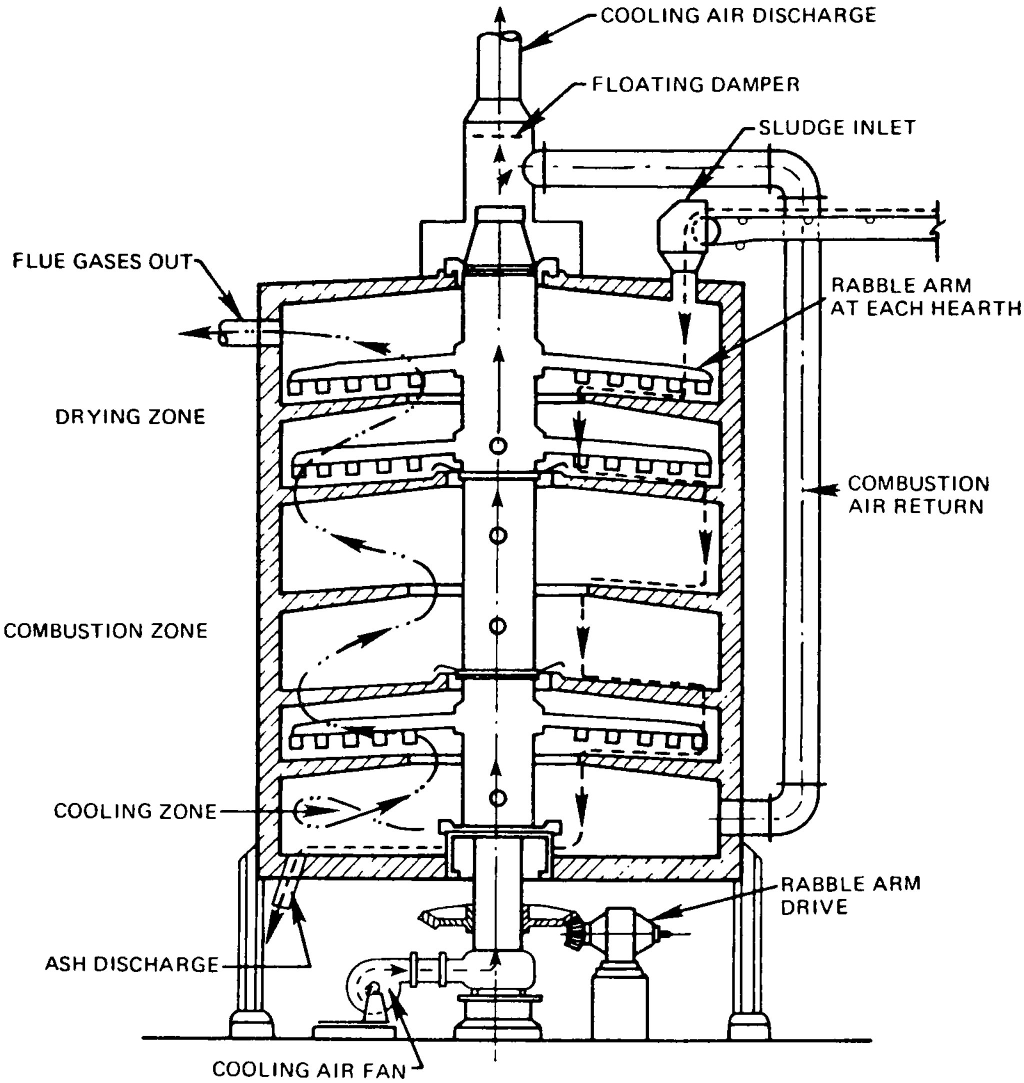

Figure 3. Cross-section of a multiple hearth furnace. Source: U.S. EPA.

air tube. Cooling air is fed to the cold air tube by the cooling air fan. Each of the rabble arms is connected to the cold air tube by a return tube which returns the heated air to the annular space between the cold air tube and the outer shell of the central shaft. The heated cooling air is usually taken from the top of the central shaft and reinjected into the lowest hearth to aid in combustion by preheating the combustion air.

The MHF can be divided into four zones for incineration. The first zone, which consists of the upper hearths, is the drying zone where most of the water is evaporated; the second zone, generally consisting of the central hearths, is the combustion zone, where temperatures reach 1400 to 1700 F; the third zone is the fixed carbon burning zone, which reduces the volatile matter to carbon dioxide; the fourth zone is the cooling zone, which includes the lowest hearths. In this zone, the ash is cooled by transferring heat to the incoming combustion air. The sequence of these zones is always the same, but the number of hearths in each zone is dependent on the quality of the feed, the design of the furnace, and the operational conditions.

When the thermal quality of the sludge feed is insufficient to sustain autogenous combustion, burners supply the additional heat by operating either continuously or intermittently on all or selected hearths. Generally, off-gas temperatures of 600 F or lower indicate incomplete combustion and a need for supplemental fuel. Off-gas temperatures from 800 to 1600 F indicate complete combustion. Temperatures are usually maintained below 1400 F by eliminating preheating the combustion air and by adding excess air. Excess air requirements for the MHF are generally 75 to 100 percent of stoichiometric requirements when sludge is the furnace feed material. A flowsheet for the MHF is given in Figure 4. For areas where air pollution requirements are similar to those for the San Francisco Bay Area, the MHF would require an afterburner fired with supplemental fuel. This requirement would increase fuel consumption, equipment size, and capital and operating costs.

The successful operation of an MHF in the incineration mode requires a relatively constant feed. Control of the MHF can be difficult, as an hour or longer is required for the sludge to reach the combustion zone from the top hearth. Thus, an increase in the moisture content of the sludge entering the top hearth may extinguish the flame in the lower hearths, unless it is detected in time. If the moisture content is detected, additional fuel can be burned to ensure that the sludge is dry before it reaches the combustion zone.

Other MHF operating problems have included the failure of rabble arms and teeth, the failure of hearths, and the failure of refractories. The rabble arms and teeth problems have generally been solved by using different construction materials. Difficulties with the refractory are usually caused by improper operation and comprise a disadvantage

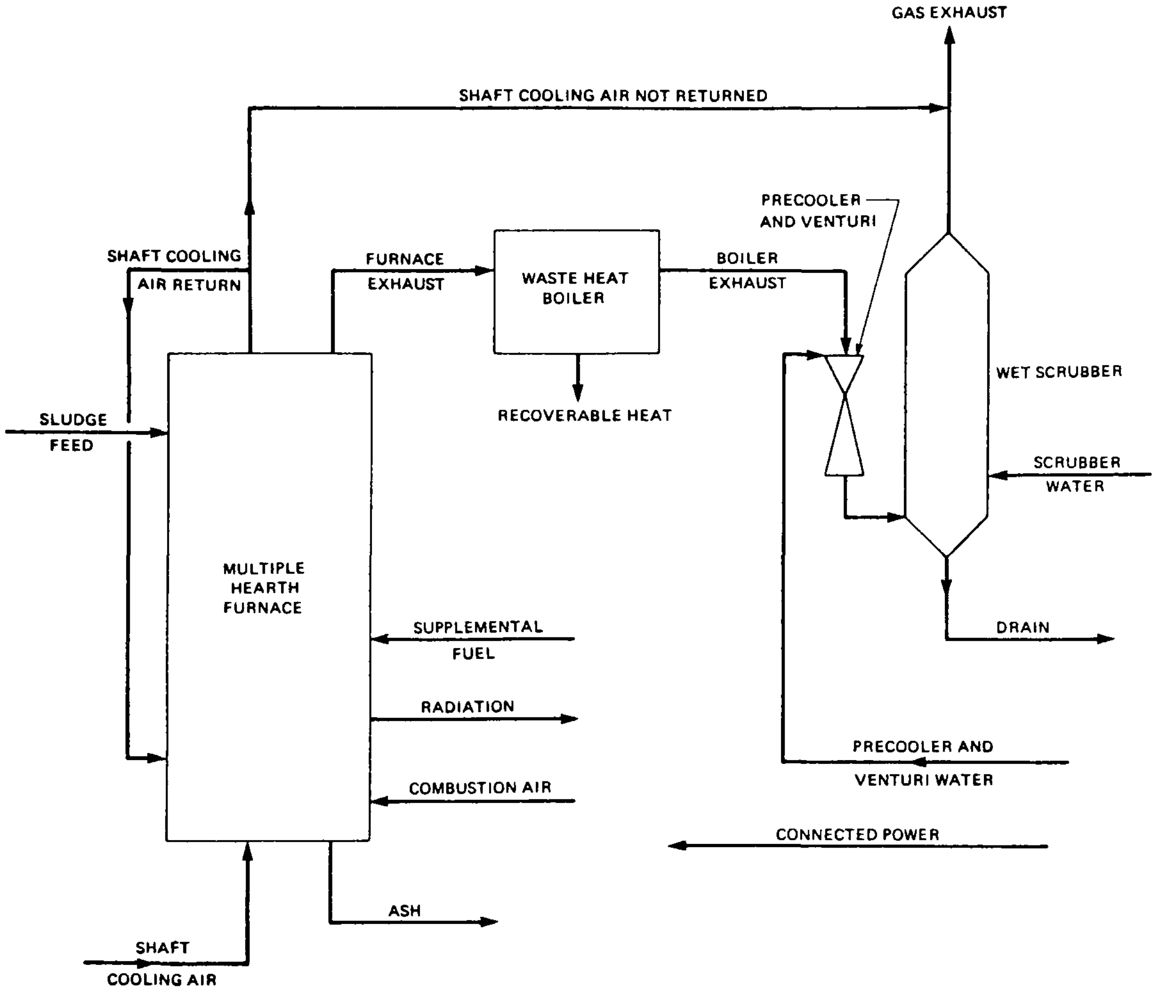

Figure 4. Flowsheet for sludge incineration in a multiple hearth furnace. Source: Brown & Caldwell.

which must be considered when evaluating an MHF. An MHF generally requires at least 24 hours to cool off or to be brought back to operating temperature. During intermittent operation, supplemental fuel is usually fired to maintain the temperature of the furnace during the hours when it is not being used. When the furnace is heated or cooled too quickly, the refractories can be damaged. Multiple hearth furnaces are generally not operated at temperatures above 2200 F; thus, with high energy fuels, there may be operational problems.

Multiple Hearth Pyrolysis

Pyrolysis is the destructive distillation of organic materials which is performed under heat and/or pressure and in the absence of oxygen. The products of pyrolysis are a combustible gas, tars and oils, and a solid char. In an MHF the heat required for the pyrolytic destruction of the organic material in the sludge is provided by the combustion of part of the sludge with or without the addition of auxiliary fuel. As a limited quantity of oxygen is required for this reaction, starved-air combustion is a more accurate term for the process.

Due to rising fuel costs and the heat value of the sludge being fed to incinerators, pyrolysis has been investigated as a means of reducing the volume of sludge to be disposed without using large amounts of supplementary fuel. In addition, a pyrolytic gas is produced which has a heat value of up to 130 Btu/standard dry cubic foot (sdcf) using air for combustion, and is suitable for combustion in an after burner, boiler, or furnace. Pyrolysis is more efficient than incineration since only a small amount of excess air must be heated. This process also allows for a reduction in the size of the off-gas system; which in turn reduces capital costs. A typical flow sheet for an MHF operated as a pyrolytic reactor is shown in Figure 5.

There are essentially three different operating modes for the pyrolysis of sludge in an MHF. These vary chiefly in the division of the energy in the sludge between the off-gas (in the form of both a combustible gas and sensible heat) and the char (as unburned carbon). A char with a lower proportion of unburned carbon will have a lower bulk density which could reduce landfilling costs.[8]

Low Temperature Char Operating Mode (LTC). The pyrolysis reaction occurs at 1200 to 1300 F. The reaction is sufficient to induce the destructive distillation of the organics in the sludge, giving off almost all of the organic vapors that are able to be released. The char discharged in this mode is a sterile, black, charcoal-like, free-flowing mixture of powder and granules with a bulk density of approximately 16 pounds per cubic foot and containing 75 percent ash. The LTC residue would retain heavy metals.

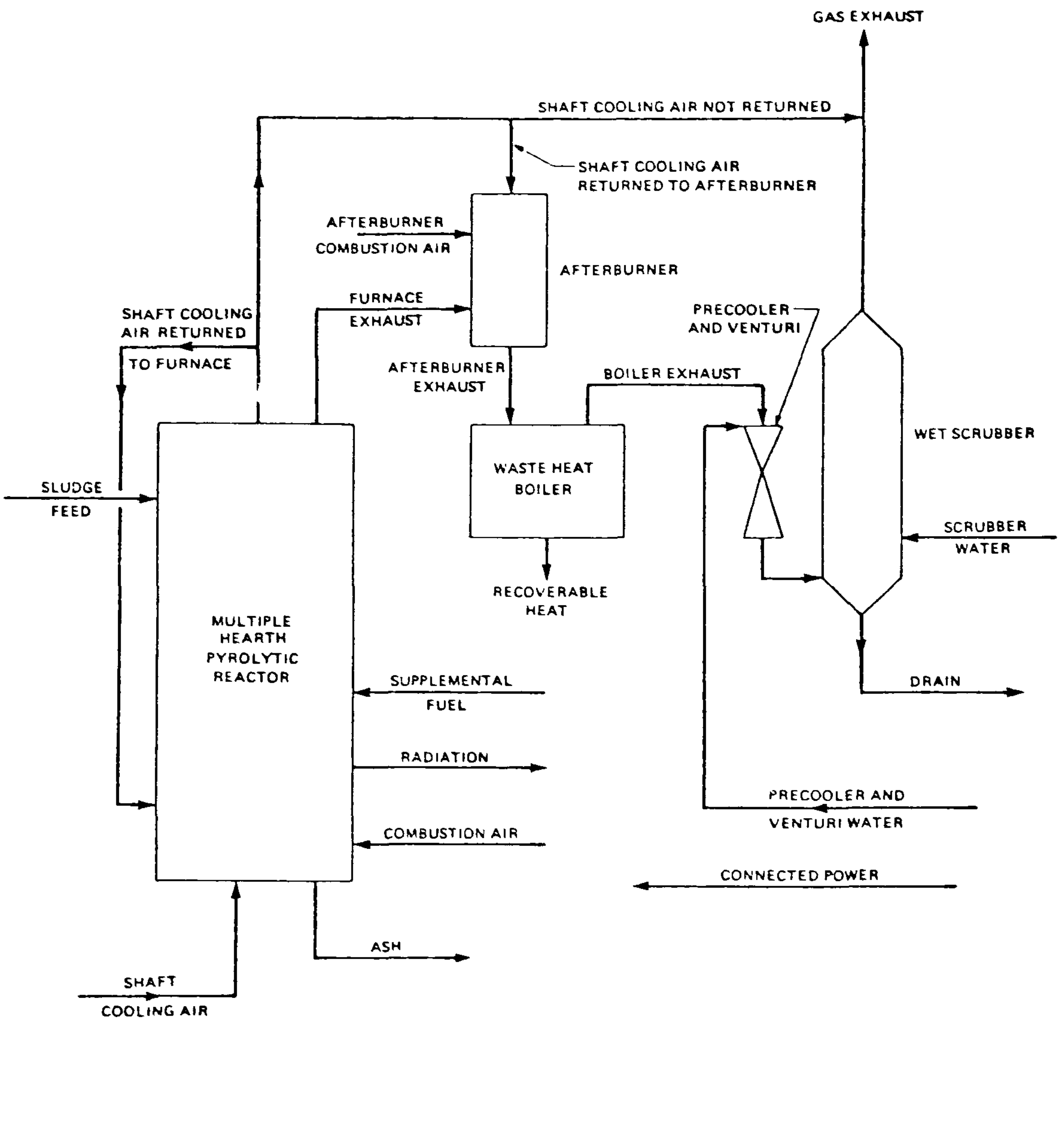

Figure 5. Flowsheet for pyrolysis of sludge in a multiple hearth furnace. Source: Brown & Caldwell.

High Temperature Char Operating Mode (HTC). At a temperature of 1600 F or higher, the char formed during this process contains only ash and carbon, and has a bulk density of 25 pounds per cubic foot. In the HTC mode more energy is released in the off-gas stream and less in the char, as compared to the LTC mode. The char, although it has a lower heating value, may be useful for its activated carbon content. The activated carbon may be suitable for addition to the waste activated sludge system in order to improve the functioning of that system.

Char Burning Operating Mode (CBA*). In this mode the char resulting from pyrolysis in the middle hearths can be combusted and then converted to ash in the lower hearths. The advantage of the CBA mode is that the energy content of the sludge is concentrated in the off-gas in the forms of combustible gas and sensible heat, leaving a minimum quantity of ash to be landfilled. This ash has a bulk density of approximately 33 pounds per cubic foot.

The autogenous pyrolysis of sludge was successfully demonstrated at a full-scale MHF project at the Central Costa Sanitary District wastewater treatment plant at Concord, California near San Francisco. The sludge had a solids content of 24 percent, a heating value of 9000 Btu/lb dry solids, and a volatile solids content of 75 percent. The pyrolysis gas had a heating value of 90 Btu/scf/ In other projects the autogenous pyrolysis of sludge was successful with sludges having a solids content of more than 25 percent. The nominal solids level for autogenous pyrolysis is a function of the net heating value of the sludge.

An MHF constructed by Envirotech in Cowlitz County, Washington has been converted for the pyrolysis of sludge, and recently began operation. Nichols Engineering and Research has been awarded a contract by Arlington County, Virginia to construct MHFs for sludge pyrolysis. Both the Eimco BSP Division of Envirotech and Nichols Engineering are actively involved in ongoing research and development on pyrolysis systems.

During test work by both MHF manufacturers, pyrolysis was found to have the following advantages over incineration:

- it is easier to control than incineration;
- pyrolysis modes have a more stable operation with little response to changes in feed;
- they possess more feed capacity per square foot of hearth area;

* Charcoal Burned Ash

- They have fewer air pollutants and an easier particle size to scrub;
- their fuel consumption is lower;
- a lower sludge solids content is required for autogenous operation; and
- their operating costs are slightly lower.

However, there are disadvantages associated with pyrolysis:

- the need for an afterburner may limit its use in existing installations due to space problems;
- more instrumentation is required;
- care must be taken with the bypass stack exhaust since furnace exhaust is high in hydrocarbons and may be combustible in the air. This may result in bypassing only after afterburning with appropriate emergency controls in some areas;
- the furnace exhaust gases are corrosive; and
- combustibles in the ash may create ultimate disposal problems in the HTC and LTC modes.

However, in this era of high energy costs, the advantages of pyrolysis seem to outweigh its disadvantages.

Fluidized Bed Furnace

The fluidized bed furnace (FBF) is a vertically oriented, cylindrically shaped, refractory lined, steel shell which contains the bed and fluidizing air diffusers. The FBF is normally available in sizes from nine feet to 25 feet in diameter. However, there is one industrial unit operating with a diameter of 53 feet. A cross-section of the fluidized bed furnace is shown in Figure 6. The sand bed is approximately 2.5 feet thick and sits on a refractory lined grid containing tuyeres. To fluidize the bed, air is injected through the tuyeres into the bed at a pressure of 3 to 5 psig. The bed's expansion is approximately 80 to 100 percent. The temperature of the bed is controlled at 1400 to 1500 F by auxiliary fuel guns. The fuel (oil or gas) is injected directly into and burned in the fluid bed. The preheat burners which are located either above (for cold windbox design) or below (for hot windbox design) the bed, are used during start-up to raise the temperature of the bed. In some installations temperature is controlled by a water spray or heat removal system above the bed which reduces the furnace temperature when it is too high. The ash is carried out the top of the furnace and is

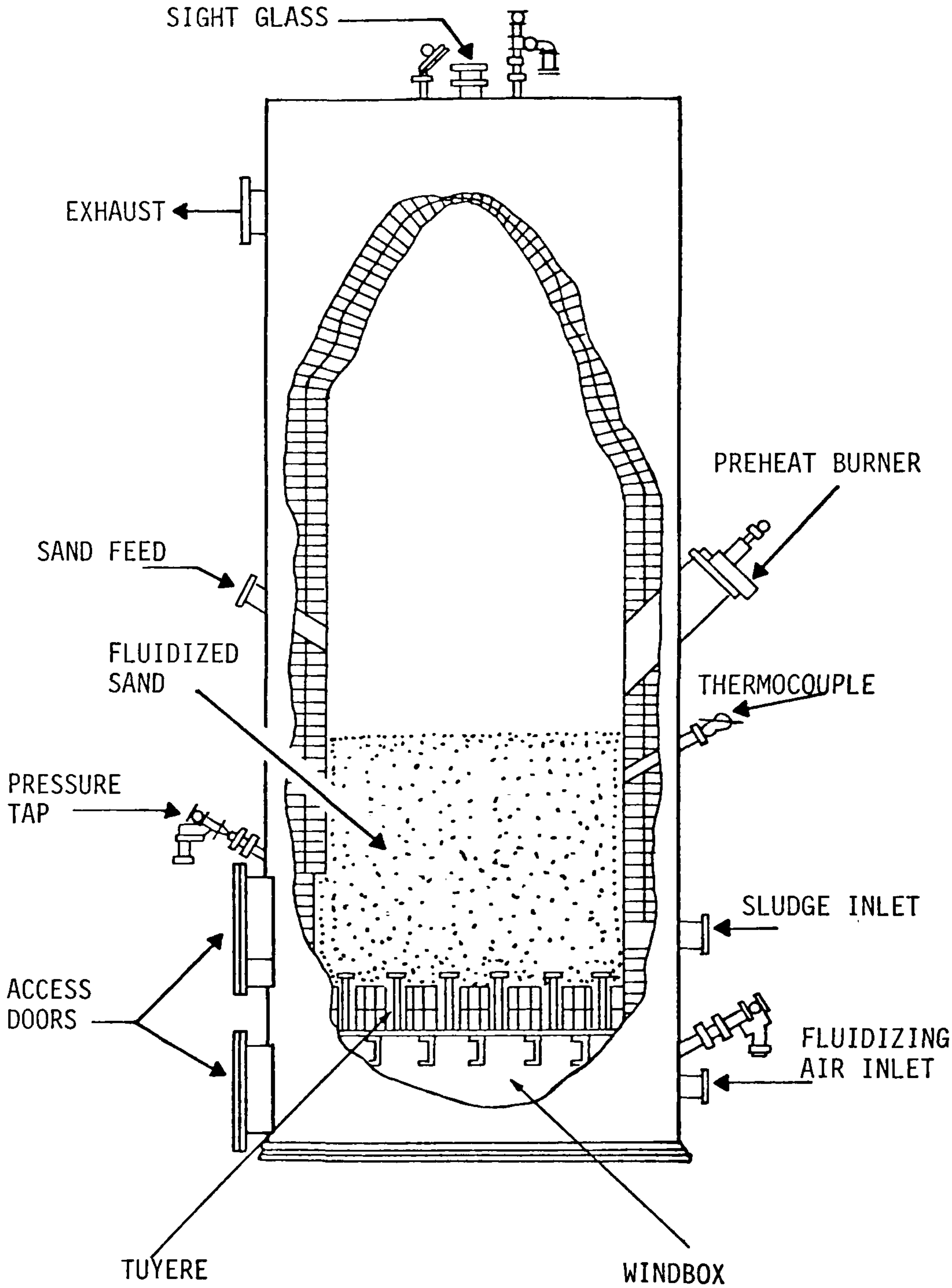

Figure 6. Cross-section of a fluidized bed furnace. Source: U.S. EPA.

removed by air pollution control devices, usually wet venturi scrubbers. Sand, which is carried out with the ash, must be replaced. Sand loss is generally five percent of the bed volume every 300 hours of operation. Furnace feed can be introduced either above or directly into the bed, depending on the type of feed. Generally, sewage sludge is fed directly into the bed.

Excess air requirements for the FBF vary from 20 to 40 percent. This reduces supplementary fuel requirements and provides a more efficient thermal balance around the furnace than with the multiple hearth furnace. The mixing caused by the air flowing through the bed and the injection of sludge directly into the bed ensures complete contact between the sludge solids and the combustion gases.

The fluid bed incinerator can be arranged in two general configurations. In the first system, the fluidizing air passes through a heat exchanger or recuperator prior to its injection into the combustion chamber. This arrangement is known as a hot windbox. It increases the thermal efficiency of the system by utilizing the high temperature of the exhaust gases to heat the incoming combustion air. In the second system, the fluidizing air is injected directly into the furnace and is known as a cold windbox. A general flowsheet for the FBF is depicted in Figure 7.

The FBF has a lower capital cost than the MHF. Its start-up fuel requirements are very low, and no fuel is needed for start-up following an overnight shutdown. The fluid bed reactor has a minimum of mechanical components and is relatively simple to operate. The sand bed acts as a large heat reservoir which minimizes the amount of fuel required to reheat the system following shutdown. This makes the FBF very attractive for intermittent operation. Since the exhaust temperatures of the FBF are in excess of 1400 F, an afterburner with supplemental fuel to comply with air pollution regulations is not required, as it may be for an MHF in some areas.

Problems were encountered in early FBFs with the feed system and temperature control for high energy feeds. Screw and pump feeds jammed because of overdrying of the sludge when it was fed directly into the bed. Where spray nozzles were used, thermocouples were burned out occasionally. There were also some problems with preheaters and with scaling of the sand on the venturi scrubber. Dorr-Oliver maintains that these problems have been addressed and corrected.

The FBF can easily be operated at temperatures of 2200 F and when appropriately designed, is suitable for high energy sludges. Thermal efficiency (i.e. the quantity of auxiliary fuel required per ton of sludge) can be maintained when the feed is reduced to 60 percent for the cold windbox design and 75 percent for the hot windbox design. The

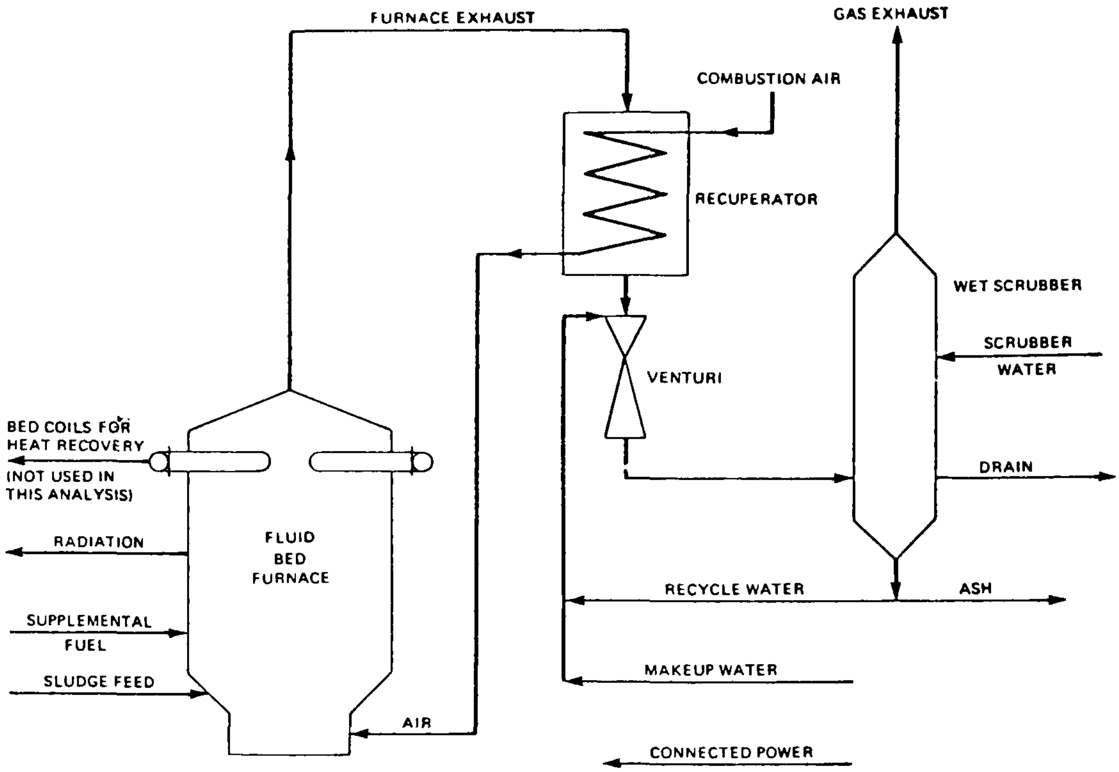

Figure 7. Flowsheet for sludge incineration in a fluid bed furnace. Source: Brown & Caldwell.

greater turndown capabilities of the former are due to the use of overbed air. Since there is a minimum amount of air always required for bed fluidizing, thermal efficiency is reduced by further turndown.

Fluidized-Bed Pyrolysis

FBFs also have potential as pyrolytic reactors. However, the design of such systems differs from fluidized-bed incineration in that the fluidizing gases must be preheated to provide heat for the pyrolytic process.

A pilot scale FBF at West Virginia University has been operated using both sludge and MSW as the feed. The fluidizing gases were preheated in a combustion chamber (hot bottom) located directly beneath the fluidized bed chamber and separated from it by a high temperature grid plate with small holes (0.096 inch diameter) to permit passage of the heated air into the FBF. MSW was pyrolyzed in this system at 1500 F to yield a pyrolysis gas with a heating value of 421 Btu/scf. The sludge, which has been digested and consequently had a low fuel value (3900 Btu/dry lb), produced a gas with a heating value of 360 Btu/scf.[9]

A demonstration plant in Japan has successfully pyrolyzed MSW, plastic wastes, and sludges from a pulp and paper plant.[10] The process, which has been adapted from its original olefin cracking application in the petrochemical industry, employs two FBFs. One acts as the pyrolytic reactor and the second preheats the fluidizing air by combustion of the char produced by the pyrolytic reactor. The gas generated from the MSW feed ranged from 405 to 438 Btu/scf in four test runs.

The leading FBF manufacturers have not promoted the pyrolysis of sludge since they believe that the energy content of the sludge can be efficiently recovered through incineration as sensible heat, due to the greater heat release capacity of the FBF in the incineration mode. If producing steam is the object, then pyrolysis has no advantage over incineration. Capital costs for a pyrolytic FBF system would be larger than those for combustion due to the requirement for a furnace to preheat the fluidizing gases. For this reason, the conversion of FBFs for pyrolysis would be impractical in most cases. If, however, a combustible gas is desired, an FBF system is capable of producing a high quality gas from a variety of feed materials.

4. CODISPOSAL OF SEWAGE SLUDGE AND RDF

Municipal wastewater sludge has a high water content and a low net heating value when compared to other potential fuels. Unit processes which dewater sludge typically have a high energy demand. By combining sludge with other materials such as RDF, a combined furnace feed can be formed which has both a low water content and a heating value high enough to eliminate the need for supplemental furnace fuel. This technique is termed codisposal.

Coincineration is incineration using a combination of sewage sludge and a combustible material, other than natural gas or fuel oil, in a single furnace. Copyrolysis is pyrolysis using a combination of sewage sludge and combustible materials, other than natural gas or fuel oil, in a single reactor.

A variety of materials can be combined with sewage sludge to form a furnace feed with a higher heat value than a pure sludge feed. Some of these materials are: municipal solid waste, coal, wood wastes, textile wastes, bagasse, and farm wastes such as corn stalks, rice husks, etc. Virtually any material which can be combusted can be combined with the sludge. The coincineration of coal and sludge, and municipal waste and sludge, have been investigated in recent test programs.

The coincineration of sludge with processed MSW in multiple hearth furnaces has been practiced in Great Britain, Germany, and Switzerland. At Reigate (England) and Alloa (Scotland), MSW is shredded by a hammermill, and the ferrous materials are removed by magnetic separation before being fed into the top hearth of a Lurgi MHF along with thickened sludge.[11] Considerable difficulties with the conveyor carrying the shredded MSW to the MHF were encountered during initial operation of the Reigate plant. Also, cracks were experienced in the rabble shaft castings due to local overheating, probably caused by occasional high heat release during firing of refuse with a high energy content. As of the last report, these problems have been corrected.[12]

In Nieder-Uzwill, Switzerland, a Nichols MHF has been converted for coincineration. After oversized materials have been separated, the MSW is shredded by a hammermill and ferrous metals are removed by a magnetic drum. The remaining material is conveyed onto a vibrating screen with 30 mm (1.2 inch) holes. The oversized material is conveyed to the top hearth of the MHF and introduced with digested sludge (six percent solids). A separate furnace is used to incinerate large items (mattresses, tires, etc.) and the combustion gases from this furnace are then fed to the MHF to provide additional heat. The plant operates 24 hours per day, and incinerates 86 to 88 tons/day of refuse and 22 to 27 wet tons/dry of digested sludge, which represents an application rate of about seven wet $lb/ft^2/hr$.[13]

In the United States, codisposal was successfully demonstrated in a 16-foot diameter, six-hearth, MHF operated by the Central Contra Costa Sanitary District at Concord, California. Mixed municipal refuse was shredded, classified, and screened prior to addition to the MHF, where the RDF comprised the light fraction from the air classifier. The sludge had a solids content of 16 percent, a volatile solids content of 75 percent, and a heating value of 9,000 Btu/lb dry solids; whereas the RDF had a solids content of 75 percent, very few inerts, and a heating value of 7,500 Btu/lb of dry solids. The furnace feed rate was varied from pure sludge to pure RDF.

During the test, the furnace was operated in both a pyrolytic mode and an incineration mode. Approximately 70 to 100 percent excess air was introduced in the incineration mode to ensure complete combustion. The pyrolysis mode was run under oxygen-starved conditions at a constant furnace temperature. The volatile gases were combusted in the afterburner with minimum excess air in order to maximize the temperature. Afterburner temperatures well over 2000 F were common. The system was operated for up to 8.3 hours per day during a two-month demonstration program. Both pyrolysis and incineration modes were tested on feed material that ranged from pure sludge to pure MSW. Maximum capacity was obtained in the pyrolysis mode with a feed consisting of 2.5 parts of MSW to one part of sludge. The feed rate of this material was reported to be 8,716 wet pounds per hour[14] which represents a loading rate of 10.3 wet pounds per square foot per hour. During copyrolysis, a combustible gas was produced with a heating value of 130 Btu/sdcf. This combustible gas could be fired in a waste heat boiler for steam production, used as the fuel for a lime recalcination furnace, or used for space heating.

A flow diagram of the system is depicted in Figure 8. During the test, the RDF could be fed to hearths number three or one. Sludge was always fed to hearth number one. Temperatures were maintained during pyrolysis by controlling the amount of air fed to the furnace. The off-gases from the furnace were allowed to burn in an afterburner with the introduction of combustion air. Afterburner temperatures were approximately 2200 F, although the pyrolysis gas could be combusted to produce a temperature as high as 2500 F with no supplemental fuel addition.

Autogenous combustion could be maintained with an RDF-to-sludge ratio of one to two using a sludge solids content of 16 percent. Autogenous combustion in a pyrolysis mode could be maintained with sludge alone, but only when the solids content was 24 percent or more. Energy recovery and general system operation and control were significantly improved when the RDF was fed to hearth number three, rather than to the top hearth.

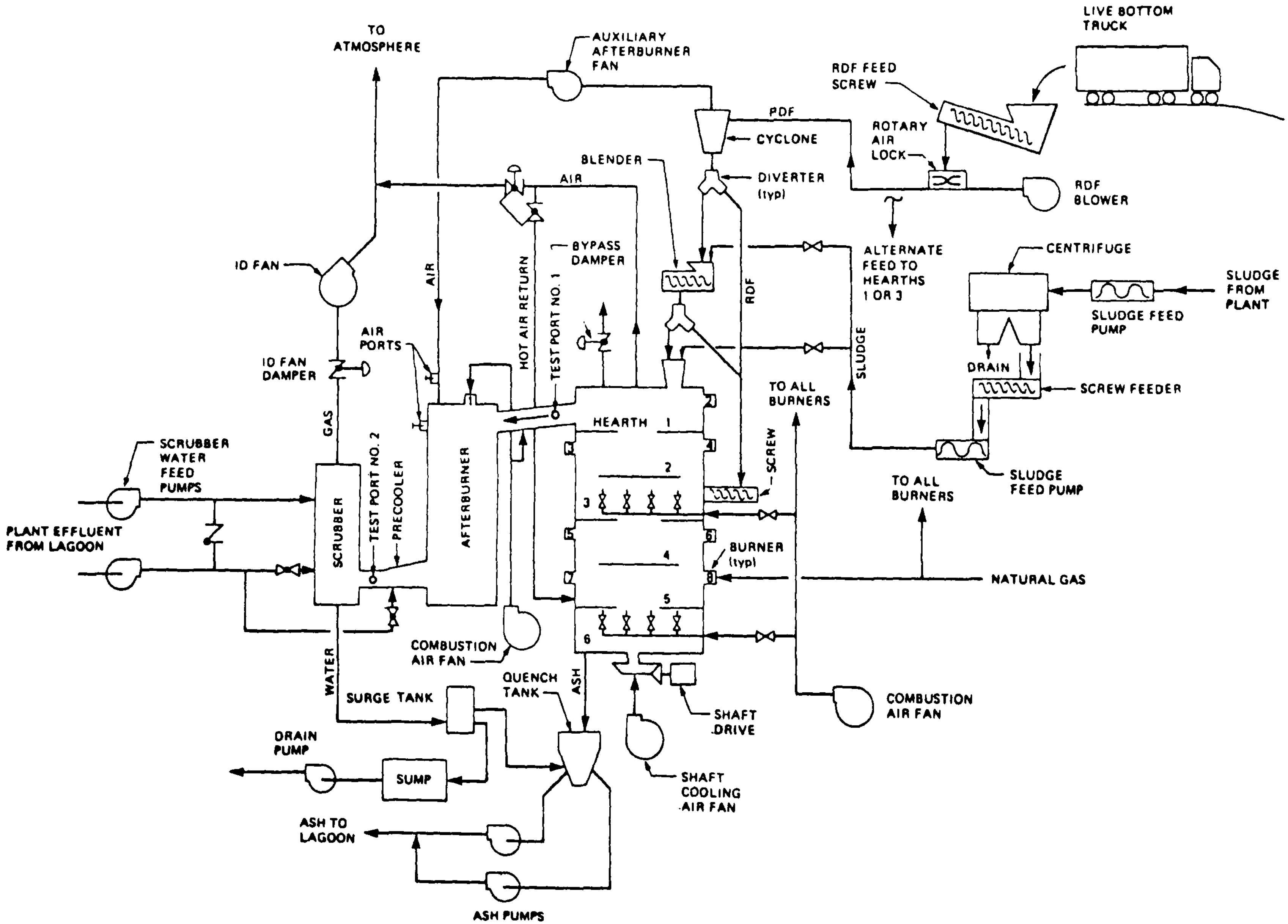

Figure 8. Central Contra Costa Test Project flow diagram. Source: Brown & Caldwell.

MSW and sludge have been coincinerated in an FBF in Franklin, Ohio. The furnace preparation utilizes a Black Clawson wet pulper to remove ferrous metals and heavy solids from the pulped refuse. Sludge from a 2.5 MGD secondary treatment plant is added to a major portion of the pulper effluent, and the combined stream is dewatered to 15 to 20 percent solids by a primary pulp screw press. The furnace feed is further dewatered to 40 to 45 percent with a disc or V press before being injected into the FBF at the bottom of the bed. There is a build-up in bed volume with the coincineration scheme, and a small amount of bed material must be periodically removed from the furnace. The system has a capacity of ten wet tons/hr, and the feed preparation steps now reduce the non-combustible fraction to three to six percent.

Another coincineration project utilizing an FBF is under construction in Duluth, Minnesota for the Western Lake Superior Sanitary District. Unlike the Franklin plant, the MSW will be shredded rather than pulped, to produce a dry RDF fuel. A flow diagram for this project is shown in Figure 9. An FBF in Thunder Bay, Ontario is being used to incinerate hogged bark and wood debris with pulp mill sludge. Tests have been run using unsorted solid wastes in place of the wood waste.

In their review of codisposal techniques,[15] Roy F. Weston, Inc. stated that large materials will accumulate at the bottom of the fluid bed, causing ultimate defluidizing of the bed, thus requiring that the RDF be uniform in size, generally in the one to three inch range. This has been strongly disputed by Dorr-Oliver, who claims that RDF for use in an FBF can be as large as six inches in diameter.

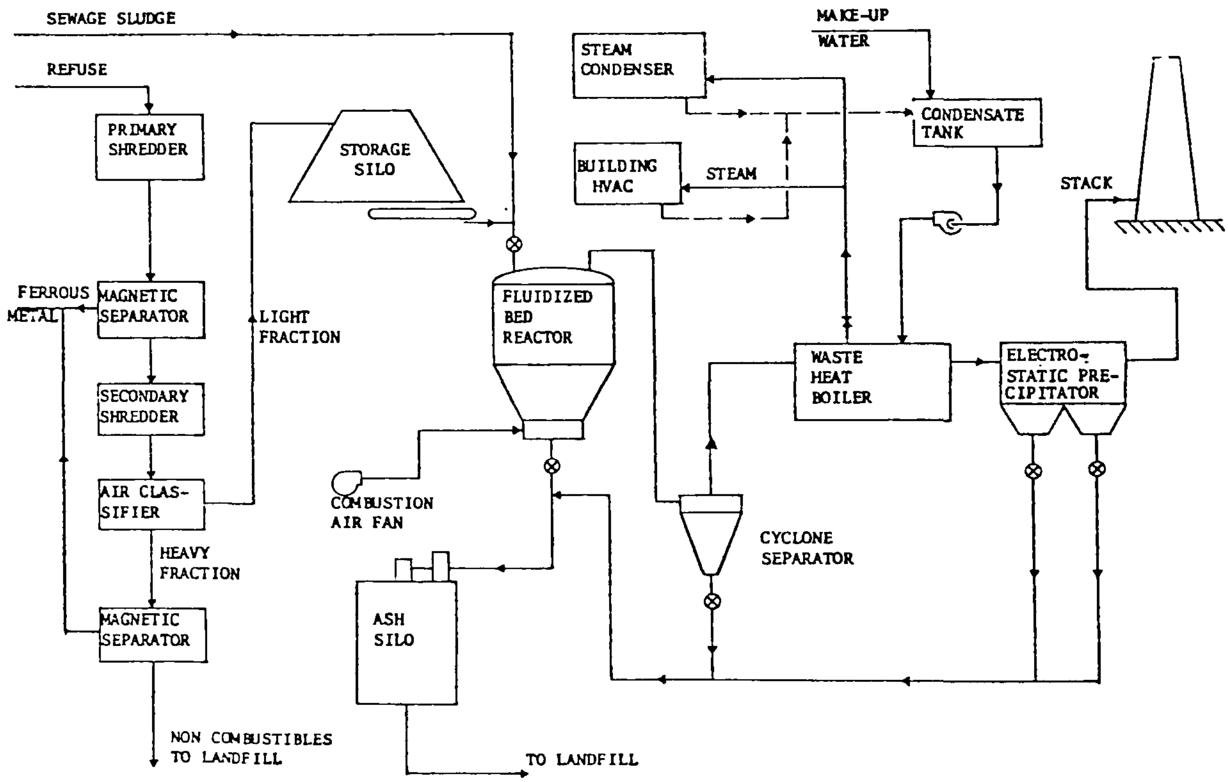

Figure 9. Flow diagram for FBF-coincineration, Western Lake Superior Sanitary District, Duluth, MN. Source: Consoer, Townsend & Associates.

5. TECHNICAL CONSIDERATIONS FOR CODISPOSAL IN EXISTING SLUDGE INCINERATORS

In order to assess the application of RDF in existing sludge incinerators, lengthy discussions were held with key staff members of four major sludge incinerator manufacturers. As a result of those discussions and upon review of the available literature on this subject, various technical considerations have been identified. These considerations are summarized in Table 6.

Codisposal in MHFs

Mode of Operation. Coincineration in an MHF would be most applicable in locations where excess incinerator capacity is available and the solids content of the sludge is low. The addition of RDF would raise the proportion of combustible solids in the furnace feed, thereby eliminating the need for auxiliary fuel except during start-up. If heat recovery is not being considered and furnace capacity is sufficient, it may not be worthwhile to modify the MHF for pyrolysis.

In most locations, the solids content of the RDF/sludge feed is likely to be high. The heat released during coincineration of such a feed material would be a problem in many MHFs, since the volume of air required to cool the furnace would result in the velocity of this gas, moving upwards through the drop-holes in each hearth, to be high. If this gas velocity exceeds approximately three feet per second, then RDF would be prevented from dropping downward through the drop-holes. This problem would be particularly severe in tall, narrow MHFs, where the area of the drop-holes at each hearth is small, and could severely limit the capacity of the furnace. According to Nichols, this problem could be overcome by split drafting, where a portion of the hot combustion gases is removed from the middle hearths, where the RDF would be burned, and conveyed to the off-gas system.

However, for most MHF installations, the manufacturers recommend that the pyrolysis mode be adopted for codisposal for the following reasons:

- furnace capacity is increased;
- heat recovery, particularly in a waste heat boiler, is enhanced;

Table 6

TECHNICAL CONSIDERATION FOR RDF USE IN

EXISTING SLUDGE INCINERATORS*

Consideration	MHF-Pyrolysis	FBF
RDF Process	• Shred, air classify, screening • 65% RDF output • d-RDF may be preferable	• Trommel, coarse shred, air classify
RDF Specification	• ≤ 2-3" particle size • Low inerts • Low BTU/lb. & moisture content variation prefered	• Coarse • 95% 6" • Low inorganic content preferable • BTU & moisture variation not critical
Feeding	• Screw conveyor feed at 1 or 2 points or pneumatic feed to table feeder	• Ram feeding or pneumatic feeding • Feed into sand bed
Site	• Individual analysis required • Waste heat boiler location should be as close as possible	• Individual analysis required • Waste heat boiler location should be as close as possible
Fuel Useage	• Significant supplementary fuel still required for warm up periods	• Due to heat sink, nature of design, less supplementary fuel required

* Source: Gordian Associates Inc.

Table 6 (cont'd.)

TECHNICAL CONSIDERATION FOR RDF USE IN

EXISTING SLUDGE INCINERATORS

Consideration	MHF-Pyrolysis	FBF
Incinerator Modifications	• Add feed system • Replace induced draft fan • Seal air linkages • Add hot cyclone venturi scrubber • Water jacketed ash screw • After burner required	• Add waste heat boilers especially to older installations • Add bed-removal classification system if RDF quality is low
Incinerator Modifications	• Add and raise rabble arms • Additional controls & instrumentation • Add waste heat boiler • Anti-corrosion lining for off-gas system • (Add split-draft ducting)	• Modify/add scrubber capacity • Make "hot shell" design in order to inhibit corrosive gas condensation of HCl's and HFl's • Add feed system
Cost to Convert	• $1-2 M per conversion, depending upon unit size, for boiler, air pollution modifications, etc.	• $.15-.5 M per conversion, depending upon size, for boiler, air pollution mods, etc.
Ash Handling	• Ash output increased has larger heat sink, requires water jacketed ash removal system	• With high inorganic RDF, bed material will require removal and classification • Ash at scrubber and waste heat boiler will increase

Table 6 (cont'd.)

TECHNICAL CONSIDERATION FOR RDF USE IN

EXISTING SLUDGE INCINERATORS*

Consideration	MHF-Pyrolysis	FBF
Air Pollution	• Increase in scrubber capacity required	• Increase in particulate emissions and shift in particulate particle size
Operational	• Around-the-clock operation will result in lower maintenance costs and longer equipment life	• Intermittent operation less harmful due to heat sink nature of sand bed material
Waste Heat Recovery Potential	• 75 percent of input BTUs for CBA mode, less for LTC and HTC modes	• 50 percent of input BTUs

* Source: Gordian Associates Inc.

- pyrolysis can become autogenous with sludge with a lower solids content; and

- pyrolysis is easier to control than incineration in an MHF.

Codisposal System Design. The first generation of MHF-codisposal projects in the United States is likely to be modelled after the demonstration plant at the Central Contra Costa Sanitary District treatment plant. Although MHF manufacturers are confident that this represents a viable technology as it stands, they recognize that there are a number of possible refinements which might improve the MHFs' performance in coincineration and particularly in copyrolysis.

RDF Process. For codisposal in an MHF, the RDF process should include shredding, air classification, and screening of the MSW. One process modification currently receiving much attention is the placement of the trommel (rotary screening) unit operation prior to shredding. This process change provides two significant benefits:

- glass and other abrasive inorganics are removed in large pieces prior to shredding, thus reducing shredder wear, maintenance, and power consumption; and

- air classification performance improves relative to its ability to separate large versus very small inorganic particles, thus improving the quality of the light RDF fraction.

The resulting RDF should have the following characteristics:

- $\leq$ two to three inch particle size;

- as much wire, string, rags, etc., as possible should be removed or reduced in length, as these items tend to jam the rabbling mechanism;

- the water and heat content should be constant to facilitate control of the furnace, particularly for coincineration; and

- to prevent equipment wear, the abrasive content should be low, particularly if a screw-feeding machine is used.

Due to volume considerations, densified RDF (d-RDF) may be preferable so that the necessary Btu input can be fed to the furnace. However, this would increase capital and operating costs for RDF production.

Furnace Feed System. RDF can be fed to the MHF by a screw conveyor at one or two locations, or by pneumatic feed to a table feeder. A screw feeder is required for pyrolysis, since the additional air added by a pneumatic feeder would upset the balance in the pyrolysis condition. The screw feeder creates an air seal between the atmosphere and the combustion chamber. Again, control of the incineration and, to a lesser extent, the pyrolysis processes is highly dependent on maintaining a uniform feed rate.

Waste Heat Recovery. Seventy-five percent of the Btus in the furnace feed can be recovered by means of a waste heat boiler in the CBA-pyrolysis mode. This figure will be lower for the LTC and HTC pyrolysis modes, as a substantial amount of the heat value of the furnace feed is retained by the char and may not be recovered.

In order to maximize heat recovery, the location of the waste heat boiler should be as close to the furnace as possible. Finding space sufficiently close to the furnace to justify heat recovery may be difficult in existing sludge incinerators. Thus, an individual analysis of each site is required in order to determine the feasibility of heat recovery.

Incinerator Modification. The following items must be added to, or modified on, an existing MHF before it can be used for coincineration or copyrolysis:

- An RDF feed system should be added.
- Rabble arms should be raised and their number increased in order to handle the bulky RDF/sludge feed.
- A hot cyclone venturi scrubber is required to handle the increased quantity of particulates in the off-gas. An incidental benefit of the LTC-pyrolysis mode may be the elimination of the need for a scrubber. Due to the large diameter of the particulate matter, a cyclone located in front of the afterburner may be sufficiently effective to meet air quality emission standards.
- A split-draft duct may be added in order to remove some of the hot combustion gases and convey them to the off-gas system. Dampers would be required to control the relative split of hot gases (as well as the furnace pressure in the pyrolysis modes).

The following additional modifications are required to retrofit an MHF for copyrolysis (but not coincineration):

- The MHF should be sealed to prevent air leakages into the furnace, since additional air cannot be added without upsetting the balance of the pyrolysis condition.

- Reduction of the induced draft fan speed, or alternatively, closing of the damper is required in order to provide less air to the system.

- An afterburner is required for the combustion of the pyrolysis gas. Most states require that the off-gas temperature exceed 1400 F in order to prevent odors.

- A waste heat boiler, located as close to the MHF as possible, must be added if heat is to be recovered efficiently. This utilizes the sensible heat in the off-gases in addition to the heat released during the combustion of these gases.

- A water-jacketed ash removal system is required to remove the greater quantity of ash/char produced in codisposal.

- Additional controls and instrumentation are required particularly for the regulation of excess air, since the pyrolysis process is controlled by limiting the admission of air into the furnace.

- A corrosion-resistant lining should be applied to the interior walls of the off-gas system, since pyrolysis gas can be quite corrosive. Sufficient protection may already exist if the MHF was designed for sludge containing ferric chloride.

Retrofit Costs. Envirotech estimated that the cost to convert an MHF to copyrolysis would be $1 to $2 million depending on the size and characteristics of the unit in question.

Codisposal in FBFs

Mode of Operation. Incineration would be the preferred mode of operation for codisposal in an FBF. A relatively high quality pyrolysis gas (360 to 440 Btu/scf) can be produced by pyrolysis in a fluidized bed system. However, in most cases, the additional capital and operating costs would far outweigh any benefits of producing this gas.

Codisposal System Design. The fluidized bed manufacturers believe that a dry RDF system, like that designed for the Western Lake Superior Sanitary District in Duluth, Minnesota, would be adequate for codisposal in FBFs. Wet pulping of the MSW would produce a better feed material, but the advantages of this system would not justify the additional capital and operating costs that would be incurred.

RDF Process. The RDF process for codisposal in an FBF would ideally include trommelling or rotary screening to remove glass and other abrasives; shredding, and air classification. The RDF can be coarse (up to six inches in diameter) resulting in lower capital and operating costs for RDF production.

Furnace Feed System. RDF can be fed by either ram-feeding or by means of a pneumatic system.

Waste Heat Recovery. Several of the more recent FBFs already have waste heat boilers installed, with the steam being used to heat the fluidizing air. Where a waste heat boiler must be added, it may be difficult to locate it near the furnace. As with the MHF, individual analysis of each site is required in order to determine the feasibility of waste heat recovery.

Approximately 50 percent of the Btus in the furnace feed can be recovered as steam from a waste heat boiler in an FBF system. This is less than for an MHF (CBA pyrolysis mode) since a greater volume of excess air is used which reduces the efficiency of the boiler.

Incinerator Modifications. Before an FBF can be used for coincineration, the following modifications must be made:

- Add a feed system.

- Add a waste heat boiler. Some of the more recent installations already have this piece of equipment.

- Add a bed-removal classification system for the removal of inert material that builds up in the bed. This would be particularly necessary where the quality of the RDF is low (i.e. high inorganic fraction).

- Design a "hot shell" to inhibit corrosive condensation of hydrogen chloride and hydrogen flouride gases. These gases result from the combustion of plastics in MSW.

- Modify the off-gas system to capture increased particulate emissions. Discussions with Dorr-Oliver indicate that it will be necessary only to reset the adjustable throat on the scrubber in more recent installations.

Retrofit Costs. Dorr-Oliver estimated that the costs for retrofitting an FBF would range between $150,000 and $500,000, depending on the size of the unit and whether addition of a waste heat boiler is required. This cost does not include the necessary RDF handling equipment (e.g. storage bins) and other site modifications. Retrofit costs for an FBF are lower than for an MHF, since no afterburner is needed and only minor modifications of the scrubber are required.

6. CAPACITY OF EXISTING INCINERATORS FOR RDF

In this section, methodologies are presented to estimate the amount of RDF that can be combined with a given quantity of sewage sludge for codisposal in an MHF or FBF. For an accurate determination of the capacity of a particular unit, other factors such as heat content of the feed and the design of the furnace must be taken into consideration.

Methodology For Determining RDF Potential in Multiple Hearth Furnaces

The methodology for determining the capacity for RDF comsumption in a MHF was developed by Gordian in collaboration with Nichols Engineering and Research Corporation. Two modes of operation, incineration and low temperature char (LTC) pyrolysis, are considered here. These methodologies are based on there being a limit to the amount of heat that can be released in a MHF. Nichols cautions that capacity could also be limited by the volume of RDF that can be handled by the furnace, particularly where the RDF is light and bulky. Therefore, it may be necessary for the RDF to be densified or pelletized in order to achieve the capacities estimated by the methodology presented here. Pyrolysis results in a greater furnace capacity than incineration since only part of the energy in the feed material is released in the furnace, the remainder being retained in the char (LTC, HTC modes) or in the combustible pyrolysis gas.

Prior to calculating potential RDF consumption in an MHF, it is necessary to determine the following:

- hearth area of the furnace (square feet),
- application rate of the sludge (wet pounds per square foot per hour), and
- solids content of the sludge (percent by weight).

For the incineration mode, the RDF capacity is depicted in Figure 10. The application of the sludge is located on the y-axis, and by reading across to the appropriate curve for the solids content of the sludge, the RDF capacity (wet pounds per square foot per hour) is found on the x-axis. The total capacity of the furnace is obtained by multiplying this number by the hearth area of the furnace, which can be obtained from Table 7.

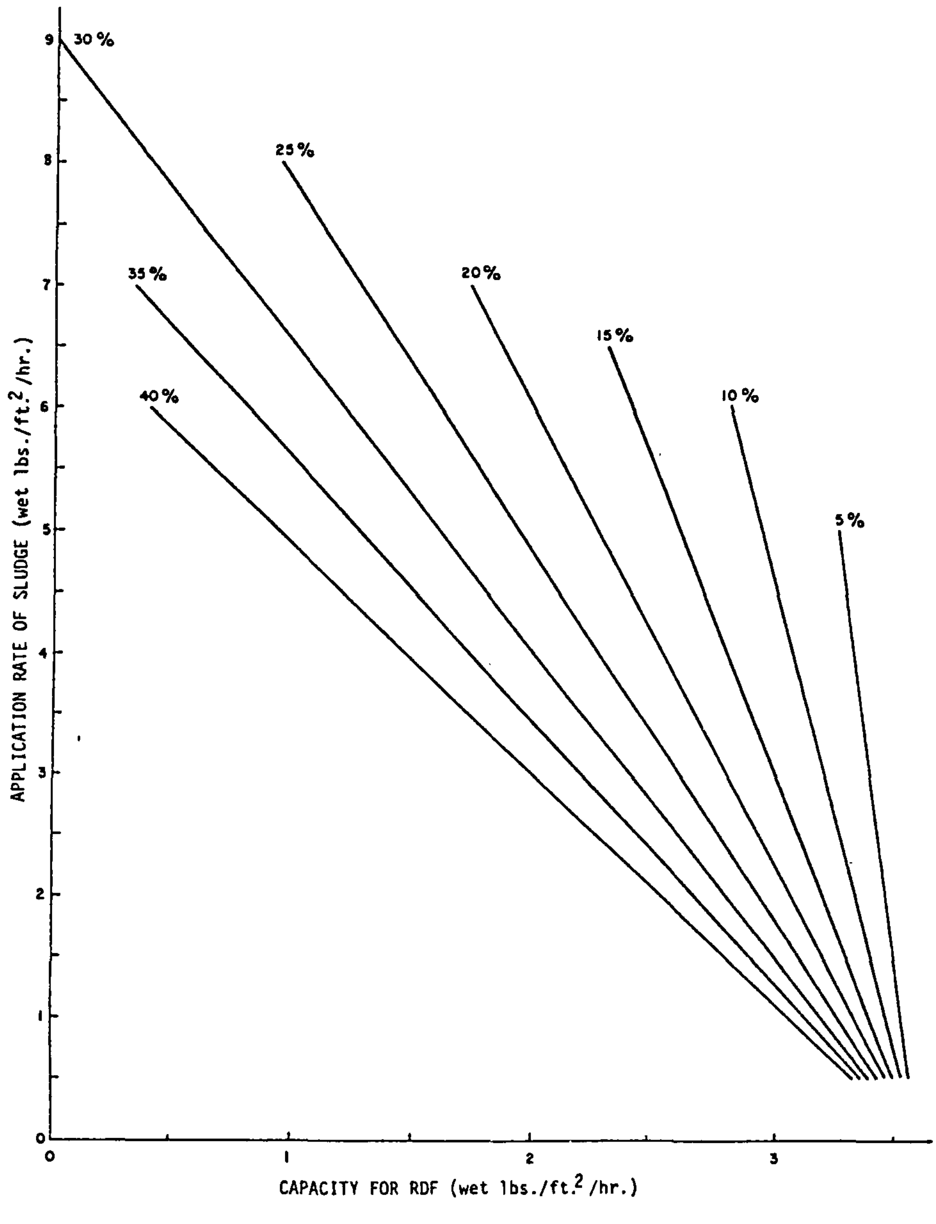

Figure 10. RDF capacity of multiple hearth furnaces in the incineration mode. Source: Gordian Associates Incorporated.

Table 7

HEARTH AREA DETERMINATION*+

Furnace ID	OD For wall thickness of:			Minimum Column height	SQUARE FEET OF EFFECTIVE HEARTH AREA AND "NORMAL" SHELL HEIGHT											
					Furnace sizing chart											
	6"	9"	13½"		1	2	3	4	5	6	7	8	9	10	11	12
13"	• 18" •@2½"			1'	1											
20"	28" @4"			1'3"	2	4 2'0"	6	8 4'0"	10	12 6'0"						
30"		44" •@7"		1½"	4	8 2'2"	12	16 4'4"	20	24 6'	28	32 7'8"				
39"	4'3"	4'9"	5'6"	2½"	7	14 3'6"	19	28 6'	32	37 8'6"	42	48 11'0"				
54"	5'6"	6'	6'9"	4'	15	31 4'2"	42	63 7'4"	74	85 10'6"	98	112 13'8"				
5½'	6'6"	7'	7'9"	4'	24	47 4'8"	63	94 8'3"	110	125 11'10"	145	166 15'5"				
7'	8'0"	8'6"	9'3"	5'	32	65 6'3"	96	130 10'10"	161	193 15'5"	225	256 20'0"	288	319 24'7"		
8½"	9'6"	10'	10'9"	6½'	47	94 6'3"	138	188 10'8"	235	276 15'1"	323	364 19'5"	411	452 23'10"		
10½'	11'6"	12'	12'3"	6½"	80	148 8'4"	227	295 14'0"	374	442 19'8"	521	589 24'4"	668	736 31'0"		
12'	13'0"	13'6"	14'3"	6½"	97	195 6'9"	287	390 11'8"	487	575 16'7"	672	760 21'5"	857	944 26'4"	1041	1128 31'2"
14½'	15'6"	16'	16'9"	7'	143	286 8'0"	422	573 13'2"	716	845 18'7"	988	1117 24'1"	1260	1400 29'6"	1540	1675 35'0"
16½'	17'6"	18'	18'9"	7'	181	363 8'4"	534	727 14'3"	908	1068 20'2"	1249	1410 26'0"	1591	1752 31'11"	1933	2090 37'9"
18'	19'0"	19'6"	20'3"	8'	215	431 8'4"	634	863 14'4"	1078	1268 20'2"	1483	1660 26'1"	1875	2060 31'11"	2275	2464 37'10"
20'	21'0"	21'6"	22'3"	8'	269	538 9'6"	790	1077 16'1"	1346	1580 22'9"	1849	2084 29'6"	2350	2600 36'2"	2860	3120 42'11"
23½'	24'6"	25	25'9"	8'	382	764 11'4"	1145	1528 18'9"	1909	2292 26'2"	2674	3056 33'7"	3438	3818 41'	4200	4584 48'5"
26'	27'0"	27'6"	28'3"	8'	463	926 12'7"	1389	1852 20'9"	2315	2778 28'10"	3241	3704 36'11"	4167	4630 45'	5093	5556 53'1"
28'	29'0"	29'6"	30'3"	8'	610	1155 13'	1690	2235 22'	2770	3315 31'	3850	4395 40'	4930	5475 49'	6010	6555 58'

* Source: Envirotech.

\+ Hearth area of multiple hearth furnaces. The wall thickness for sludge incinerators is generally 13-1/2 inches.

The capacity obtained by this methodology may not be attainable in a unit in which the hearth is distributed over a large number of hearths (i.e. a tall and narrow MHF) since the cooling air velocity would be high due to the small drop-hole area at each hearth. Flue gas velocity could limit capacity in codisposal since it could prevent the RDF from falling through the drop holes. This constraint can be alleviated by adopting a split-draft furnace design. This design could increase the heat release capacity of the furnace by as much as two and one-half times.

RDF consumption in the LTC (pyrolysis) mode can be computed by using Figure 11. Knowing the application rate of the sludge in wet pounds per hour (y-axis), the RDF capacity can be read off on the x-axis. No allowance need be made for the solids content of the sludge since the amount of combustion occurring in the furnace can be controlled to maintain a maximum level of heat release sufficient for the evaporation of all the moisture in the sludge.

The LTC mode has the greatest capacity for RDF since a greater proportion of the energy in the feed material is retained in the char than in the HTC or CBA modes. The capacity of the CBA mode is only slightly higher than that of coincineration (with a 30 percent solids sludge), since, by burning the char in the lower hearths, as much heat is released as in incineration except for the energy retained in the pyrolysis gas. The capacity of this mode could also be increased by adopting a split-draft furnace design. The capacity of the HTC mode will be intermediate between the CBA and LTC modes.

Methodology For Determining RDF Potential in Fluidized Bed Furnaces

The methodology for calculating the capacity for RDF consumption in an FBF was developed by Dorr-Oliver, Inc. This capacity is limited by either the maximum quantity of heat (Btu/hr) that can be released in the FBF during combustion (heat release capacity) or by the maximum quantity of water that can be evaporated. The factors that determine the capacity of an FBF depend on the heat value and the water content of the combined sludge/RDF feed to the FBF.

The calculations presented below assume an average sludge with a 70 percent volatile solids content and a heat value of 9,500 Btu/lb of volatile solids (6,650 Btu/lb dry solids). The RDF was considered to be 75 percent solids, with a heat value of 5,000 Btu per wet pound. In addition, it was assumed that any retrofit would include the addition of heat recovery (e.g., a hot windbox or recuperator) where the combustion air is preheated. This would increase the capacity of the unit to consume RDF. The procedure for the calculation of RDF capacity is as follows:

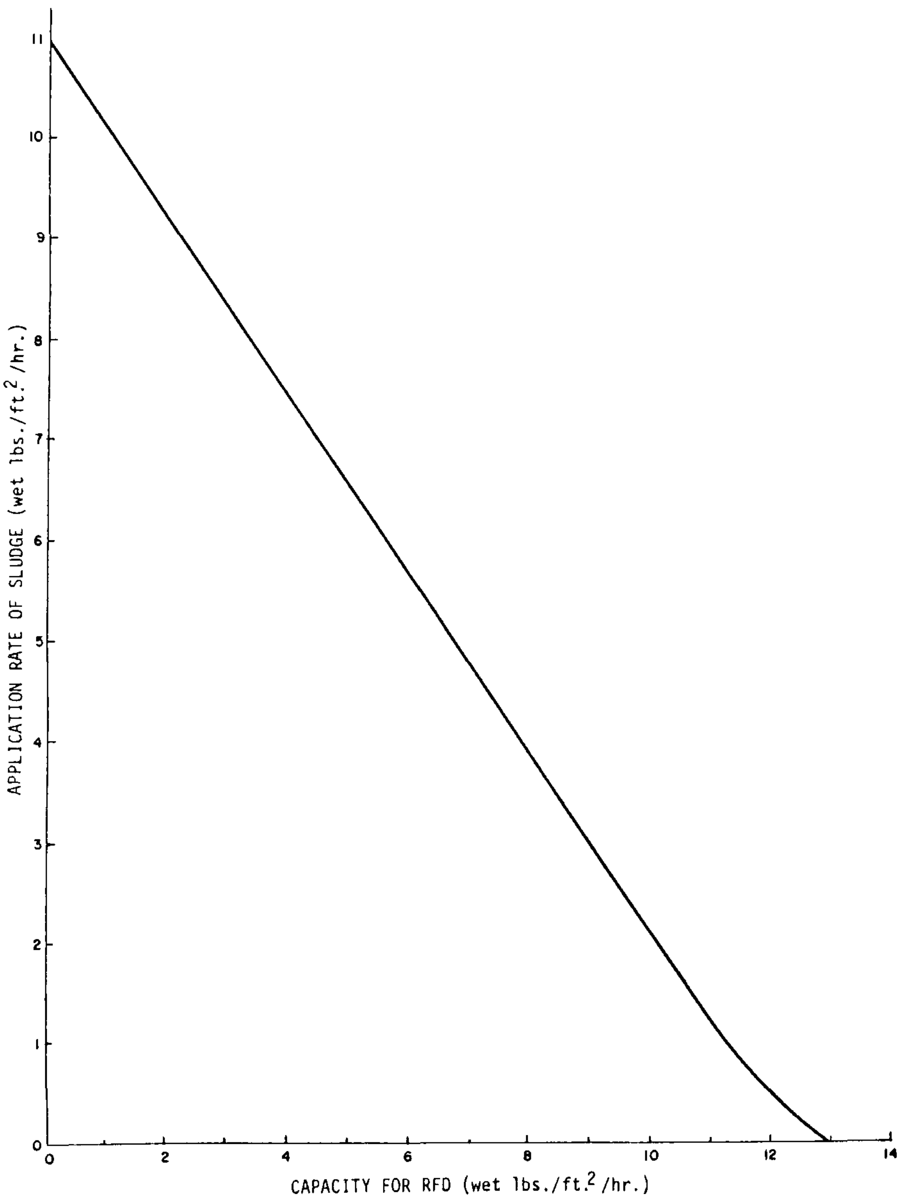

Figure 11. RDF capacity in multiple hearth furnaces in LTC (pyrolysis) mode. Source: Gordian Associates Incorporated.

(1) The freeboard area (F) of the FBF is calculated using the diameter of the furnace:

$$F = \pi r^2$$

r = radius = ½ diameter

(2) The evaporation rate (E) for the FBF can be determined from a graph supplied by Dorr-Oliver (reproduced as Figure 12) for the solids content of the sludge to be incinerated.

(3) The water evaporation capacity (W) is then calculated:

$$W = E \times F$$

(4) The capacity of the unit to incinerate sludge (C) can then be calculated:

$$C = \frac{W}{w}$$

w = percent water in sludge

(5) Using the amount of sludge (S), in wet lbs/hr that would be fed to the FBF per hour, the percent capacity that would be required to incinerate this sludge — the incineration capacity utilization (U) — is calculated:

$$U = \frac{S}{C} \times 100$$

(6) Knowing the sludge incineration capacity utilization (U) and the percentage of dry solids (S) in the sludge, the ratio of wet RDF to wet sludge (P) can be determined from a series of plots provided by Dorr-Oliver (reproduced as Figure 13).

(7) The capacity of RDF is then calculated:

$$R = P \times S.$$

Since the graph provided by Dorr-Oliver did not consider situations where the incineration capacity utilization (U) is below 25 percent, in these cases, the calculation of RDF capacity can be based on the heat release capacity (Btu/hr). (When the solids content of the feed material is high, the FBF capacity is determined by its heat release capacity rather than by its capacity to evaporate water.) The heat release capacity of an FBF with heat recovery was given as 188,797 Btu/hr/ft^2 by Dorr-Oliver. The RDF capacity is then calculated as follows:

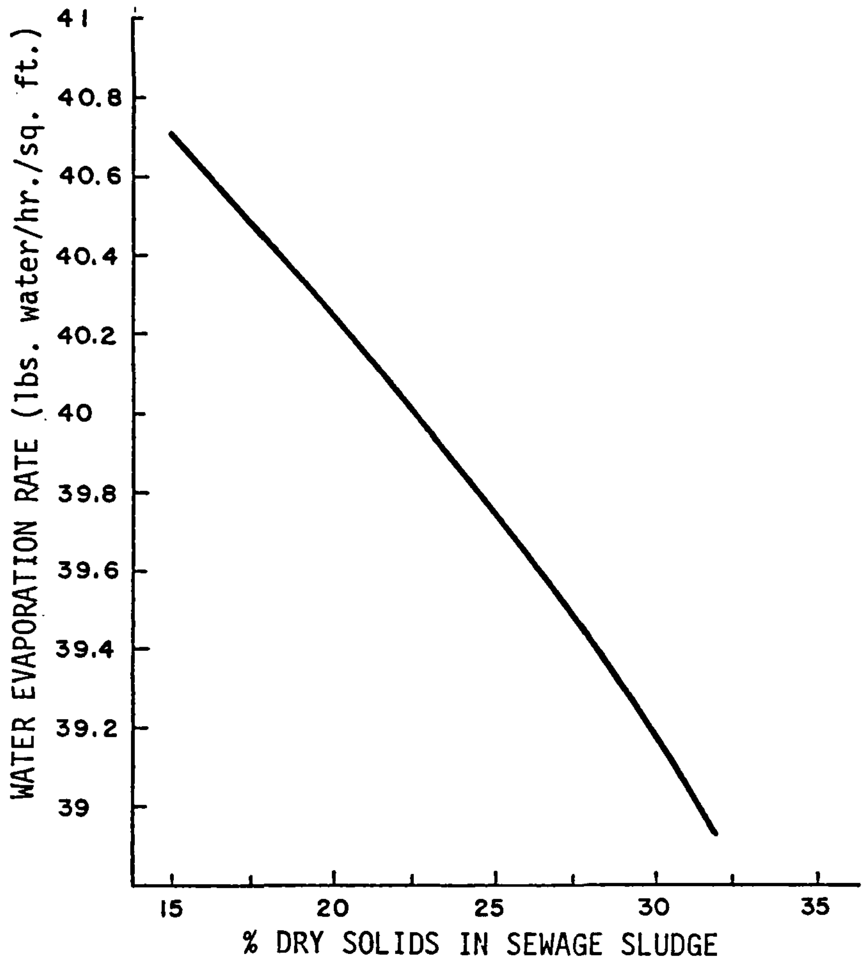

Figure 12. Water evaporation rate in Dorr-Oliver fluidized bed furnace. Source: Dorr-Oliver.

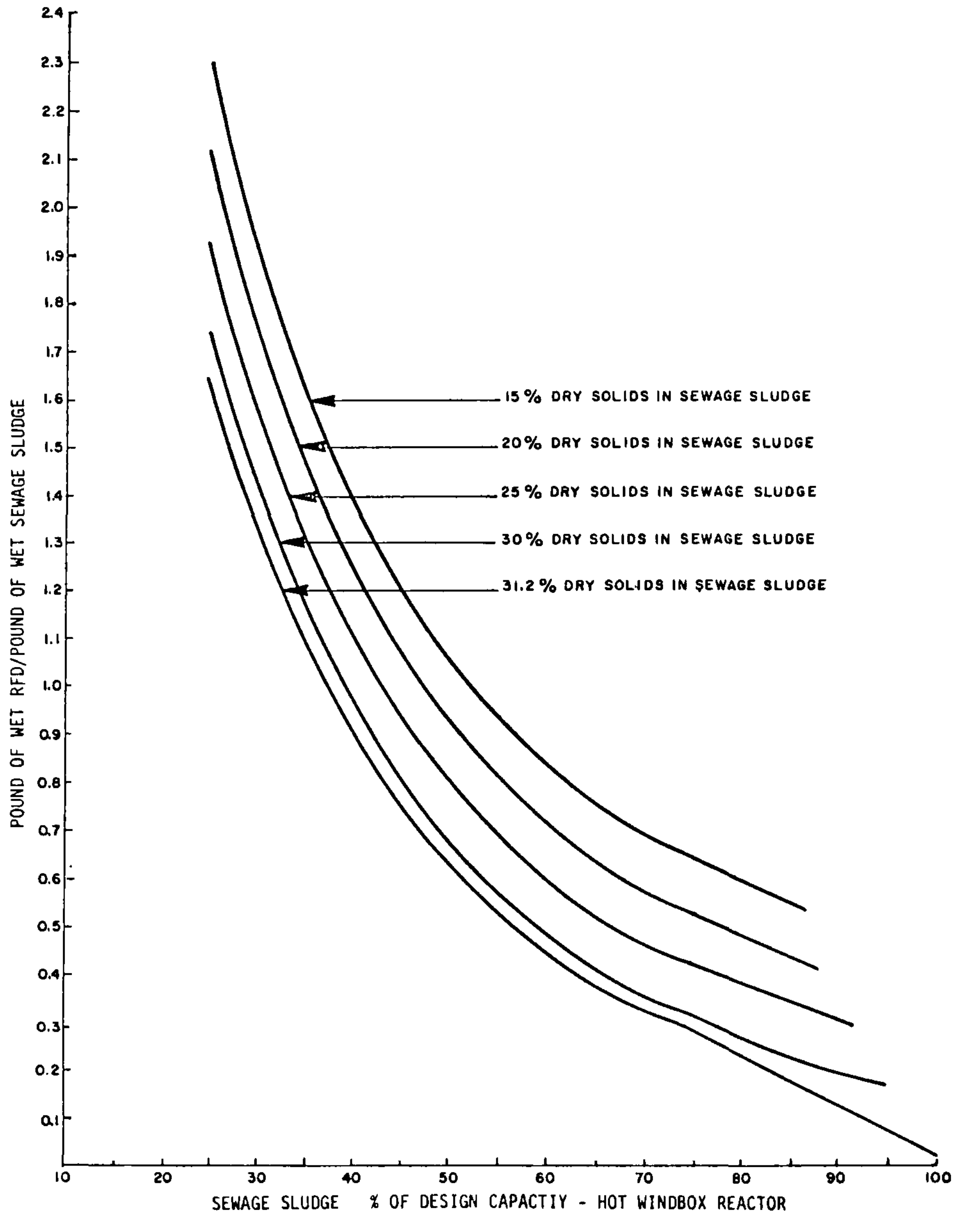

Figure 13. Ratio of wet sludge to wet RDF. Source. Dorr-Oliver.

(1) The Btu content of the sludge (H_S) is calculated using a value of 6,650 Btu/lb of dry sludge:

$$H_s = S^1 \times 6,650$$

S^1 = quantity of sludge (dry lb/hr)

(2) The remaining heat release capacity (H_r) can be found by subtraction:

$$H_r = 188,797 \times F - H_s$$

(3) Using a value of 5,000 Btu/wet lb of RDF, the RDF capacity (R) is then calculated by:

$$R = \frac{H_r}{5,000.} \quad \text{(wet lbs/hr)}$$

7. CONCLUSIONS

In order to determine the feasibility of a codisposal system at a particular location, a complete review of the system is necessary. Important considerations are:

- sludge quality and quantity,
- capital costs for the RDF plant,
- capital costs for retrofit of the sludge incinerator,
- method and cost of housing equipment,
- equipment redundancy requirements,
- operating and maintenance costs,
- uses/markets for recovered energy,
- supplemental fuel cost (for start-up and stand-by fuel),
- sludge pretreatment options,
- ash/char disposal options,
- type of operations: continuous or intermittent, incineration or pyrolysis,
- emergency methods of sludge handling, and
- institutional constraints.

As this report has documented, the codisposal of sludge and solid waste in existing multiple hearth and fluidized bed furnaces should be investigated as an alternative energy technology approach to the disposal of these wastes. Under the right circumstances, coincineration and copyrolysis are viable approaches to handling municipal solid wastes and sewage sludges. Not only are both solid waste streams disposed of in an environmentally acceptable manner, but benefits can be accrued by utilizing the waste heat or combustible gases for energy conservation. As the cost of fuel increases, the importance of energy conservation will be magnified, and codisposal will become an increasingly attractive approach to a community's sludge and solid waste problem.

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