Resource Recovery from Municipal Solid Wastes

Volume II
Final Processing

Authors

Luis F. Diaz **George M. Savage**

Clarence G. Golueke

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Authors

Luis F. Diaz
President
Cal Recovery Systems, Inc.
Richmond, California

George M. Savage
Vice President
Cal Recovery Systems, Inc.
Richmond, California

Clarence G. Golueke
Director of Research and Development
Cal Recovery Systems, Inc.
Richmond, California

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THE AUTHORS

Dr. Luis F. Diaz received his B.S. degree in Mechanical Engineering from San Jose State University. He then entered the University of California (Berkeley) where he received his M.S. and Ph.D. degrees in the area of Environmental Engineering. Dr. Diaz was instrumental in developing the solid waste processing facility at the Richmond Field Station of U.C. Berkeley. During the course of developing this facility, Dr. Diaz played a major role in developing the fiber recovery system for extracting cellulose fiber from municipal solid waste. Dr. Diaz then undertook an extensive study of biogasification of various waste fractions. This work dealt with the digestion of organic waste fractions and sludges. This work later expanded to include the study of integrated energy-agro-waste systems. This dealt primarily with the use of waste heat as an energy source in an agricultural complex integrated with a wastewater treatment facility.

Dr. Diaz now serves in the capacity of President of Cal Recovery Systems. He has served as a consultant to various municipalities and governmental agencies, as well as leading the work of Cal Recovery Systems in various international projects. He has given numerous invited lectures at technical meetings and has served as the co-organizer of several seminars. He has also worked as consultant to international agencies such as the United Nations (WHO and UNIDO), the World Bank, the Asian Development Bank, and the U.S. Agency for International Development.

George Savage was born in 1948 in Faribault, Minnesota. He received his B.S. and M.S. degree in Mechanical Engineering at the University of California (Berkeley). He currently serves as Vice President of Cal Recovery Systems. He has been actively involved in the development of waste processing technology. He conducted pioneering efforts in the areas of developing test methods and procedures and of testing of waste communition, air classification, screening, and densification systems. He has conducted field testing programs at all of the major resource recovery plants in the U.S. In addition, he has advised equipment manufacturing companies on improvements and devices for recovering various waste fractions from the solid waste stream.

He is a member of several technical societies and has served as a lecturer on various aspects of solid waste management at several national conferences.

Dr. Clarence G. Golueke, Ph.D., has been the Director of Research and Development at Cal Recovery Systems, since 1978. Prior to that date he was a member of the faculty of the Division of Sanitary Engineering of the Department of Civil Engineering, University of California.

Dr. Golueke received his B.A. degree from St. Louis University, Illinois and his M.A. degree from the University of Illinois in Urbana. He received his doctorate of philosophy from the University of California at Berkeley.

He is a member of several professional and technical societies and the honor society of Sigma Xi. He was the recipient of the A.M. Wellington Award (American Society of Civil Engineers) in 1966.

His professional activities include service as consultant to federal, state, and local governments and to industry on various aspects of solid and liquid waste management and environmental control.

Dr. Golueke is the author or co-author of more than 100 publications, a large portion which are concerned with biological systems of resource recovery from solid and liquid wastes. He is also on the boards of five scientific journals.

RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTES

Luis F. Diaz, George M. Savage, and Clarence G. Golueke

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Chapter 1

INCINERATION

I. INTRODUCTION

A. Methods of Thermal Energy Recovery

Energy can be recovered directly from municipal solid waste (MSW) as heat, or the waste can be processed into a storable fuel. Direct recovery is accomplished by mass burning. Indirect recovery can take several forms and involve many different procedures, each of which may be fitted into one of the three categories: physical, thermal, and biological. In physical processing, the MSW is processed such that its combustible and noncombustible fractions are separated one from the other. The physical characteristics of the combustible fraction are further altered to enhance its utility as a fuel. The resulting combustible product commonly is termed "refuse-derived fuel" or simply "RDF". In thermal processing, usually termed "pyrolysis", the goal is to convert the waste almost entirely into a combustible gas. However, the usual outcome is a collection of solid, liquid, and gaseous products that are more or less combustible. The product from biological processing may be either gaseous or liquid, depending upon the system used. Descriptions and discussions of biological and thermal processing are presented in detail in other sections of this book.

Of the several thermal energy recovery processes, mass burning and RDF production are regarded as having the greatest potential, even though several obstacles may impede the attainment of the full realization of that potential. Some of the obstacles are technical in nature; others are related to marketing. Both types of obstacles can be overcome in part by using the heat energy to generate steam and then market it (steam) off-site for the generation of electricity, for heating and cooling, or for a combination of the two. However, such an approach is circumscribed by limitations that restrict its application to only a few localities. Consequently, public officials, particularly in large metropolitan areas, are forced to go on to the next potential solution, namely, on-site generation of electricity. A difficulty attending the generation of electricity is that the community or agency must construct a power plant and install transmission and distribution equipment. In short, the community would have to assume the functions of an electrical utility. Two alternatives to steam and electrical generation are (1) sell the fuel (RDF) to individual customers for use in power generation by them; or (2) sell the fuel to the local utility. The first approach could prove to be quite costly. On the other hand, with the second approach, not only would the utility benefit through the use of an inexpensive fuel, the disposal problem would also be significantly lessened. However, it should be noted that even though it would seem that utilities would be ideal users of RDF, certain technical, economical, and institutional issues remain to be resolved before the utilization becomes a common practice.

Incineration

The use of incineration as a means of disposing of municipal refuse is by no means a recent one, as is attested by the fact that it was described as a viable and ongoing practice in a book published in 1901.[1] The early interest in incineration stemmed from the fact that in terms of disposal, a maximum volume or weight reduction could be achieved. In the U.S. this early period of promise came to an all but complete end in the mid 1960s, a time when extremely few of the early incinerators were as yet in operation. The responsible problem was mainly one of an excessively large emission of particulates.

However, it should be pointed out that the early popularity continued to be strong in western European nations. A major contributing factor to the continuation of the acceptance in Europe was the practice prevalent there of incorporating energy recovery into the incineration process. A belated recognition of the energy potential of incineration finally is bringing about a resurgence of interest in the practice in the U.S. An important factor in this recognition is the realization of the continuing increase in the heating value of refuse being brought about by a corresponding rise in the ratio of plastics and paper to food preparation wastes and garden debris. In recent years, Japan has taken the lead over Europe and the U.S. in terms of numbers and capacities of incinerators.

II. TECHNOLOGY

A. General Design Features

Key features of an incineration facility are (1) the tipping area; (2) the storage pit; (3) the equipment for charging the incinerator (typically, a crane or a front-end loader); (4) the combustion chamber; (5) the stack emission cleaning equipment; and (6) the boiler, if energy is to be recovered.

In a typical incinerator operation, the municipal solid waste (MSW) is discharged from collection vehicles either onto a tipping floor or directly into a storage pit. The pit serves a twofold purpose: (1) It permits the storage of an amount of refuse sufficiently large to ensure, if desired, a 24-hr/day, 7-day/week operation of the incinerator; and (2) it provides an area where large noncombustible items can be removed, and the remaining wastes can be blended into a fairly uniform and constant charge. The waste is transferred from the pit to a charging hopper. The charging hopper is designed to maintain a continuous feed of waste into the furnace. The waste falls from the hopper into the furnace and onto the furnace stoker, where combustion takes place.

The furnace is the essential element of an incineration system. It may be rectangular or cylindrical in shape, and may consist of only one chamber or may have a primary and a secondary chamber. The principal function of the secondary chamber is to provide the conditions needed to complete the combustion process. The size and shape of the furnace usually are determined by the manufacturer, and usually are based upon a number of parameters, among which are solids and gas flow rates, residence time, and bed depth. The temperature in the furnace commonly is maintained at roughly 900 to 1000°C.

A stoker is a series of grates provided with openings through which air can be passed. Generally, grates are movable (vibrating, rocking, and reciprocating). The movement of the grates serves to agitate the refuse and thereby promote combustion, as well as ensure the removal of the residue from the furnace.

Air for combustion is forced into the furnace through and around the grates and through the sides or through the roof. Air forced through and around the grates is known as "underfire air", and air forced through the sides and roof, not surprisingly, bears the designation "overfire air". Overfire air typically is introduced through jets positioned at specific points in the furnace. It is used to regulate combustion gases driven off during the incineration of the refuse.[2] The flow of the air and combustion gases is controlled by forced- and induced-draft fans to provide from 50 to 100% excess combustion air. Air is forced into the furnace by means of forced-draft fans, whereas it is drawn in by means of induced-draft fans. Both types of fans are used in modern combustion units. Central overfire and underfire air is provided by the forced-draft fans, and the flue gases are exhausted by the induced-draft fans.

B. Classification

Incinerators may be classified on the basis of: (1) the recovery or nonrecovery of energy; (2) the state in which the residue (e.g., slag and ash) emerges from the combustion chamber; and (3) the shape and number of furnaces (e.g., rectangular and multiple). Energy is recovered by way of the introduction of a waste heat boiler for steam generation. Incinerators designed for energy recovery can be classified into several groups. Of the types, the waterwall and the modular incinerators have been the ones most used in the U.S.

III. WATERWALL INCINERATORS

The application of the waterwall furnace, originally developed for the combustion of low-grade coal, was a response to the need for combustion chambers more efficient than those of earlier refuse incinerators. The earlier incinerators were designed mainly for disposal, and energy was a minor consideration. The inferior design together with the relatively low heating value of refuse generated at that time resulted in a release of thermal energy barely sufficient to complete the combustion of the wastes. On the other hand, the design of the waterwall incinerator is such that combustion efficiency is promoted and energy recovery is facilitated. Moreover, the incinerator can be readily modified to minimize the emission of air pollutants.

The waterwall furnace began to come into use for incinerating urban wastes in the early 1960s. Thereafter, its popularity spread rapidly throughout Europe with the result that in the succeeding years several hundred units were built that were within a size range of 120 to 1600 Mg/day (130 to 1800 TPD). In sharp contrast, only a few waterwall incinerators have been built in the U.S. The popularity of the unit in Europe is due to a number of factors, among which are lack of land suitable for land disposal, government subsidies, availability of markets for steam, and relatively high costs of fossil fuels.

A. Description

The overall incineration system is essentially the same as that of a "conventional" refractory-lined furance. The main difference in the system described herein is in the furnace design. In this case, the walls of the furnace consist of closely spaced tubes through which water circulates. The water circulating through the walls absorbs thermal energy radiated from the burning wastes. The water cools the furnace walls and simultaneously reduces the temperature of the exhaust gases, thus decreasing the volume of flue gases to be treated. More energy is recovered from the combustion gases in waste heat boilers by producing steam. Waterwall boilers can be designed to produce high pressure, superheated steam. Air pollution control equipment typically used for treating the waste gases includes wet scrubbers and electrostatic precipitators.

B. Performance

Certain key factors must be considered in an evaluation of the performance of an incinerator, regardless of type. They include weight and volume reduction, composition of flue gas, quantity and composition of residues, and boiler efficiency. With the data on these factors it is possible to determine at what percent of capacity a unit is operating, the temperature and pressure of steam being generated, the quantity of combustible matter present in the residue, and the type and degree of treatment required for the residues prior to final disposal.

Performance characteristics that may be expected of a waterwall furnace are exemplified by those of the waterwall unit in the Nashville, Tennessee incineration facility.[3] Data collected in the operation of the facility indicate that when it was operated at full capacity (325 Mg/day (350 tons/day)), the steam production amounted to 49,000 kg/hr of 2525-kPa/300°C (107,000 lb/hr of 366 psi/573°F) steam. This production was equal to about 98% of the plant's steam producing capacity, and a boiler efficiency of about 72%. Refuse burned in the Nashville incinerator had an "as-fired" heating value of about 11,600 J/g (5000 btu/lb), and was reduced in weight by slightly more than 78%. According to the data on air emissions, the average uncontrolled particulate loading was 3.35 g/Nm^3 (1.46 g/dscf) at 12% CO_2, and the NO_x concentration in the flue gas, 146 ppm at 9.5% O_2.

C. Problems

The design of a modern incineration facility has become a very complex undertaking and can pose a number of problems. In particular, there are three potential problems that must be given special attention. These are (1) system availability; (2) fouling of heat transfer surfaces; and (3) corrosion.

The system availability of waterwall furnaces characteristically is only about 80%. The limitation on availability is mainly a result of the need to frequently clean out grates that have become clogged with partially burned or noncombustible materials in the fuel. The frequency of the downtimes necessitates a duplication of equipment (i.e., 100% "standby"). Thus, two 62- or 72-Mg/day waterwall units would be recommended for an operation in which 91 Mg (100 tons) of refuse had to be burned per day. In addition, in order to meet maximum reliability in the case of energy production, the furnace should be capable of firing a fossil fuel.

Almost all of the heating surfaces are subject to fouling. This is caused by the deposition of slag and fly ash. Research efforts, primarily on coal, have demonstrated that ash deposition can be alleviated by modifying the furnace design, by the introduction of additives, and through the improvement and proper use of boiler-cleaning equipment. Among the modifications in design are those geared to the provision of sufficient volume and detention time to achieve complete combustion of all combustible solids and gases, and of enough heat absorption by the furnace to dry the ash before it comes in contact with the boiler tubes. The heat transfer surfaces in convection passes, particularly those in the high-temperature zones, should have wide spaces.

Corrosion is a major technical problem in the operation of refuse-fired boilers. Basically three types of corrosion can take place: (1) corrosion due to the existence of a reducing atmosphere; (2) halogen corrosion; and (3) low-temperature corrosion.

Corrosion caused by a reducing environment usually takes place in mass burning facilities. It is precipitated by the products of partial combustion which are a consequence of a reducing atmosphere. A reducing atmosphere may be a direct result of poor distribution and stratification of air or fuel, or of both. These conditions could promote the formation of carbon monoxide and hydrogen sulfide. The two gases can react to remove the protective coating on the furnace tubes and expose the tubes to additional corrosion.

Halogen corrosion is attributed largely to the combustion of Cl-containing materials (e.g., PVC, NaCl) in the refuse. Although halogen corrosion has been recognized for many years, a certain amount of disagreement exists as to the mechanism involved and to the temperatures at which it takes place.

Points of low-temperature corrosion are those at which the flue gas comes in contact with surfaces that have a temperature lower than the dew point of water vapor. HCl and SO_x dissolve in the water of condensation to form corrosive acids. Dew-point temperatures may be encountered in air pollution control equipment, in air heaters,

Table 1
MANUFACTURERS OF WATERWALL INCINERATORS

European manufacturer	U.S. representative/manufacturer
Von Roll (Zurich)	Wheelabrator-Frye[a]
Josef Martin (Munich)	Universal Oil Products[a]
Voklund (West Germany)	Waste Management[a]
Voklund (West Germany)	Trans Energy Systems[a]
Voklund (West Germany)	Browning—Ferris Industries[a]
	Babcox and Wilcox[b]
	Combustion Engineering[b]
	E. Keeler[b]
	Foster Wheeler[b]
	Zurn Energy Systems[b]
	Riley Stoker[b]
	Detroit Stoker[b]

[a] Market complete systems.
[b] Market components only, e.g., boilers and stokers.

and in economizers. Low-temperature corrosion can, of course, pose a serious problem when the boiler is taken out of service.

D. Manufacturers

Waterwall combustion systems and components are available from several manufacturers in Europe and in the U.S. In Table 1 is a list of manufacturers in the U.S. and of European manufacturers who have representatives in the U.S.

E. Types of Marketed Systems

The three types of waterwall combustion systems presently on the market are distinguished from one another on the basis of the form in which the refuse is burned. The form can be one of the following three (1) raw ("as-received") refuse; (2) shredded refuse; and (3) refuse derived fuel (RDF). In the first type, also known as "mass" or "bulk" incineration, the raw or as-received municipal solid waste is dropped onto moving grates which move the refuse through the furnace. Inert material falls off the end of the stoker and is quenched with water. The cooled residue is then stored or transported to a truck for final disposition. In the second system "as-received" MSW is coarsely shredded and then is mechanically or pneumatically introduced into the furnace and incinerated on a moving grate. This method of combustion is termed "semisuspension firing", because the waste is ignited as it falls through the chamber and, hopefully, its combustion is completed on the grate. A more extensive processing of MSW results in the production (i.e., separation) of a light, combustible fraction, which is the refuse-derived fuel or RDF described in another section. RDF can be used directly in a boiler, or it can be used as a supplemental fuel in boilers especially designed to fire coal, wood, or other biomass.

1. Units for Burning Unprocessed Refuse

Energy recovery from as-received refuse in waterwall incineration has the longest record of application in that it has been used for over 20 years in the U.S. and Europe. Prompted by the more or less successful records of the waterwall combustion systems in Europe, interest in the potential of the system for energy recovery is intensifying in the