SOLID WASTES FOR POWER GENERATION

Swithenbank J, Nasserzadeh V and Goh R
Sheffield University Waste Incineration Centre, UK

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Summary

Energy production, waste disposal, and the minimization of pollution are key problems that must be addressed for sustainable cities of the future. Furthermore, waste management has become a major concern worldwide, and incineration is now being used increasingly to treat waste that cannot be recycled economically. For the foreseeable future, fossil fuels will be the major source of energy, but because of the dwindling resources of oil and gas and the need for fuel security, coal will become the major source of energy for heat and power in due course. The need for clean coal technology precludes the construction of new conventional pulverized fuel power stations in developed countries, and new technology is required. The total heat content of municipal waste in a developed country such as the United Kingdom now totals about 30% of that of the coal used for present needs. The current best technology for the

low pollution disposal of this waste is incineration with the production of electricity, and heat for district heating. Unfortunately, current electrical generation efficiencies for coal burning plant and waste incinerators are only about 37% and 20% respectively.

A detailed understanding of the combustion of either waste or fossil fuels is required in order to optimize the efficiency of future power plants.

The combustion of conventional well-specified fossil fuels is a very complex process since it involves two-phase turbulent reacting flow including radiant heat transfer. Incineration is even more complex, since the waste is poorly specified and its composition varies from moment to moment. In the past, the design of incinerators has not been based on fundamental understanding and modeling of the process, and empirical rules have been used.

Over the last few years, computational fluid dynamics (CFD) has provided a means to model the freeboard region in a conventional municipal solid waste incinerator, but the open literature contains no rigorous fundamentally based model of the bed region. The prediction of the flow composition emerging from the bed region is particularly important since it provides the “upstream” boundary condition for the flow calculations in the freeboard. For example, the calculation of the subsequent history of heavy metals requires knowledge of their emission rate from the burning bed.

The processes in the bed include drying, pyrolysis, oxidative burning, and gasification of the char. Furthermore, the movement of the grate is designed to mix the waste as it burns. The emission of gases from the surface of the bed is very nonuniform, with oxygen emitted from either end of the bed, and organic compounds and carbon monoxide from the center. The calculation of flow and combustion in the freeboard using CFD can quantify the consequences of design concepts; however, guidelines are needed to devise specific concepts that are worthy of investigation.

Thus the computer cannot “invent” a design but it can quantify the results of ideas. Incinerator design thus requires a judicious combination of fundamental combustion science, ingenious engineering guided by an understanding of the mixing process, and last but not least, practical experience of previous failures and successes.

The optimum process to generate electrical power from these combustion systems requires an understanding of the underlying thermodynamics. In addition to a simple boiler/steam turbine system, various pyrotechnology systems can be considered, some of which integrate the use of fossil fuels with waste processing in order to provide superior electrical power production efficiencies.

One integrated pyrotechnology system is conceivable in which the steam from a conventional “mass burn” waste incinerator is gasified with coal to yield a mixture of (environmentally clean) carbon monoxide and hydrogen that in turn is used in a combined gas turbine/steam cycle. The dramatic effect on pollution control is perhaps more significant than the efficiency improvement. The massive investment in flue-gas cleanup in a conventional pulverized fuel power plant is no longer required. Sulfur, in particular, is removed in salable, elemental form in place of landfill of the vast amounts of calcium sulfate presently produced. Furthermore, a high temperature heat exchanger could be used in a recuperative gas turbine to achieve generation efficiencies of 60% without the use of a steam cycle.

In addition to flue-gas clean up, the need to clean or eliminate all discharges from the overall waste, energy and pollution control (WEP) plant requires the elimination of liquid effluents and conversion of ashes to usable products by thermal treatment. High waste transport costs and their low pollution lead to the conclusion that plants based on these technologies can be located acceptably within cities. This not only reduces the electrical distribution losses but also permits the “waste” heat to be used in the plant locality, resulting in overall combined heat and power (CHP) efficiencies greater that 80%.

1. Introduction

Major problems facing modern society include the provision of energy with the minimum generation of pollution, and the environmentally friendly disposal of waste. The objective is to develop and optimize future waste, energy and pollution management systems, including any synergistic advantage resulting from integrating these technologies. This article presents some key technologies and some potential systems in order to provide an understanding of the strategy for the eventual introduction of integrated waste/energy and pollution management centers. Thus a long-term objective is to achieve the transition to sustainable cities through the evolution of the enabling technologies. The anticipated result is an integrated and highly efficient low-pollution system to provide heat and electricity for towns and cities, and simultaneously dispose of waste that it is not practicable to recycle or reuse.

The fact that electricity is one of the most convenient forms of energy for use in industry and the home accounts for the disproportionate swing towards electricity in the growing energy market. At present, most of the electricity is produced from fossil fuels such as coal, which is burned as pulverized coal in electricity generating station boilers. These boilers produce steam that drives turbines that in turn drive the electricity generators.

Many modern electrical power generation systems use gas (or oil) fuel in a gas turbine, followed by a steam boiler heated by the gas turbine exhaust, to yield electricity generation from both the gas turbine and the steam turbine. The efficiency of such a system can approach 60%; however in this case a premium fuel is required.

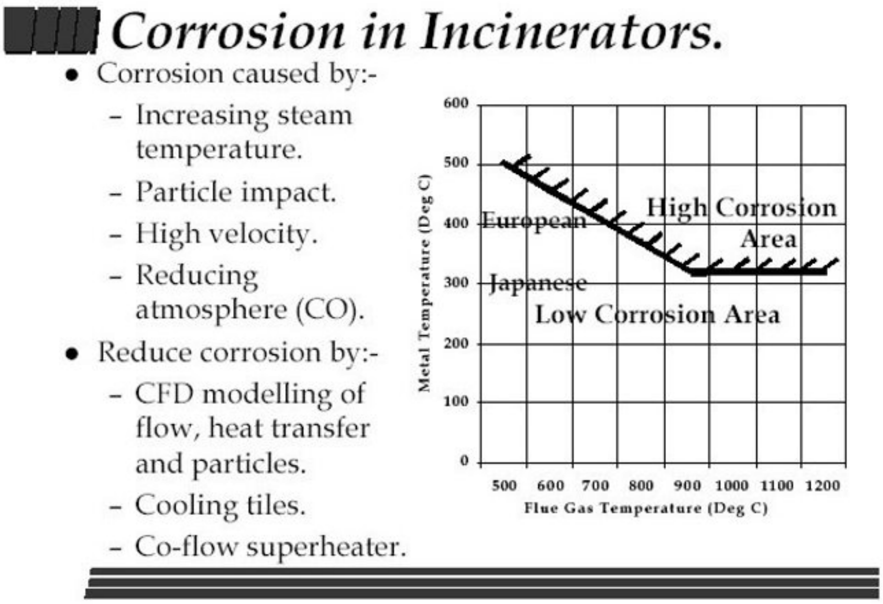
2. Waste as Fuel

Developed countries produce up to one tonne of municipal waste per person per year. The high cost and large energy requirement of reuse and recycling limit the application of these apparently desirable techniques to a few specific constituents of the waste. The remaining option is to recover as much of the energy content of the waste as possible. It is important to recognize that much of the waste consists of organic materials such as wood, paper, and fabrics. Because these materials form part of a biocycle, their combustion does not contribute to the net output of carbon dioxide to the atmosphere.

Furthermore, any plastics that cannot be recovered from the waste and reused economically can be burned to recover their calorific value. They thus displace oil or other fossil fuels that would otherwise have to be burned. When the energy content of wastes can be recovered cleanly and efficiently, their combustion represents a reuse of material and thereby contributes to our energy needs in an environmentally friendly manner.

This approach to waste management can be contrasted with open dumping of rubbish. Decomposition of landfill waste results in the emission of the powerful greenhouse gas, methane, and the potential leakage of toxic leachates into groundwater. The environmentally unfriendly nature of landfill has been acknowledged in many countries by the imposition of legal and tax penalties. The landfill tax of £10 per tonne currently charged by the UK government is now causing many UK local authorities to reassess their waste management strategies.

The total amount of municipal waste in the United Kingdom is currently about 30 million tonnes per year. Its energy equivalent of about 10 million tonnes of coal per year can be compared with the total UK coal consumption of 30 to 40 million tonnes per year. Thus the energy available in waste represents a significant fraction of the energy needs of a typical country. Unfortunately, combustion of municipal solid waste (MSW) and many other wastes results in corrosive flue gases that attack boiler components such as superheater tubes. The normal method to convert the energy in waste into electricity is via a boiler, which makes steam, followed by a turbine/generator set. The efficiency of conversion of waste energy into electricity depends strongly on the steam temperature. Unfortunately, due to the rapid corrosion that occurs when the steam temperature is high, the efficiency of current waste to electricity plants is only about 20%. The corrosion is a function of both boiler flue gas temperature and wall temperature, as shown in the Figure 1.



Corrosion in Incinerators.

- Corrosion caused by:-
  - Increasing steam temperature.
  - Particle impact.
  - High velocity.
  - Reducing atmosphere (CO).
- Reduce corrosion by:-
  - CFD modelling of flow, heat transfer and particles.
  - Cooling tiles.
  - Co-flow superheater.

Figure 1. Corrosion in incinerators

In Europe the economics of energy from waste typically results in higher steam temperatures than in Japan. However this is at the price of more frequent superheater tube maintenance.

3. The Energy Content of Waste

The energy content of a fuel is measured in terms of its calorific value (CV), expressed as Joules per kilogram. In the case of coal fuel, a typical value is approximately 30 MJ kg^{-1}, while for oil the value is about 40 MJ kg^{-1}. These values can be compared with that for MSW of about 10 MJ kg^{-1}. In fact the calorific value of MSW has increased about 20% since the early 1970s, because of factors such as the decreasing quantity of ash in the waste from coal fires, and the increasing proportion of dry packing material. Nevertheless, the principal cause of short-term fluctuation in the calorific value (CV) of MSW is variations in its moisture content.

A typical municipal waste incinerator installation consists of one or more individual streams, each of which consumes between 10 and 25 tonnes of waste per hour. Thus a typical two-stream plant would consume 200 000 tonnes per year for a city of about 400 000 inhabitants.

Assuming that the CV of the waste is 10 MJ kg^{-1}, the total energy output of such a plant can be evaluated very simply since 1 tonne (i.e. 1000 kg) per hour yields:

$1000 \times 10 / 3600 \text{ MJ sec}^{-1}$ (MW) = 2.8 MW per tonne of waste per hour

This corresponds to a continuous output of more than 150 watts per person. About 75% of this total energy can be used to generate a combination of electricity and district heating/cooling. It is therefore clear that the energy-efficient incineration of waste can provide a large proportion of the energy needs of a city population.

The above facts explain the feasibility and desirability of the use of solid wastes for the combination of power generation and district heating, which is known as combined heat and power (CHP).

4. Incineration Principles

The combustion of waste in an incinerator is arguably one of the most complex combustion problems known. The design and control of such a combustion device poses many problems since there is no satisfactory model of the system as a whole. In particular, a process as basic to its operation as the combustion on the grate has not yet been fully elucidated. At present, a typical design "equation" for the combustion on the grate is merely that the burning rate is about 400 $kg\,m^{-2}\,h^{-1}$. Clearly this is a gross oversimplification of the many complex processes taking place simultaneously. This poor state of knowledge can be contrasted with the dramatic progress that has been made recently in the modeling of pulverized coal, gas, and liquid fuel combustion systems, which has resulted in impressive reductions in the emission of pollutants without a sacrifice of efficiency.

The fundamental analytical approach typically involves identifying the governing differential equations for all of the relevant processes, then solving these equations simultaneously, often using a numerical code in which the equations are converted from differential into algebraic form. This generic approach has resulted in fundamentally based commercial fluid dynamic codes that have developed remarkably rapidly. They have proved to be very versatile in their applicability to a wide range of engineering design problems.

The primary objective of present incinerator research programs is to identify the appropriate set of governing equations for combustion on the grate of an incinerator and to develop and validate a procedure for solving these equations. A key aspect of incinerator bed combustion is the mixing of the solid material on the grate. Experiments are required to characterize and quantify this mixing process so that it can be modeled accurately during the numerical solution of the governing equations.

The efficiency of incinerator combustion, and particularly the residual carbon in ash that determines the suitability of the ashes for reuse, depends critically on this mixing process. There are several significantly different types of grate employing distinct waste mixing strategies that are used in current MSW incinerator design. The four most common are:

1. The stepped grate, in which the burning waste is mixed as it falls from one level of the grate to the next, thus giving oxygen access to the unburnt material.
2. The reciprocating grate (and its variants), in which the grate bars reciprocate, resulting in local mixing of the waste.
3. The rotating cylinder grate, which consists of a series of slotted rotating drums. The waste mixes as it tumbles from one drum to the next.
4. The rotating kiln.

4.1. Mathematical Modeling of the Gas and Particle Flow

Over the last few years, computational fluid dynamics (CFD) has provided a means to model the freeboard region in conventional municipal solid waste, clinical waste, sewage sludge, and special waste incinerators. The prediction of the flow composition emerging from the bed is particularly important since it provides the “upstream” boundary condition for the flow calculations in the freeboard. For example, the calculation of the subsequent history of heavy metals demands precise knowledge of their emission rate from the burning bed.

CFD is arguably the most important development in modern engineering practice, since it is having such a great influence on research, design, development, and production. Almost all CFD codes were originated by combustion technology research groups as a result of the effort to understand the complexities of the process by solving the set of interacting governing differential equations. Thus combustion technology can claim to be the father of CFD.

Developments in CFD have always gone hand-in-hand with developments in digital computer technology, and even a basic PC is now a very powerful machine. What of the future of CFD? In a few short years, the range of applications of the codes has increased dramatically. In response to demand, their capabilities are still expanding. For example, the need for the user to be involved in internal details such as grid generation is gradually receding. Nevertheless, engineers must still understand the fundamentals of fluid dynamics, and exercise their ingenuity, since CFD can only be used to quantify ideas.

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Biographical Sketches

Professor **Jim Swithenbank** has been a member of the Department of Chemical and Process Engineering at the University of Sheffield since 1961. During that time his research interests have covered every field of combustion from rocket motors through advanced concepts of power generation and clean coal technology to waste incineration. He is currently director of the Sheffield University Waste Incineration Centre. A prolific researcher with over 200 refereed papers to his credit, he is an internationally respected consultant to the combustion and incineration industry. his research interests include industrial furnaces, physical and mathematical modeling, optical diagnostics (laser Doppler anemometry, holography, tomography), gas turbines, rockets, ramjets, cyclone design, fluidized beds, droplets and sprays, pool fires, IC engines, feedback control, energy problems, and waste incineration. He is the co-inventor of the

Malv8ern Instrument and the original FLUENT CFD package. He is a Fellow of the Royal Academy of Engineering and a member of numerous international combustion committees. He was president of the Institute of Energy 1986–1987 and has served on many national and international committees.