ENVIRON IMPACT ASSESS REV 1989;9:199–222 

# COMBUSTION CONTROL OF TRACE ORGANIC AIR POLLUTANTS FROM MUNICIPAL WASTE COMBUSTORS

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*The US Environmental Protection Agency (EPA) is considering the use of combustion techniques for controlling air emissions of chlorinated dioxins, chlorinated furans, and other trace organics from municipal waste combustion (MWC) facilities. Recommendations for good combustion practice (GCP) for controlling trace organics were initially published in June 1987. These recommendations provided key criteria for the design, operation, control, and verification (compliance testing) of three types of combustors: waterwall mass burn, refuse-derived fuel, and modular starved-air combustors. This paper provides a summary of the technical considerations on which the initial GCP were based. It also discusses current activities in revising the initial GCP and in developing GCP for other classes of municipal waste combustors. GCP is one of the pollution control options being considered for MWC air pollution standards. Standards which are to be applicable to new MWC facilities, and emission guidelines which are to be applicable to existing MWC facilities, are to be proposed in November 1989 and promulgated in December 1990.*

On July 7, 1987, an advance notice of proposed rule making (ANPRM) was published in the *Federal Register*. This notice from the Environmental Protection Agency (EPA) announced its intentions of regulating air pollution emissions from municipal waste combustion (MWC) facilities under Section 111 of the Clean Air Act. This decision was based, in part, on a comprehensive study of municipal waste combustion (US EPA 1987a). This study involved the evaluation

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This paper has been reviewed in accordance with the US Environmental Protection Agency peer and administrative review policies and approved for presentation and publication.

of health and environmental risks associated with municipal waste combustion and an assessment of technology for limiting emissions of criteria and hazardous air pollutants, either by control of the combustion process or by the use of flue gas cleaning technology (US EPA 1987b; Seeker, Lanier, and Heap 1987; Sedman and Brna 1987).

Concurrently with this ANPRM, EPA's Office of Air Quality Planning and Standards (OAQPS) issued operational guidance to EPA's regional offices concerning approval of applications for permits (under prevention of significant deterioration and nonattainment new source review) to construct new incinerators prior to promulgation of the revised New Source Performance Standards (Emison 1987). These guidelines specified that all new incinerators use good combustion practice and the appropriate flue gas cleaning technology to ensure adequate control of air pollution emissions. Appropriate flue gas cleaning technology was defined as the use of a dry scrubber (spray dryer absorber) in combination with a fabric filter or electrostatic precipitator (ESP). Although the criteria for achieving good combustion were not defined by OAQPS in the operational guidance, the regional offices were referred to recommendations for good combustion provided in the report entitled Municipal Waste Combustion Study: Combustion Control of Organic Emissions (Seeker, Lanier, and Heap 1987).

This presentation provides a summary of the EPA's original recommendations for achieving good combustion in MWC facilities, and the status of activities in developing final recommendations associated with the standards scheduled for proposal in November 1989.

## Original Recommendations for Good Combustion

### *Background*

In response to requirements of Section 102 of the Hazardous and Solid Waste Amendments of 1984 and to petitions filed by the Natural Resources Defense Council and the States of New York, Connecticut, and Rhode Island, the EPA conducted a comprehensive study of air pollution from MWC facilities. This study was documented in nine volumes, the summary volume being a report to Congress (US EPA 1987c). Other volumes included reports dealing with the following: the combustion control of organics, flue gas cleaning (FGC) technology, the costs of FGC, sampling and analysis techniques, health effects and risks associated with exposure to MWC emissions, MWC emission data, a characterization of MWC facilities, and a study of recycling. Based on the results of this study, it was determined that there is a need for additional regulation of MWC emissions from both new and existing facilities under Section 111 of the CAA. This decision was based in part on the facts that: (1) new MWCs are likely to be significant sources of criteria pollutant emissions; (2) MWC emissions contain a wide variety of constituents, including chlorinated dioxins (CDD), chlorinated furans (CDF),[1] other potentially toxic organics, heavy metals, and acid gases that can have adverse effects on public health and welfare; and (3) the MWC industry has a potential for significant growth over the next 20 years.

Optimal control of emissions from MWC was deemed to result from a dual application of good combustion control techniques and appropriate flue gas cleaning technology (US EPA 1987a). The capabilities of various flue gas cleaning techniques for controlling emissions from MWC are the subject of two volumes of the comprehensive EPA municipal waste combustion study, a volume on flue gas cleaning technology and a volume on the emissions data base (Sedman and Brna 1987; US EPA 1987c).

Combustion practices for control of organic emissions from MWC systems were identified and documented in the study on combustion control of organics (Seeker, Lanier, and Heap 1987). This study, performed under EPA direction by the Energy and Environment Research Corporation (EER), Irvine, California, included; (1) investigation of conditions under which CDD/CDF are created and destroyed; (2) an evaluation of technology used for combustion of municipal solid wastes (MSW); (3) a consideration of design or operating conditions that will result in the failure to achieve complete combustion with subsequent emission of trace organics; and (4) the development of recommendations on combustion practices which, when applied to commercial MWC systems, will minimize emission of CDD/CDF and other organics.

### *Origins of CDD/CDF*

Numerous theories have been proposed to account for CDD/CDF emissions from MWCs, but no consensus has been reached regarding their validity in actual MWCs. The theories that have been proposed can be grouped into three general categories, as depicted in Figure 1. First, there may be trace quantities of CDD/CDF in the waste fed to the incinerator, especially as contaminants or production byproducts in paper products, pesticides, or herbicides (Lustenhauwer, Olie, Hutzinger 1980). Second, CDD/CDF may be created during incineration by products of the combustion process. Third, CDD/CDF may be created at low temperature conditions downstream of the furnace. The second and third sources of CDD/CDF are believed to be the most important origins. The first origin may not be significant except where large amounts of contaminated wastes are burned and the combustion is poor. A well-designed and well-operated incinerator should effectively destroy the CDD/CDF which are contained in the combustor feed.

The synthesis of CDD/CDF during combustion is thought to originate from the combination of chlorine, hydrocarbons, chlorinated organics, and other precursor materials in the burning refuse bed or in fuel-rich regions in the furnace (Shaub and Tsang 1983; Choudhry et al., 1982). The specific compounds most commonly considered to be likely precursors include: chlorobenzenes (CBs), chlorophenols (CPs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). These precursor compounds are predominantly the thermal decomposition products of the various materials that constitute municipal

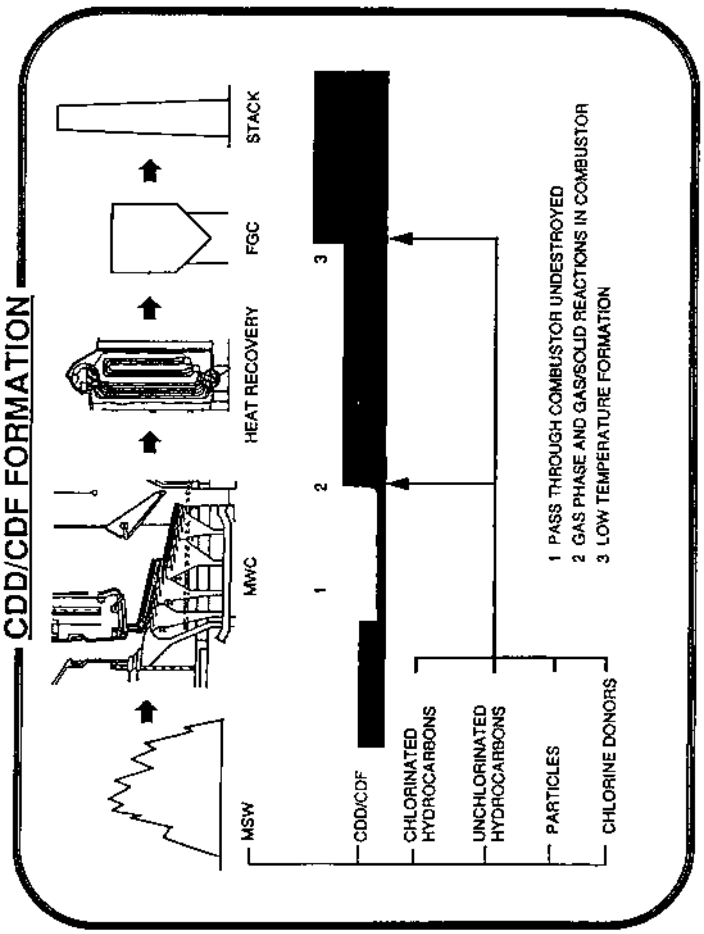


**FIGURE 1.** CDD/CDF formation theories

wastes: paper products, yard wastes, food wastes, plastics, wood, textiles, rubber, leather, and other organic materials.

Experiments by Hagenmaier (1987), Vogg (1986), Stieglitz (1988), Karesek (1987), and others have provided convincing experimental evidence that CDD/CDF can be created in MWC systems downstream of the furnace. This third source of CDD/CDF is believed to result from the catalytic reaction of appropriate precursor materials on the surface of fly ash. The reactions which create CDD/CDF under these conditions occur over a temperature range of approximately 200–400°C. Below 200°C, no reactions are observed. Above 400°C, CDD/CDF and their organic precursor compounds are subjected to thermal destruction. At temperatures from 200–400°C, and in the presence of concentrations of water vapor, oxygen, and hydrogen chloride, which are typical of MWC flue gas environments, carbonaceous materials, most likely in the form of benzene ring structures, are converted to CDD/CDF. Octa- and hepta-isomers are preferentially produced. It has been theorized that copper, if present in the fly ash, acts as a dechlorination catalyst which affects the degree of chlorination of the CDD/CDF isomers. These catalytic dechlorination reactions can increase the amount of 2,3,7,8-TCDD and 2,3,7,8-TCDF, the most hazardous CDD/CDF isomers. Experiments with MWC fly ash show that, under simulated MWC flue gas environments at an optimum reaction temperature of 300°C, the amounts of total CDD/CDF contained on the surface of the fly ash can be increased to 7- to 10-fold (Steiglitz and Vogg 1988).

The existence of this low temperature source of CDD/CDF emphasizes the importance of destroying all precursor materials (nonchlorinated and chlorinated ring structures), along with any CDD/CDF, before they leave the high temperature regions of the furnace.

### *Combustion Control Strategy*

It is postulated that good combustion conditions will minimize the furnace emission of all organics which can result in the emission of CDD/CDF and other potentially hazardous organic pollutants. The difficulty arises in defining criteria for good combustion which will be applicable to all incinerators or MWC systems. The vendors and manufacturers who have developed and who supply MWC systems often take distinctly different design and operating approaches to meet the same overall objective—the combustion of MSW in a thermally efficient and cost-effective manner. The basic design and operating conditions for systems offered by major MWC manufacturers in the United States and Europe are described in the report on the combustion control of organic emissions (Seeker, Lanier, and Heap 1987).

Four classes of MWC systems were defined in the EPA's study on MWC: mass-burning incinerators, refuse-derived fuel (RDF) combustors, modular incinerators, and fluidized-bed combustors. Recommendations for GCP were developed for waterwall mass burn, RDF spreader-stoker, and modular starved-air combustors. Insufficient information was available to develop recommendations for fluid-bed combustion systems.

A number of fundamental combustion goals were deemed appropriate for all classes of combustion systems. Combustion conditions should be controlled to limit the formation of soot and difficult-to-destroy precursor compounds. Combustion conditions should also maximize the destruction of any of these compounds, which are formed before they leave the high temperature regions of the furnace. Conditions within the combustors' environment which satisfy these goals include the following:

(1) Control of combustion at various locations along the length and breadth of the burning refuse bed. This, in turn, will permit control of the thermal decomposition rates of waste materials and release of pyrolysis and combustion products to various regions of the furnace above the fuel bed.
(2) The mixing of thermal decomposition products and air to minimize the existence of long-lived, fuel-rich pockets of combustion products.
(3) The attainment of sufficiently high temperatures in the presence of oxygen for the destruction of all organic compounds.
(4) The prevention of quench zones or low-temperature pathways that will allow partially reacted thermal decomposition products from exiting the combustion chamber undestroyed.

The initial recommendations for GCP involved three different elements, each with a number of subelements or components. These elements included design, operation/control, and verification. The design of the combustion system must be consistent with the objectives of ensuring that the temperature, oxygen concentrations, and mixing within the combustor are consistent with minimum formation of precursor organics and the maximum destruction of organic compounds. Operation/controls are necessary to ensure that the system functions in a manner consistent with the design goals, and that appropriate steps are taken to ensure that the combustion system is constrained to operate within the established operating envelope. Verification refers to validation of good combustion by monitoring of combustion process conditions and furnace/stack emissions during compliance testing.

### *GCP for Mass Burning Systems*

Modern waterwall, mass-burn incinerator technology, originally developed in Europe, was introduced into the United States in the late 1960s. Now at least 10 manufacturers offer mass-burning units that range from 100–1000 tons/day (91–910 Mg/d) in capacity. Although many of the designs are similar, there is a wide variety of approaches taken to attempt complete combustion of wastes. Some incineration systems are licensed European designs and represent two or three generations of technology. Some of the US systems are based on substantially fewer years of experience. None of these incinerators were originally developed with the intent of minimizing air pollution emissions.

Many of the mass-burn waterwall incinerators have combustor configurations which are typified by the Takuma incineration plant illustrated in Figure 2. This type of incinerator is defined here as a conventional waterwall combustor. The GCP recommendations for mass-burning systems are believed to be applicable to plants with similar combustor arrangements. Conventional waterwall incinerators operate at 80–100% excess air. Approximately 70% of the total combustion air is supplied through the grate system as primary or underfire air. The remainder or secondary air is added above the burning refuse bed as overfire air. The relative amount and distribution of underfire and overfire air along with the upper furnace geometry are important considerations in ensuring complete combustion and the prevention of CDD/CDF emissions.

The original recommendations for GCP for minimizing trace organic emissions from conventional mass burn waterwall incinerators are summarized in Table 1. Important design criteria were as follows: the attainment of 1800°F (980°C) at the fully mixed condition (height) in the furnace after introduction of overfire air; the ability to separately control underfired air to the drying, burning, and burnout sections of the grates; the provision of an overfire air design which is capable of providing 40% of the total combustion air as overfire air; the design of an overfire air injector system which allows for effective penetration and coverage of the entire furnace cross section; and the incorporation of an auxiliary fuel system that provides a capability of providing sufficient heat input to avoid excessive emission of organics during start-up and part-load operation.

Operation and control recommendations included: the provision of sufficient excess air to maintain oxygen concentrations in the flue gas in the range of 6–12% dioxide (dry basis); limitation of operation to no greater than 110% or no less than 80% of the fully rated design load; and use of auxiliary fuel during start-up or when combustion conditions in the furnace produce prolonged periods of low temperatures or high carbon monoxide concentrations.

Verification recommendations related to confirmation of combustion criteria during continuous operation included: monitoring and maintaining the flue gas oxygen within the range of 6–12% (dry basis); monitoring and maintaining carbon monoxide emission below 50 ppm on a 4-hour average; and measurement of furnace temperatures to ensure that a minimum mean temperature of 1800°F (980°C) is maintained at the fully mixed height. Adequate air distribution can be verified when the unit is put into operation and periodically thereafter by measuring either in-furnace carbon monoxide profiles or exhaust emission of trace organics.

The 1800°F temperature criterion was selected because theoretical calculations indicated that achievement of this temperature was necessary to destroy major precursor compounds (Seeker, Lanier, and Heap 1987). The criteria for underfire and overfire air were to ensure a capability of providing air for mixing and the

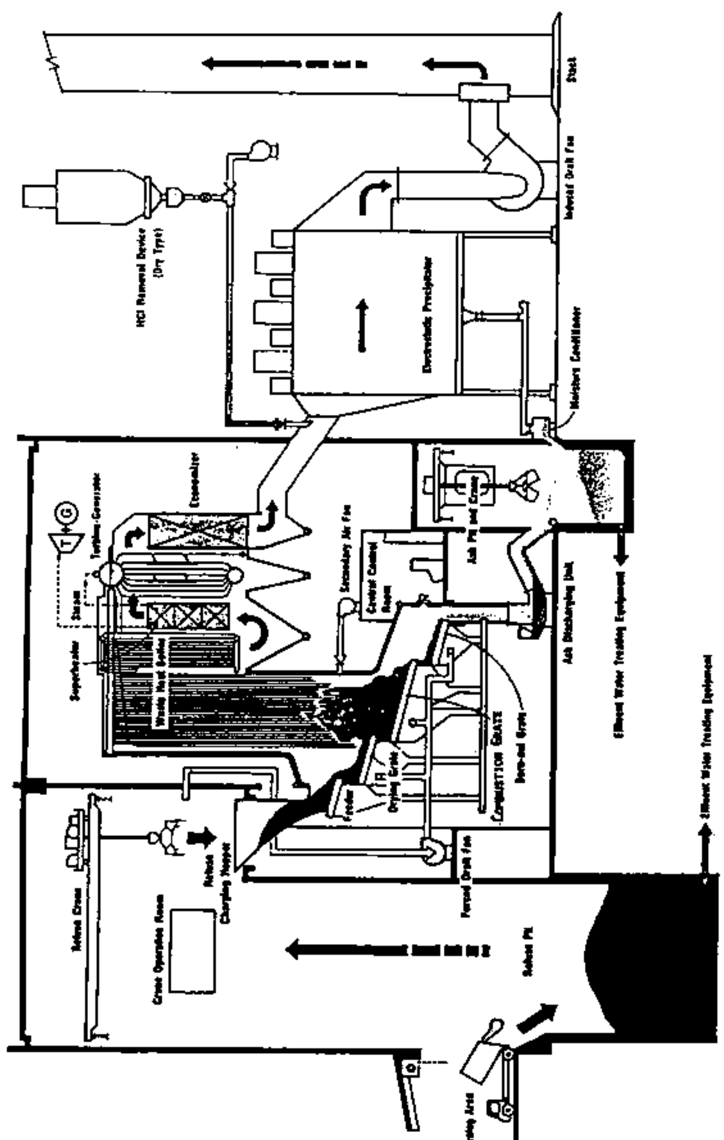

**FIGURE 2.** Municipal waste mass burner. Reduced schematic of Takuma Incineration Plant

**TABLE 1.** Recommended Good Combustion Practices for Minimizing Trace Organic Emissions from Mass-Burn, RDF, and Modular Starved-Air Combustors

| Element | Component | Recommendations |
|---|---|---|
| Design | Temperature at fully mixed conditions | All: 1800°F (980°C) at fully mixed conditions |
| | Underfire air control | MB: At least four separately adjustable plenums, one each under the drying and burnout zones, and at least two separately adjustable plenums under the burning zone<br>RDF: As required to provide uniform bed burning stoichiometry<br>MSA: No recommendations provided |
| | Overfire air capacity (not an operating requirement) | MB, RDF: 40% of total air<br>MSA: 80% of total air |
| | Overfire air injector design | All: That required for penetration and coverage of furnace cross-section |
| | Auxiliary fuel capacity | All: That required to meet start-up temperature and 1800°F criteria under part load |
| Operation/Control | Excess air | MB, MSA: 6–12% oxygen in flue gas (dry basis)<br>RDF: 3–9% oxygen in flue gas (dry basis) |
| | Turndown restrictions | All: 80–110% of design lower limit may be extended by verification tests |
| | Start-up procedure | All: On auxiliary fuel to design temperature |
| | Use of auxiliary fuel | All: On prolonged high CO or low furnace temperature |
| Verification | Oxygen in flue gas | MB, MSA: 6–12% (dry basis)<br>RDF: 3–9% (dry basis) |
| | CO in flue gas | All: 50 ppm on 4–hour average corrected to 12% $CO_2$ |
| | Furnace temperature | All: Minimum of 1800°F (mean) at fully mixed conditions |
| | Adequate air distribution | All: Verification tests (adequately low exhaust emission of trace organics or combustion uniformity using in-furnace CO profiles) |

All = all combustors; MB = mass burn combustors; RDF = refuse derived fuel combustors; MSA = modular starved air combustors

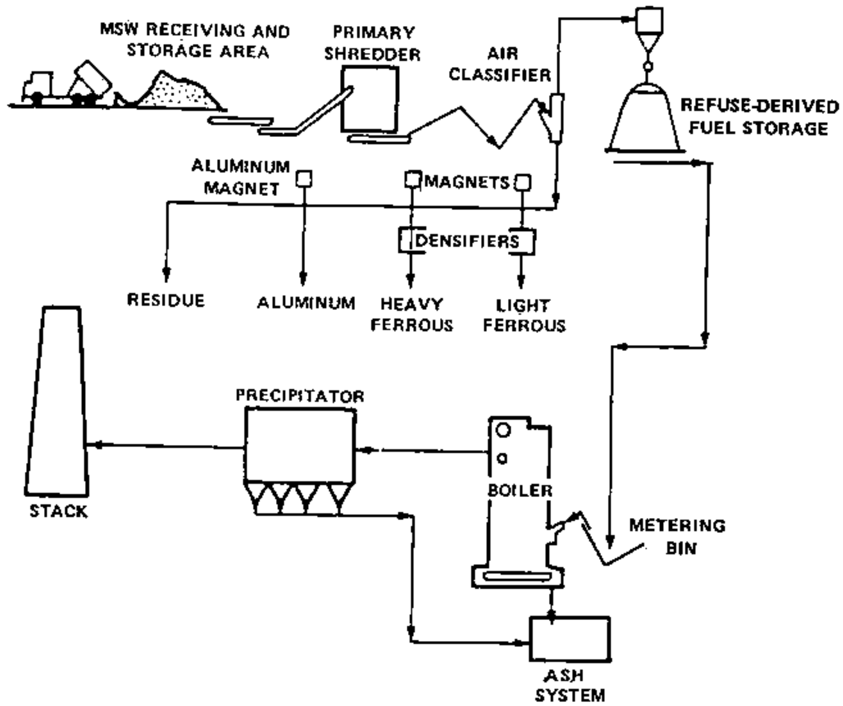


**FIGURE 3.** RDF processing facility with on-site boiler

attainment of appropriate stoichiometries throughout the combustion system. The limitations on furnace load are believed necessary to prevent operation at conditions that represent low combustion product residence times in the furnace (high load), low temperatures (low load), or low mixing intensities (low load). Previous tests on full-scale incinerators have indicated that limiting carbon monoxide emission is a necessary but insufficient criterion for adequately controlling furnace emission of CDD/CDF (Environment Canada (1988). Below 6% oxygen, it is expected that complete mixing may become a problem and increased levels of trace organics may occur. Above 12% oxygen, high levels of excess air may cause lowering of localized temperatures and quenching of combustion reactions.

## *GCP for RDF Combustors*

In refuse derived fuel (RDF) plants the wastes are processed before being injected into the incinerator or boiler (see Figure 3). This processing generally involves shredding, screening, and/or air classification to remove noncombustible material such as glass, grit, and rocks. Magnetic separation devices are often used to remove ferrous and aluminum materials. The processed waste may in some instances be pelletized or made into briquettes to facilitate storage and handling.

The processed waste may then be co-fired with coal or oil in an existing utility or industrial boiler, or it may be fired in a unit designed specifically for RDF. Some existing units were originally designed to fire coal or wood wastes and include tangential-fired, wall-fired, cyclone-fired, and spreader-stoker-fired boilers. New RDF units generally employ either spreader-stoker technology adapted from the coal and wood combustion technology or fluid-bed combustors.

A majority of new RDF projects employ boiler systems manufactured by either Combustion Engineering or Babcock & Wilcox. Combined, these two manufacturers represent approximately 80% (ton per day basis) of the active RDF projects. For the projects using Babcock & Wilcox boilers, most will employ combustion systems (grates and overfire air equipment) supplied by Detroit Stoker. Combustion Engineering provides all combustor and boiler equipment for their RDF systems. Both the Combustion Engineering and Babcock & Wilcox systems employ spreader-stoker or semisuspension firing systems. In semi-suspension systems, RDF with a top size of 2–4 inches (5–10 cm) is injected through the wall of the furnace above a traveling grate. Lighter, more buoyant particles burn in suspension while large heavy particles fall to the grate for burnout on a fuel bed. The Babcock & Wilcox systems, which have only one underfire air plenum, depend on even RDF distribution on the grate to provide uniform bed-burning conditions (see Figure 4). The Combustion Engineering design incorporates multiple undergrate air compartments, and the air flow distribution through the grate can be adjusted to match the RDF distribution pattern on the grate (see Figure 5).

There are two Babcock & Wilcox spreader stoker systems now in use, a conventional system and a controlled combustion zone (CCZ®) system (see Figure 4). Both systems incorporate several elevations of overfire air ports on both the front and rear walls of the boiler. In the Combustion Engineering system, overfire air is added in a tangential injection pattern, characteristic of Combustion Engineering's tangential-fired utility boilers. Unlike conventional mass-burn waterwall incinerator designs, which have lower furnace geometries that aid in mixing, the furnace walls of the Combustion Engineering and the conventional Babcock & Wilcox systems are straight and vertical. Adequate overfire air mixing is extremely important in these RDF systems because the lower furnace geometry does not promote mixing. The Babcock & Wilcox controlled combustion zone boiler contains features that will provide for improved mixing.

The original recommendations for GCP in RDF combustors are summarized in Table 1. These criteria are similar to those previously described for mass-burning systems. The only differences are in the design recommendations for underfire air control, the operation/control recommendations for excess air, and the verification recommendations for oxygen in the flue gas.

The recommendations for underfire air control are given "as (those) required to provide uniform bed burning stoichiometry." This requirement implies that the underfire air distribution and fuel bed conditions should be controlled to the

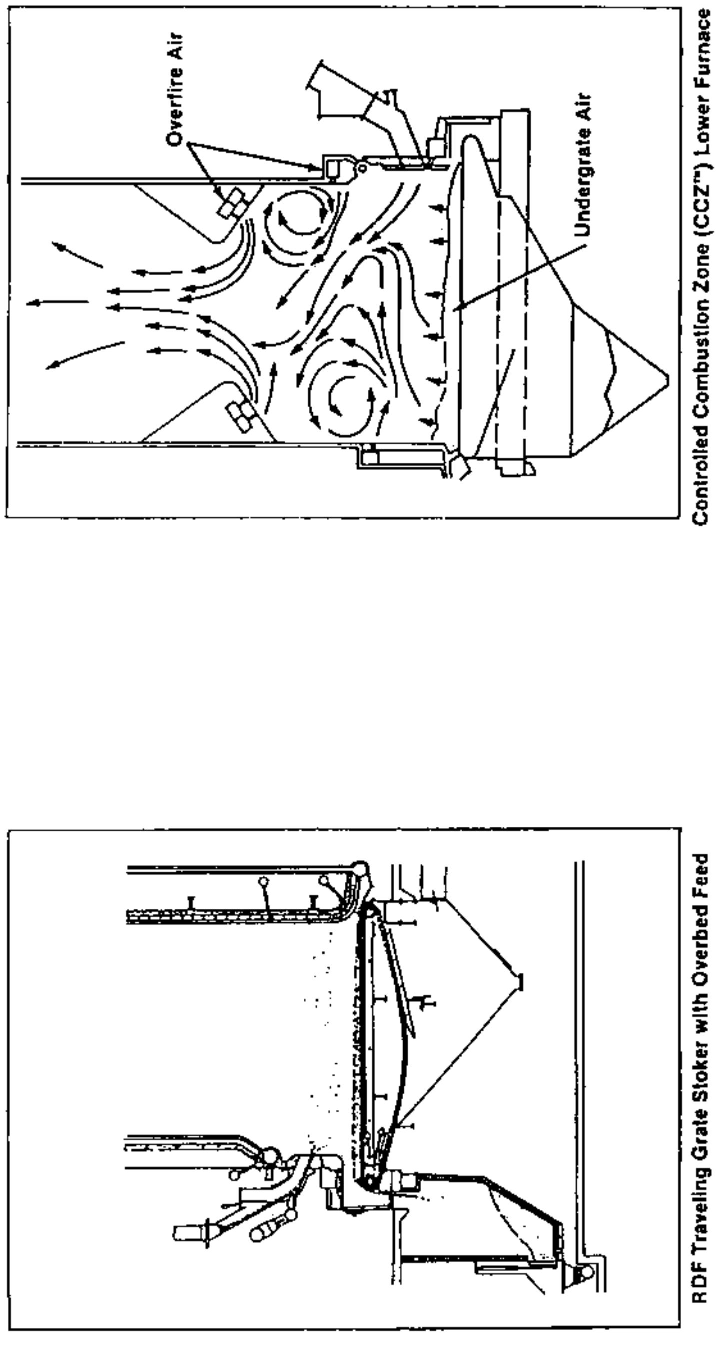


**FIGURE 4.** Babcock and Wilcox RDF stoker boilers

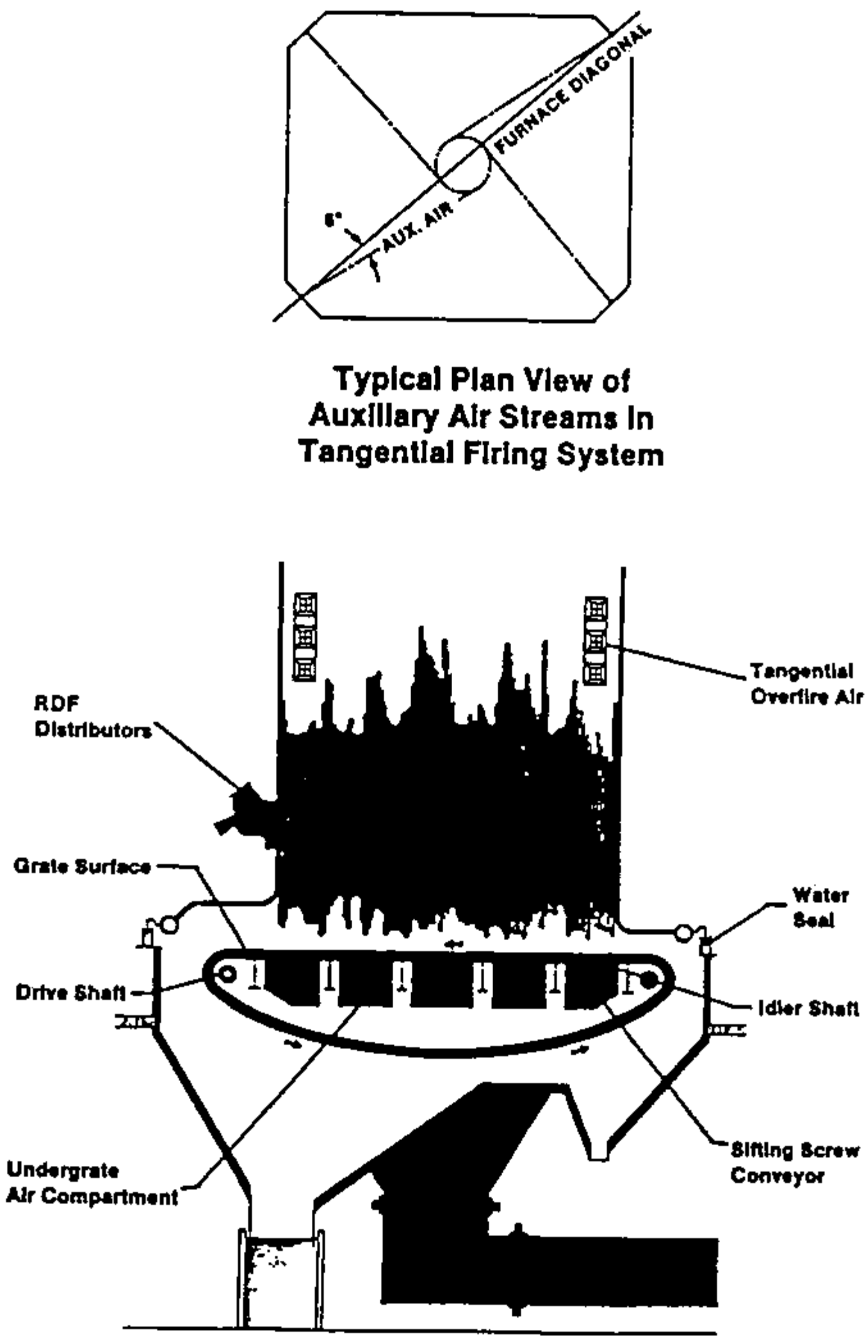


FIGURE 5. Combustion engineering RDF stoker boiler

extent that localized conditions representing excessively rich or lean conditions are avoided. This is needed to avoid the formation of soot and difficult-to-destroy organic compounds (rich conditions) or the quenching of combustion reactions (lean conditions).

The operation/control recommendation for excess air and the verification recommendations for oxygen in the flue gas both specify that oxygen in the flue gas be maintained within a range of 3–9% oxygen on a dry basis. The comparable recommendations for the mass-burn systems were 6–12% oxygen. The lower oxygen requirements for the RDF combustors reflect differences in design and operating conditions in these systems. RDF combustors are typically operated at approximately 50% excess air while mass-burn waterwall incinerators normally operate at 80–100% excess air.

### *GCP for Starved Air Combustors*

Modular incinerators generally include a primary and secondary combustion chamber (see Figure 6). These incinerators may be designed to operate in a starved-air or excess-air mode in the primary combustion chamber. Unprocessed refuse is fed into the primary combustion chamber where volatile material is thermally released from the waste fuel bed, and the residual carbonaceous char is burned. Final combustion of the volatilized waste material occurs in a secondary combustion chamber. Some incinerators use auxiliary burners in either the primary or secondary combustion chambers and some do not. After the combustion products exit the secondary combustion chamber, they are sometimes passed through a waste heat boiler.

There are more than six vendors of modular two-stage combustion systems in the United States. The market is dominated by Consumat. Most of the remaining market is shared by Clean Air, Inc., Ecolair, Inc., and Synergy, Inc. Consumat incinerators have been extensively tested. Tests by Environment Canada on the Consumat incinerator at Prince Edward Island indicated that emissions of CDD/CDF, trace elements, and total particulate can be controlled to relatively low levels, if close attention is paid to operation and maintenance of the incinerator. This high degree of emission control was attained without the use of flue gas cleaning equipment (many two-stage systems do not employ flue gas cleaning equipment because they are generally low emitters of particulate matter).

The original GCP recommendations applying to modular starved air (MSA) combustors are given in Table 1. With two exceptions, these recommendations are identical to those for mass-burn systems. The recommended design overfire air capacity of 80 percent reflects the fact that starved-air units operate under fuel-rich conditions in the primary chamber. Most of the combustion air is added in the secondary (overfire) combustion zone. The recommendations for verification of furnace temperature require that it be referenced to a measurement of

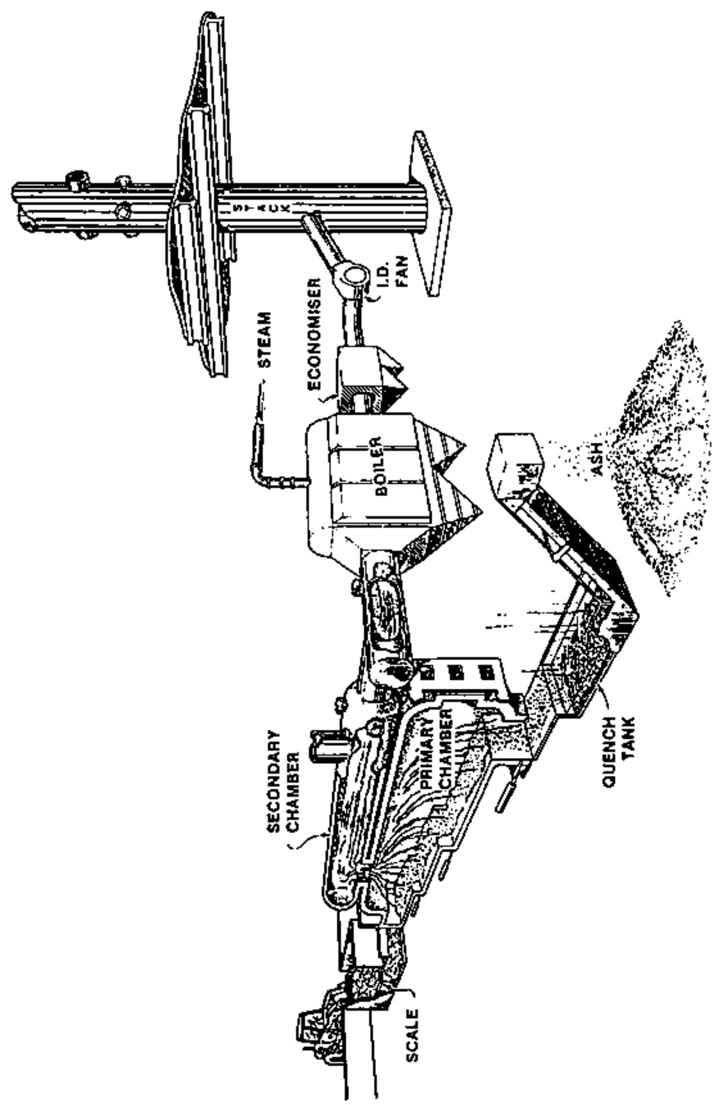


**FIGURE 6.** Process schematic of two-stage combustion system

1800°F (980°C) at a fully mixed vertical plane in the secondary combustion chamber.

### *GCP Revision and Extension*

The original GCP were largely predicated on the success of modern, well-operated MWC systems in significantly reducing trace organic emission when compared with older incinerators of the same type. More direct evidence on the importance of combustor design and operation in achieving low emission of CDD/CDF is now available through the Environment Canada National Incineration Test and Evaluation Program (1988) combustion project at the Quebec Urban Communities incinerator plant. In this project an older incinerator was modified to incorporate design and operating features of modern incinerators. Figure 7 illustrates features of the incinerator before and after modification.

The emission of total CDD before and after modification of the Quebec City incinerator is shown in Figure 8. The 1984 data are for tests performed for Environment Quebec. CDD emissions for these tests ranged from 850–3980 $ng/Nm^3$. The 1986 data are from 13 Environment Canada (1988) tests on the modified incinerator. They reflect the averages for nine tests at good combustion conditions and four tests at poor combustion conditions. The poor combustion conditions represent operating conditions outside of the normal operating envelope. Average CDD emission for the bad combustion tests were 200 $ng/Nm^3$ while average CDD emission for the good combustion tests was 40 $ng/Nm^3$.

These Environment Canada test results and the downward trend in CDD/CDF emissions from new well-controlled incinerators provide strong evidence of the effectiveness of good combustion conditions in reducing emissions of organic pollutants.

The original GCP applied only to conventional mass-burn waterwall combustors, RDF spreader stoker combustors, and modular starved air combustors. Work is now being performed to revise the original GCP and extend development of GCP to other classes of combustors. This work includes validation of GCP concepts and definition of numerical parameters which can be used to monitor and control the combustion process.

The revision and extension of GCP is based on the evaluation of new information obtained from the following:

(1) The results of research and field tests published in the open literature;
(2) The response to comprehensive questionaires obtained by EPA from the operators of more than 140 MWC facilities in the United States;
(3) Meetings with researchers, MWC system manufacturers, MWC system operators, and air pollution regulators in the United States, Canada, Japan, Italy, Switzerland, the Federal Republic of Germany, Denmark, and Sweden;
(4) Field tests sponsored by Environment Canada and the EPA.

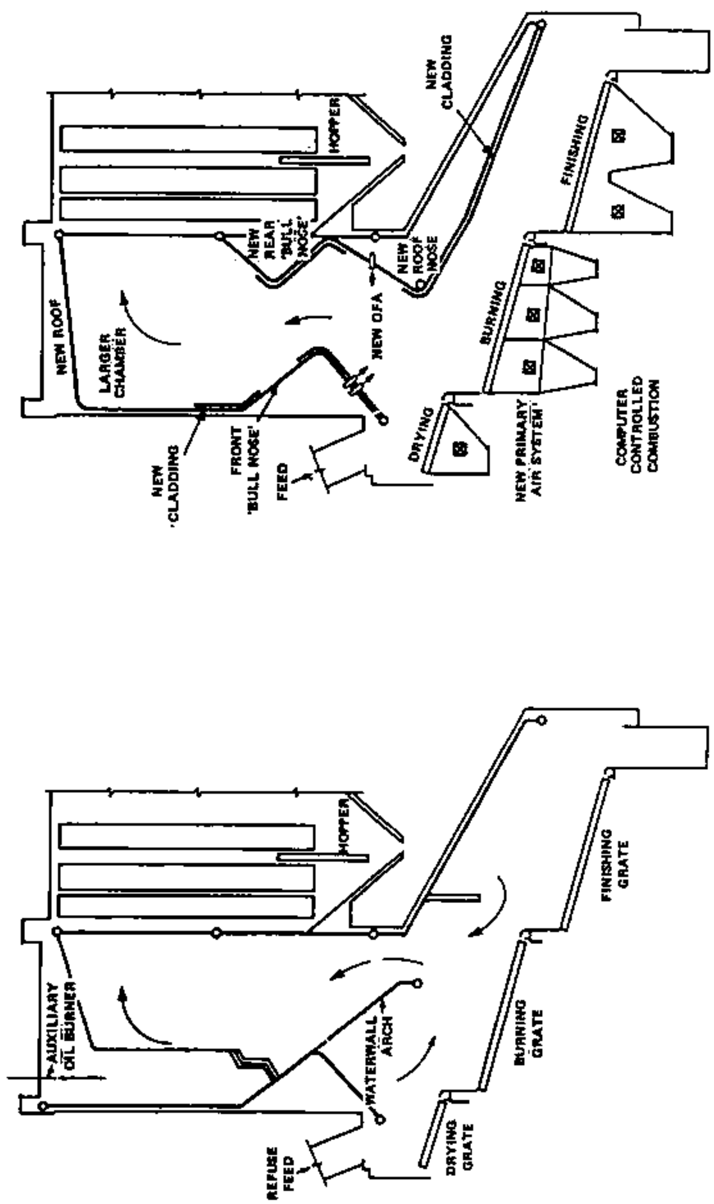


FIGURE 7. Quebec City Incinerator. (Left: before modification; right: after modification)

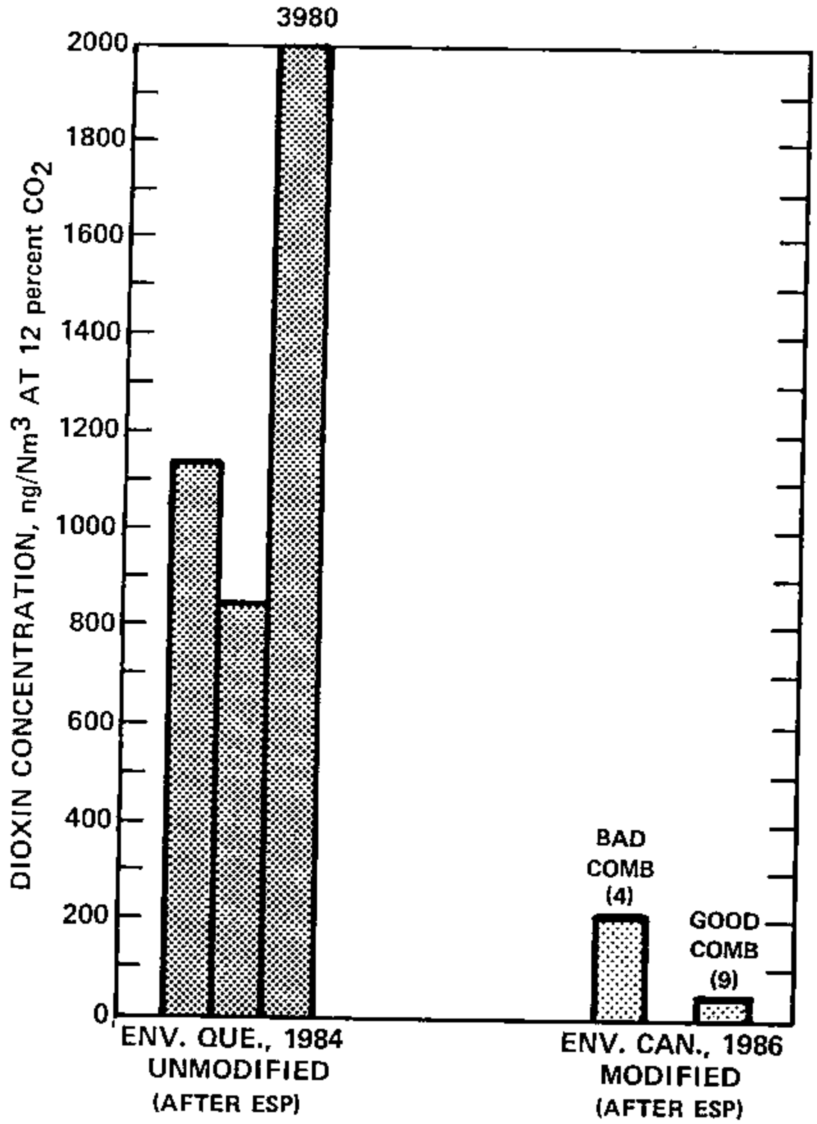


**FIGURE 8.** Quebec City comparative dioxin results

There are a number of technical and regulatory issues driving the development of GCP. As of January 1989, there were more than 160 operating MWC facilities in the United States. Of this number only eight employed the flue gas cleaning technology which has been shown to be highly effective in controlling the emission of organics (dry scrubber followed by a fabric filter and electrostatic precipitator (Sedman and Brna 1987; Brna 1989). One option for controlling emissions of organics is to use more effective combustion practices. Environment Canada has demonstrated the feasibility of combustion retrofits in waterwall mass-burn combustors (i.e., upgrading the combustion system for improved effectiveness) by their work at the Quebec City Urban Community Incinerator. A recent EPA study of potential retrofit technologies has shown that GCP costs less but is not always as effective as advanced FGC techniques in reducing organic emissions (personal communication with R. E. Meyers, EPA, September 5, 1988). It is, therefore, desirable to define GCP for various classes of MWC systems so that combustor retrofits can be used as one method to reduce organic emission. Also, the use of GCP on new facilities will result in lower release rates of CDD/CDF into the environment (emissions and residues) when compared to less well-controlled combustion MWC facilities without GCP.

GCP are also needed to provide a methodology for monitoring and controlling the combustion process to verify that CDD/CDF emissions are continuously maintained at low levels. There are currently no techniques for continuously monitoring CDD/CDF emissions. Measurement of CDD/CDF requires a stack sampling team and expensive laboratory analysis. Besides being expensive (approximately US $30,000 for each compliance test), results are commonly not available until several weeks after the test. Therefore, it is desirable to use GCP, a methodology which will ensure that low furnace emissions of CDD/CDF are continuously achieved.

Key components for good combustion are considered to be the amount and distribution of combustion air and adequate temperature and mixing. If these are all satisfactorily achieved, then the destruction of organics is nearly complete, as evidenced by relatively low levels of carbon monoxide. The difficulty arises in defining "relatively low" in a numerical sense. Test data from several incinerators have shown that by itself carbon monoxide does not provide a strong correlation with CDD/CDF, and the correlation between carbon monoxide and CDD/CDF emissions breaks down for carbon monoxide emissions lower than some value of carbon monoxide which may fall in a range from 50–200 ppm (see Figure 9) (Environment Canada 1988; Midwest Research Institute 1987). Below this value, lower carbon monoxide emissions may not be associated with lower CDD/CDF emissions. Alternatively, the breakdown in correlation below this value may mean that some CDD/CDF formation mechanism which is not reflected in carbon monoxide level plays a more important role in CDD/CDF formation.

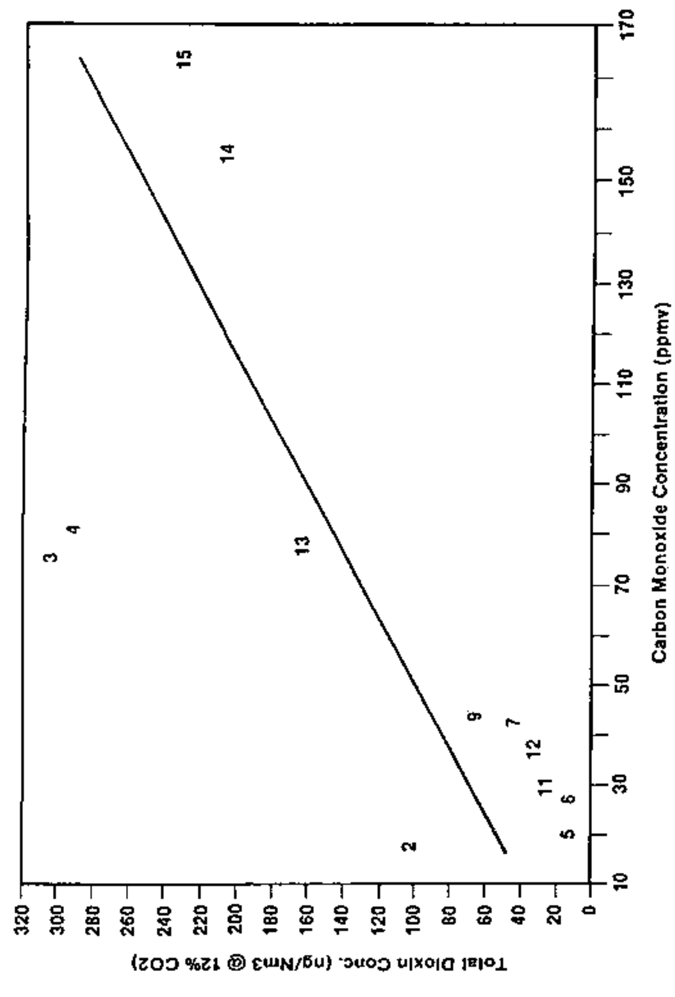


**FIGURE 9.** Quebec mass burn tests on modified combustor (1986)
*Source:* Environment Canada

An extensive evaluation of test data from the Quebec City mass-burn incinerator test program indicates that the strongest correlation for stack emissions of CDD/CDF is the furnace emission of particulate matter (see Figure 10). On a theoretical basis, the amount of CDD/CDF produced by catalytic reactions with fly ash will depend on the temperature, fly ash surface area, and time of reaction. Higher amounts of fly ash are generally associated with high underfire air rates relative to the overfire air rates and/or high loads (i.e., high furnace volumetric flow rates). More particulate material is entrained with the gaseous combustion products and more organic material in the form of particulate matter is carried to the colder portions of the boiler before it can be completely burned out. Under these conditions more fly ash, with a higher organic content, is carried downstream, where low temperature catalytic formation occurs.

The above postulations are supported by the results of field tests of RDF spreader-stoker combustors. Because RDF combustors employ semisuspension firing of processed RDF, there is an inherently greater amount of fly ash carried out of the furnace. Field test data from at least one RDF spreader stoker confirm a correlation between furnace particulate emissions and CDD/CDF concentrations at the inlet to the flue gas cleaning equipment (see Figure 10) (Linz, 1989).

If CDD/CDF emissions are indeed proportional to furnace particulate emissions, then the revised GCP will probably specify that actions be taken to minimize particulate carry-over. In addition, air pollution control devices such as ESPs should not be operated in the temperature range between 250–400°C. Otherwise, the ESP may serve as a large particulate reactor where CDD/CDF can be formed. The revised GCP will probably contain recommendations against operating FGC devices within this temperature range.

Some of the values of parameters recommended in the original GCP may be overly restrictive for some combustors. For example, there are no data that show that RDF combustors can consistently operate below 50 ppm as recommended by the original GCP. Tests are now being sponsored by Environment Canada and the EPA to develop correlations between combustion conditions and furnace emissions of organics in RDF spreader stoker combustors. If good combustion conditions can be achieved at some higher value of carbon monoxide and if CDD/CDF emissions are still relatively low, then the carbon monoxide recommendations for RDF combustors could possibly be revised to this higher value. The numerical parameters recommended in the initial GCP are all being reviewed for attainability and effectiveness.

The above observations are, at present, based on theories which help to interpret a limited amount of field test data. Additional field data are now being acquired from two test sites to provide further evidence for development of the revised GCP.

Other classes of MWC facilities for which GCP are being developed include the following:

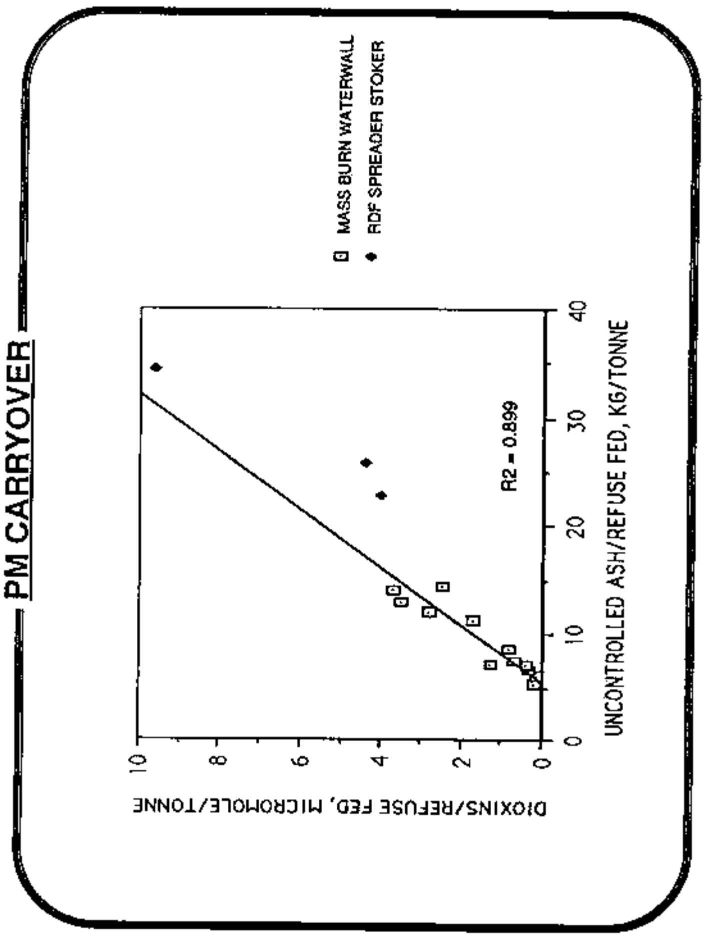


**FIGURE 10.** Effect of PM carryover on dioxin emissions
*Source:* Linz (1988).

- Mass-burn rotary waterwall combustors (Westinghouse);
- Mass-burn refractory split-flow combustors (Volund);
- Mass-burn refractory mono-flow combustors;
- Modular excess-air combustors;
- Fluidized-bed combustors.

Not as much field test data are available for these combustors, but it is believed that GCP principles developed for the other types of combustors can be extended to the above combustors.

The author acknowledges the technical contributions of W. R. Seeker, W. S. Lanier, and M. P. Heap of Energy and Environment Research Corporation and W. Niessen of Camp Dresser and McKee, Inc., in development of the original recommendations for good combustion practices in municipal waste combustors.

## Note

1. In this paper CDD/CDF means the combined emissions of tetra- through octa-chlorinated dibenzo-p-dioxins and dibenzofurans. The terms "polychlorinated dibenzo-p-dioxins" (PCDD) and "polychlorinated dibenzofurans" (PCDF) are sometimes used in the literature as terms for chlorinated dioxins and furans. The most toxic dioxin and furan isomers are 2,3,7,8-Tetrachlorodibenzo-p-dioxin and 2,3,7,8-tetrachlorodibenzo furan. The tetra homolog groups for dioxins and furans are designated by TCDD and TCDF.

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