UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IV
345 COURTLAND STREET
ATLANTA, GEORGIA 30365

JUN - 1 1987

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JUN 4 1987
BAQM

Mr. Thomas M. Henderson
Project Director
Broward County Resource Recovery Office
115 South Andrews Avenue, Room 521
Fort Lauderdale, Florida 33301

Re: South Broward Resource Recovery Facility Permit
(PSD-FL-105)

Dear Mr. Henderson:

Please find enclosed page 1 of your PSD permit and page 21 of the final determination which correct an error in the student T test equation as referenced in condition 1.a.(2) of the Specific Conditions. We request that you replace your versions of page 1 of the permit and page 21 of the final determination issued on May 15, 1987, with the enclosed corrected versions.

Sincerely,

Bruce P. Miller

Bruce P. Miller, Chief
Air Programs Branch
Air, Pesticides, and Toxics
Management Division

Enclosures
cc (Enclosures):
Mr. Steve Smallwood, P.E., Chief
Bureau of Air Quality Management
Florida Department of Environmental
Regulation

PART I. - Specific Conditions

1. Emission Limitations

a. Stack emissions from each unit shall not exceed the following:

Particulate:	0.0150 gr/dscf dry volume corrected to 12% CO_2.
Sulfur Dioxide:	(1) 0.140 lb/mmBtu heat input and 60 ppm (3-hr rolling average, dry volume, corrected to 12% CO_2); or (2) 65% reduction of uncontrolled SO_2 emissions.* In no case shall the SO_2 emissions exceed 0.310 lb/mmBtu heat input and 124 ppm (3-hr rolling average, dry volume, corrected to 12% CO_2). The 124 ppm limit above shall be modified to reflect a new emission limit (in ppm) from the control device at 65% control efficiency. Within 18 months of start-up of operation, the County shall submit compliance tests that will be used to determine the new SO_2 emission limit (in ppm). The limit will be determined by observed average emission rate ($\bar{x}$) from the submitted compliance tests and will be statistically analyzed using the one tailed student T test ($t_{.05} = (\bar{x} - u)\sqrt{n}/s$) at the 95% confidence level to derive a mean emission rate (u), where s is the standard deviation of observed values n. The final operating SO_2 emission limit (in ppm) shall be this mean emission rate (u). This value shall be restricted to no more than 124 ppm or less than 60 ppm (3-hr rolling average, dry volume, corrected to 12% CO_2).
Nitrogen Oxides:	.560 lb/mmBtu heat input and 350 ppm (3-hr rolling average, dry volume, corrected to 12% CO_2).
Carbon Monoxide:	.090 lb/mmBtu heat input; 400 ppm (1-hr rolling average, dry volume, corrected to 12% CO_2); and 88 ppm (4-day rolling average, dry volume, corrected to 12% CO_2).
Lead:	.00150 lb/mmBtu
Fluorides:	.0040 lb/mmBtu
Beryllium:	9.30×10^{-7} lb/mmBtu
Mercury:	7.50×10^{-4} lb/mmBtu

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* Uncontrolled SO_2 emissions will be measured at the inlet to the acid gas control device.

VII. FINAL PERMIT

PART I. - Specific Conditions

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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345 COURTLAND STREET
ATLANTA, GEORGIA 30365

MAY 27 1987

4APT/APB-eaw/ljf

Mr. Steve Smallwood, Chief
Bureau of Air Quality Management
Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32301

Re: Issues, Options, and Choices for Control of Emissions from Resource Recovery Plants

Dear Mr. Smallwood:

As you may know, the ongoing problems of waste disposal, specifically with regard to landfills, have caused increased public interest in resource recovery facilities (RRFs). Taking this into consideration, EPA anticipates there will be a substantial increase in permit applications for RRFs in the future. Although RRFs have been in existence for a number of years, these facilities are still relatively new with respect to environmental regulations. For our agencies, we feel that every bit of information made available to you will aid in your future decision making concerning these facilities. Therefore, we are enclosing the paper, Issues, Options and Choices For Control Of Emissions From Resource Recovery Plants for your use.

If you have any questions, please contact me or Mr. Gary Ng of my staff at (404) 347-2864.

DER
MAY 29 1987
BAQM

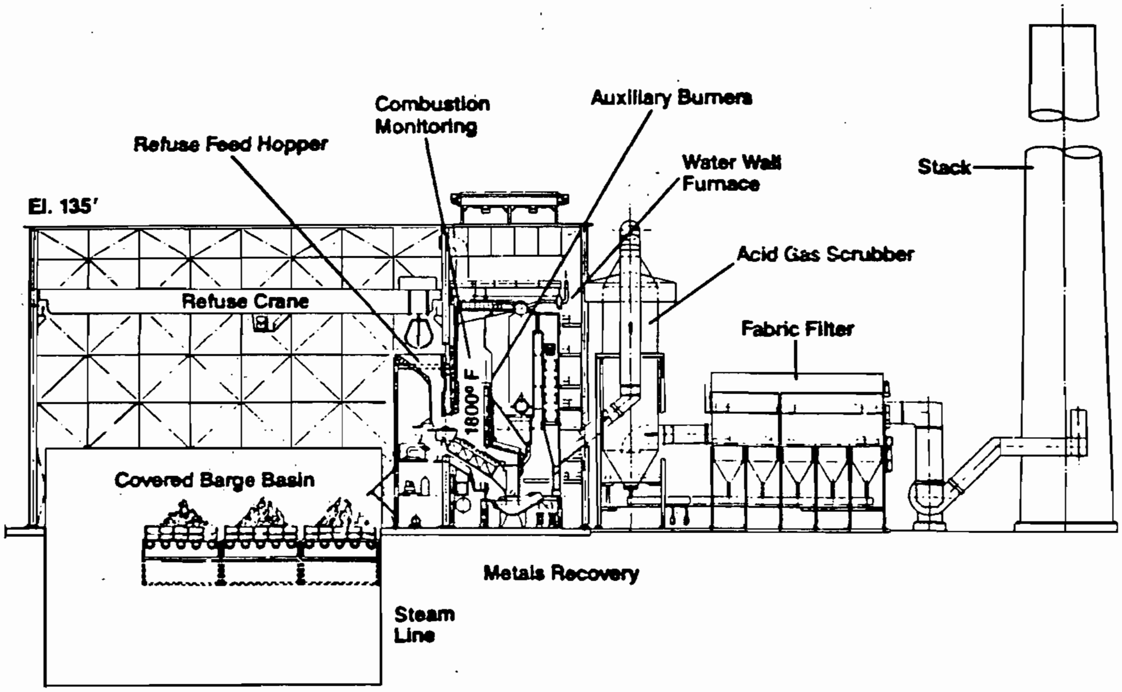
Sincerely yours,

Bruce P. Miller

Bruce P. Miller, Chief
Air Programs Branch
Air, Pesticides, and Toxics
Management Division

Enclosure

ISSUES, OPTIONS AND CHOICES FOR CONTROL OF EMISSIONS FROM RESOURCE RECOVERY PLANTS



Marjorie J. Clarke
Environmental Scientist
Resource Recovery and Waste Disposal Planning
NEW YORK CITY DEPARTMENT OF SANITATION

Presented at
Sixth Annual Resource Recovery Conference

Sponsored by:
U.S. Conference of Mayors/National Resource Recovery Association

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ABSTRACT

Solid waste incineration technologies are associated with a number of environmental impacts, most notably emissions of particulates, acid gases, heavy metals, and organics and also generation of ash residue. As a municipality commences planning of a resource recovery facility it is faced with a number of regulatory, environmental and/or political constraints which influence whether (1) the community is best served by a state-of-the-art plant which satisfies stringent emission limits with cost as a secondary consideration (LAER), or (2) selection of a facility meeting minimum emission/design requirements with cost as a more prominent factor in the design of the facility is sufficient (BACT). Once this choice is made, there are a number of options to consider in the designing of new resource recovery plants and the retrofitting of older incinerators to minimize emissions. This paper explores these design options (including stoker, grate and furnace design features and the various air pollution control devices) and the mechanism(s) by which each design feature reduces emissions. In addition, emissions data from actual incinerators indicating relative performance of some of these design options are presented and comparisons made. Also, since it is increasingly recognized that proper operation of solid waste incinerators is critical to retarding the mechanisms of formation and thermal destruction as well as condensation/capture of pollutants prior to emission from an incinerator, a section of the paper is devoted to describing the efficacy of a number of operations designed to achieve the greatest possible reductions in emissions. Such operations include materials separation and improved grate, furnace, boiler, baghouse, ESP and scrubber operating practices.

In response to these continuing developments in emission control technologies and practices over the past decade or so, stoker/grate/furnace designs to maximize combustion efficiency, more efficient design of control devices, and proper modes of operation are increasingly employed on new resource recovery plants as well as older municipal incinerators. As a result, there has been a marked downward trend in most emissions (e.g. particulate emissions are now one to two orders of magnitude lower than they were 15 years ago). Recent research studies of municipal waste combustors using various emission control technologies indicate that over 99% removal efficiency for all the pollutants of concern, including toxic organics such as dioxin and furan, is achieved at a number of plants when efficient control devices are operated under optimal conditions. In addition, when older municipal incinerators have been retrofitted with improved designs to maximize combustion, efficient emissions control devices, and operated to minimize emissions, considerable reductions as high as 99+% have been achieved. It is recommended that research be continued to verify these findings and demonstrate even better ways of reducing emissions, not only from resource recovery plants, but also from older, smaller, and less well designed and operated plants.

INTRODUCTION -- THE PROBLEM

The impending solid waste crisis in New York City and certain other large urban centers has been recognized for some time. Though the ultimate solutions are not clear or universally agreed upon, certain possible disposal methods, for example, further large-scale landfilling, are made impractical by the constraints of the real world (e.g. limited space and considerable deleterious impacts on land, groundwater and air). Though total (100%) separation and recycling of materials from the waste stream, is very attractive, both from the standpoints of prevention of air or water quality impacts and conservation of natural resources, this has not yet been demonstrated in any urban area in the U.S. A very few, less urbanized, municipalities have achieved as much as 40% materials separation and reuse, and urban recycling in Japan exceeds 50% in some communities, but this seems to be the limit of practicality for recycling given current reclamation technologies and markets. Thus, the need for some form of incineration process to dispose of some or most solid waste, at least in the short-term, is considered by many to be unavoidable.

Up until the last decade, the older types of incineration (e.g. large, possibly retrofitted municipal incinerators and small apartment flue-fed units) were the predominant means of burning MSW in large cities, such as New York. With the advent of resource recovery in this country, the modern mass burning and RDF burning technologies and even a few fluidized bed systems and gasifiers, designed for vastly reduced emissions, are slowly replacing the older style units. However, despite the improvements in pollution control, the new plants do emit a variety of common and exotic pollutants. Recognizing this, the public is concerned about the potential health and environmental effects, making emissions the biggest issue affecting siting and construction of resource recovery plants. As a result, researchers and governmental agencies worldwide have been focussing a great deal of attention and financial resources on understanding and addressing this problem. With the goal of preventing and/or reducing emissions, research has concentrated on determining with greater precision and accuracy the types and quantities of emissions generated, the relationship of waste composition to emissions (and emissions reductions potential from separation), the environmental and human health impacts of the various pollutants of concern, and the efficiency of various emission control design and operating methodologies in minimizing resource recovery emissions.

SOLUTIONS TO THE PROBLEM

At this stage, with research, development and demonstration of emissions reduction strategies still ongoing, a municipality which requires resource recovery capacity in the short term may find itself in a difficult predicament with respect to selecting the optimal combination of plant design, emissions control devices and operations both to fit its needs and satisfy the public. In addition, since new technologies are being developed and refined all the time, capital as well as operation and maintenance cost estimates are in a continual state of flux, making decisionmaking even more difficult. Furthermore, regulatory policy on the federal and state level is also evolving with time as new technologies are developed and tested.

As a result of the continuing improvements in particulate control technology, emission guidelines for particulate are becoming ever more stringent. For example, the federal standard of 0.08 gr/dscf issued in the 1970s is reflected in the level of emissions attained by incinerators tested in the 1970s. A few years ago, the major particulate removal technology of the time (old-style, 2-field ESP) routinely attained emission levels of .03 gr/dscf and a few state governments have taken the prerogative of issuing permits and guidelines reflecting the capability of the available technology. Since that time, with the recent development of more efficient technologies (the fabric filter, or baghouse, as well as the three and four-field ESP's), a number of states, such as Maine, Connecticut and the bellwether state of California, are requiring that resource recovery facilities emit no more than 0.01 gr/dscf overall, (and 0.008 gr/dscf for fine particles in the case of California).

In those states where BACT (Best Available Control Technology) or LAER (Lowest Achievable Emission Rate) requirements are promulgated as guidelines or permit requirements (e.g. California, New Jersey, Pennsylvania, Connecticut, etc... -- see Tables I and II), a municipality's choices are made easier. However, in other states, there may be little guidance from the regulatory authorities prior to the permit process. In most cases though, and with the passage of time, the trend has been for each new state to follow the development of technology and issue more stringent resource recovery emission guidelines, both with respect to the number of pollutants regulated and the level of emissions permitted, as well as with respect to the required design and operation of the emission control devices. In certain states, however, (e.g. New Jersey and Connecticut), state guidelines and permits are evolving and becoming more stringent with time, negating the reassuring effect of having an established state regulation on which to base decisionmaking.

Where does this leave the municipality wishing to design and implement a resource recovery facility? Some cities, particularly those with densely populated areas, in nonattainment for one or more criteria pollutants due to traffic and/or industry, large MSW capacity requirements, and an active and vocal citizenry might choose state-of-the art (LAER) designs employing all the latest furnace designs and emission control technologies that are the most efficient (and possibly more expensive) than the current applicable regulation requires (i.e. the "Cadillac" model). Other municipalities, possibly located in more sparsely settled areas, with little industry, good air circulation, etc... might be content to choose the least expensive and least technologically risky arrangement meeting BACT requirements (i.e. the "Budget" model). Obviously, some municipalities will fall inbetween. In any event, the selection of the optimal combination of facility design features, including furnace and emission controls will be a difficult one, possibly evolving during the planning process, and will depend on a number of regulatory, technological, political, economic, and environmental factors. In the following discussion, a number of technologies and methodologies, designed to prevent, reduce and collect emissions will be described, their relative efficiencies compared, and recent test results presented.

FACILITY/POLLUTION CONTROL DESIGNS

Aside from the separation of certain components of the waste stream prior to incineration, the two predominant emission control methods in use today and undergoing refinement have been the regulation of combustion efficiency (i.e. to design and operate the furnace to maximize conversion of the organic matter in solid waste to carbon dioxide and water vapor) and utilization of properly operated and maintained, efficient, emissions control devices (to maximize the condensation, adsorption, and/or removal of pollutants from the flue gas). There is a wide variety of technologies in use and under development today. This section examines the major technologies in each of these categories of resource recovery emission controls.

Since furnace designs and emission control devices are usually specific to a one or a group of pollutants, the technologies will be grouped according to the following categories:

(1) particulates
(2) acid gases, (i.e. SO_x, HCl, and HF)
(3) NO_x
(4) products of incomplete combustion (PICs)
(5) heavy metals

Particulates

Particulate emissions fall into two categories: solid and condensible. Solid particulates are formed under normal combustion conditions in the furnace, as some of the noncombustible materials in the solid waste feedstock are released into the flue gas in the form of fly ash. Particulate matter is emitted over a wide range of particle size, with diameters of less than a micron to hundreds of microns, often consisting of inorganic oxides similar to the earth's crustal material, heavy metals and other unburned solid matter. Condensable particulates are formed when, upon entering the combustion zone, certain portions of the refuse are vaporized (but not converted to CO_2 or H_2O, the end products of clean combustion), enter the flue gas stream, and eventually, after passing through the boiler or emission control device, cool and condense. Vapor phase organics, which constitute a portion of the condensible particulate fraction in flue gas, are produced as a result of inefficient or incomplete combustion in the furnace. If combustion occurs at too low a temperature, or with either insufficient or overabundant oxygen present, and/or with insufficient mixing or residence time, then conditions are ripe for production of a smoky fire in the combustion chamber and large quantities of condensible organic emissions.

In the last few years greater attention has been focused on the health impacts of inhaling fine particles (i.e. in the respirable range, less than three microns) on which acid gases, heavy metals and toxic organics, such as dioxin, preferentially adsorb. Since 20% to 50% of the particulate emissions from incinerators are said to be in this range (Ref. 56, p. 4), these finer particles pose the greater threat to public health. Fortunately, during recent years, efforts to develop more sophisticated and efficient particulate control devices, facility designs and operating techniques to control overall and fine particulate emissions have been proceeding with success.

Particulates are controlled by different means depending on whether they are emitted in solid or condensable form. A conservative approach to reducing condensible organic particulate emissions would involve proper operation of the furnace to maintain maximum combustion efficiency. This is described further in the section on furnace operation.

Since it is difficult to maintain absolute control over conditions in all parts of the furnace at all times, and since solid particulate emissions are not as affected by combustion regulation methods as they depend to a great extent on the level of ash and noncombustibles in the waste stream, it is difficult to avoid emissions of this form of particulate matter entirely. A number of processes can be used to remove particulates from the flue gas, including the impaction and reaction processes employed in wet and dry scrubbers, which removes a certain amount of solid particulate. However, the primary emission control method used to remove solid particulate matter from the waste stream is a collection device positioned after the heat recovery process. The electrostatic precipitator and the fabric filter are the predominant collection devices employed today on resource recovery facilities.

ESP's operate by charging the particles in the flue gas and passing this gas stream between sets or fields of plates with an opposite charge, which then pull the particles out of the gas. A distinct advantage of this technology is that ESP's have the longest operational track record on resource recovery plants, and ESP's have demonstrated high particulate removal efficiency and reliability. The major disadvantage of the old-style, two-field ESP is that it has a lower specific collection area (SCA) which decreases the capability of the unit to remove particulate matter from flue gas. The lower SCA also makes the ESP's efficiency more a function of a number of characteristics of the refuse and plant operations (e.g. particulate inlet loading, flue gas flow rate, temperature, moisture, particle resistivity, and particle size distribution). Thus, the ESP efficiency varies from about 93% for fine, respirable particles less than about 2 microns to 99.8% for larger particles -- see Figure 1). As a result, these devices have not demonstrated the capability of consistent performance at the 0.01 gr/dscf level (see Table III), a level required in some state emission guidelines and permits (e.g. California, Maine - see Table I).

To counteract these decreases in efficiency, and to compete with efficient, new fabric filters, ESP manufacturers have had to make expensive design changes to increase the specific collection-plate area (SCA) and/or number of fields). Figure 2 illustrates that lower overall particulate loadings result from a higher SCA, an increased number of fields, and/or a lower flowthrough velocity.

The fabric filter or baghouse, operates in much the same way as a vacuum cleaner, pulling the flue gas through a densely woven fabric. In a baghouse, filtration of of all sizes of solid particles is achieved not only as a result of the filtering action of the fabric itself, but also due to additional solid and condensible particulates being removed as a result of entrainment in the accumulation of particles on the filter (bag cake). Baghouses are sized for optimum pressure drop, a factor influencing cost of operation, and not particulate removal efficiency. Thus, a baghouse for a particular facility can be operated at a higher pressure drop (cost) and achieve a greater removal efficiency. (Ref. 53) Another advantage of fabric filters over the ESP is that their removal efficiencies are not as sensitive to changes in flue gas volumes, inlet concentrations, and small excursions in temperature typical of conditions in incinerators. The fabric filter's main advantage, however, is the superior collection efficiency and the even greater enhancement of particulate removal possible when used in conjunction with an acid gas scrubber. According to the California Air Resources Board, the overall mass collection efficiency in reverse-gas cleaned baghouses is 99.99% or greater with efficiency improving generally, with smaller particle size. (Figure 1 depicts fabric filter efficiency graphically.)

As experience with use of baghouses on coal-fired power plants and on resource recovery plants increases, their reliability has increased due to improvements in the design of bag fabrics, tailored for specific flyash properties and cleaning methods, and use of scrubbing devices to keep inlet temperatures lower. These measures have not only extended bag life to an average of five years or more but have also effectively prevented baghouse fires. Thus, well designed and operated baghouses have been shown, in a number of slipstream and full facility tests, to be capable of reducing overall particulate emissions to less than 0.01 -- and, in a number of cases, as low as .001 to .005 gr/dscf. (Table III) Based on the potential for greater removal efficiencies overall and in the sub-two micron particle size range, a number of states, including California, Connecticut and Michigan, as well as Environment Canada, prefer the use of scrubber/baghouses on proposed resource recovery plants.

Acid gas control

With regard to acid gas emissions, the environmental effects are more varied than with particulates. One regional environmental effect of emissions of HCl, HF, SO_2 and NO_x, is the well-known phenomenon of acid rain. Acid rain has been shown to affect adversely, forest growth, fish populations and other aspects of lake and stream ecology, and has caused increased weathering of buildings and statues made of marble and limestone.

Acid emissions from uncontrolled incineration of MSW under certain weather conditions, can potentially create acid fogs containing 18 to 20% HCl and having pH as low as 2, (Ref. 49) causing severe localized impacts on vegetation, paint finishes, iron and other corrodable materials in addition to the obvious effects on human health. Aside from these impacts, a few northeastern states have begun to ascertain that acid rain, when introduced into a water supply via open reservoirs, has the potential to dissolve copper and lead in pipes and pipe joints in water distribution systems and the lead in soil deposits near groundwater aquifers, hence rendering water supplies potentially toxic unless special water treatment is undertaken to reverse the acidity.

The control technology most often employed to remove SO_2, HCl, and HF from resource recovery emissions is flue gas scrubbers. These devices, usually positioned in the pollution control train either immediately after the boiler exit or sometimes after an ESP, capture these acid gases either by condensation, impaction and reaction of the gas molecules onto water droplets, in the case of a wet scrubber, or by impaction of the gas molecules onto alkaline slurry alone, or on both alkaline slurry and another agglomerating absorbent in the case of a spray dry scrubber, or on powdered lime in the case of dry injection scrubbers.

Though fairly effective at removing acid gases, wet scrubbers have a major disadvantage in that they consume great quantities of water, and the water pollution control devices necessary to clean the large quantities of salty effluent produced by the scrubber are considerably large and expensive. Another disadvantage of wet scrubbers is that they can be prone to acid corrosion. Wet scrubbers are also characterized by high pressure drops, requiring more energy to operate.

The major advantage of the wet scrubber is the longer operating history as compared with dry scrubbers. Wet scrubbers have been utilized on at least ten MSW incinerators in Germany and one in Japan with removal efficiences reported as high as 95% for HCl and HF, and 86% for SO_2 (Ref. 2, pp. 120-125), but apparently the disadvantages of wet scrubbers have discouraged their use to date on MSW incinerators in the U.S.

Spray dry and dry injection scrubbers, on the other hand, are coming more into favor in the resource recovery industry as experience with them increases, since the major drawbacks of wet scrubbers do not exist and high acid gas removal efficiency is not sacrificed. Disposal of the residue from spray dry and dry injection scrubbers is easier than from wet scrubbers, since a dry residue is produced either because water in the alkaline slurry is evaporated completely while acid gas capture takes place or because a dry powder is directly injected onto the refuse, into the furnace or into flue gases at the boiler or boiler exit. Also, since there is less water involved in the dry processes, corrosion of pollution control equipment and stack is reduced, and power consumption is less than for wet scrubbing. (Ref. 40, p. 6)

A major advantage of the spray dry scrubber is that use of lime or another absorbent may, through the agglomeration of particles by contact with the sprayed absorbent, enhance the overall removal efficiency of the control system for particulates as well as acid gases. Baghouse efficiency is improved because the bag cake formed as a result of prior dry scrubbing is of such character that it can become thicker, and a more effective filter of particulates. Thus, as the flue gases pass through the bag cake, additional control of SO_2 and acid gases (about 5 percent) is achieved (Ref. 32).

One scrubber vendor, Research Cottrell (Teller technology), adds an additional agent, Tesisorb, to the flue gas after the spray dry scrubbing process to cause agglomeration of fine particles into larger ones and to make the filter cake less hydroscopic. This technology purports to allow even more efficient capture of the particles by the baghouse or ESP, since the addition of Tesisorb also permits the formation of a more porous bag cake which can become a thicker, and more efficient filter of particles without excessive energy requirements. (Ref. 40, p. 6)

Since the decrease in temperature of the flue gases as they pass through a wet or spray dry scrubber has the ironic effect of decreasing the plume height from the stack due to the cooling effect of the added water, and this increases the ground-level concentrations of pollutants above what they would have been without the flue gas cooling, some researchers have suggested the addition of dry lime powder to the flue gas after combustion, or directly to the refuse instead of injecting a slurry after the boiler. These dry injection technologies are in their infancy, but the few tests done on these systems indicate a range of results with comparable removal efficiencies to spray dry scrubbing, thus, having the benefits of acid gas removal without the disadvantage of a lowered plume height caused by flue gas cooling. (Ref. 31, p 9), (Ref. 32, p. 33) A recent article (Ref. 11) alludes to another possible benefit of dry powder injection onto the refuse in addition to reduction of HCl in the combustion zone gases: reduction in chlorine available for production of chlorinated organics. This hypothesis should be tested in incinerators to show if adding lime prior to the boilers can be as efficient in controlling acid gas emissions as post-boiler acid gas controls.

On the other hand, there are a number of devices designed to maximize the condensation of flue gases to maximize recovery of both pollutants and energy. Two devices that can be used to decrease the temperature of flue gases after the boiler while recovering useful energy are (1) the addition of an extra economizer positioned prior to the emission control devices and (2) the clean gas economizer positioned after the control devices. The former can be designed with outlet gas temperatures as low as 140°C and can be used in tandem with spray dry scrubbers. The latter can be installed when flue gas existing conventional boilers is 220-250°C. A spray dry scrubber adjusted for less dilution water would minimize cooling in the scrubber and allow for further cooling (condensation) and energy recovery in the economizer, where temperatures as low as 100°C can be obtained. (Ref. 43, p. 6)

Another scrubber-related technology in its early stages of commercialization, the flue-gas condenser, positioned after the emission control devices and supplementary economizers, emphasizes the benefits to be derived from cooling the flue gases. In the direct condensation technology, flue gas is cooled by direct contact with water droplets, or humidification (condenser with heat pump). In indirect condensation, a heat exchanger cools the flue gas. Temperatures as low as 30 - 40°C allow quite effective condensation and subsequent removal, not only of acids, but also of organics and highly volatile metal vapors, such as mercury. In one case, a pilot plant trial of the indirect flue gas condensation process, conducted on the Avesta solid waste plant in Sweden showed a decrease in flue gas emissions as TCDD-equivalents (Eadon method) (from 1.8 ng/dry Nm^3 to 0.4 ng/dry Nm^3) of almost 80%. In addition, it has been reported that a further refined, full-scale, flue gas condenser is being installed on the larger Uppsala and Gothenburg plants. (This technology is becoming popular not only because of its efficiency in reducing dioxin, as well as HCl and mercury emissions, but also because by cooling the flue gas, heat is captured using heat pumps, and thus, 15-30% more energy can be delievered to the district heating systems.) (Refs. 3, 43)

However, with exhaust temperatures this low, increased corrosion is a possible result, but can be easily mitigated by using acid-resistant surfaces, or by adding alkaline absorbents prior to reducing temperatures. Investigations into corrosion resistant construction materials for condensers are currently being performed on pilot plants and funded by the Danish DOE. (Ref. 43, p. 8) Thus, plants equipped with acid gas controls can be amenable to lowered flue gas temperatures. (Ref 32, p. 63).

Since efficient condensation of flue gases also produces a lowered plume height which would result in higher ground-level concentrations of pollutants that are emitted, it is possible that much of the benefit of wet or spray dry scrubbers would be negated unless mitigative measures are taken. To counteract this effect of a lowered plume, technologies currently in use in power plants and in place in pilot MSW plants in Sweden have been developed to increase the velocity of the stack gases decreased by the addition of scrubbers (e.g. flue gas reheaters and/or larger induced draft (ID) fans at the base of the stack). Though not commonplace on U.S. resource recovery plants, reheaters are common on Japanese plants where wet scrubbers are also used, and one is in place on the Avesta plant, where a heat exchanger located near the condenser takes energy out and returns some of it to the reheater at the base of the stack, allowing full energy recovery. (Refs. 43, 50)

Based on performance data prior to 1984, control efficiencies of up to 98% for HCl and HF and 90% for SO_2 were generally achieved on full-scale as well as pilot-scale applications of spray dry scrubbers (Ref. 2, p. 138). Tests done on Teller scrubber-equipped plants indicate a capability of removing as much as 99%+ over a sustained period both for HCl and SO_2 (Ref. 57). In other tests of conventional spray dry scrubbers (Flakt, NIRO, DBA, Lurgi, etc.), it has been demonstrated that removal efficiency of HCl and SO_2 can approach 99% under optimal conditions (scrubber temperatures below 150°C and sufficiently high lime/acid ratios -- above 3 or so), but under less optimal operating conditions HCl and SO_2 emissions as low as 75% and 30%, respectively have been reported. (Refs. 21, 28, 31, and 42, p. 7)

In an article on the Malmo plant in Sweden, where the dry lime injection process (Flakt) is used in conjunction with a baghouse, emissions of dioxin equivalents (Eadon) are quite low (0.07 ng/dry Nm^3, a figure below the Swedish EPB's stringent goal for new plants of 0.1 ng/Nm^3 Eadon equivalents*), a 97.6 to 99.9% reduction over concentrations in the flue gas before entering the cleaning system. In fact, Olle Aslander, Deputy Director of the Swedish Environmental Protection Board has suggested that the lowest flue gas emissions of PCDDs and PCDFs in Sweden have been measured in plants using the dry lime injection system (Ref. 3), though equivalent values have been found on plants equipped with condensers (Ref. 4)

As a result of the encouraging reports regarding the high efficiency of the various scrubber technologies and also the increasing widespread concern over the effects of acid deposition, a number of regulations have been adopted in the last couple of years to minimize acid gas emissions from resource recovery plants. States have either required dry scrubbers (and baghouses) to be installed on new resource recovery facilities, or stringent emission limits or control efficiencies have been stipulated. For HCl, about 10 states require either 90% control and/or an emissions limit of 30-50 ppm. Some states also specify a control efficiency for SO_2 of 70-80% or an emissions limit of 50-100 ppm (see Table I).

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* (Eadon equivalents are measurements which represent the toxicity of the dioxin/furan mixture, incorporating both the overall quantity of the most toxic isomers of dioxin and furan present in an emission, and application of weighting factors for toxicity of the various isomer groups.)

NO_x

NO_x emissions are both precursors to ozone formation and acid rain. Nitrogen oxides from resource recovery plants can be reduced by three methods: reducing the nitrogen content of refuse introduced into the furnace (source separation), minimizing the quantity of NO_x generated during combustion (combustion modification), and reducing the quantity of NO_x in the flue gas stream (flue gas controls).

The three major combustion design modifications to control refuse-generated and thermal NO_x are: low excess air operation, staging of combustion, and flue gas recirculation. All three techniques are practical, and can and have been used individually or in concert to achieve reductions, not only in NO_x, but also in CO, hydrocarbons and organics as well.

As is the case with other pollutants, combustion modifications help to reduce production of NO_x, but formation of some NO_x is inevitable, necessitating use of flue gas controls to achieve any further reduction of these emissions. Three of the most promising NO_x flue gas control systems under development at present are selective catalytic reduction (SCR), wet flue gas denitrification (FGD_n) and selective non-catalytic reduction (SNCR). Though all of these technologies are in the early stages of development and commercialization for use on resource recovery plants, some show promise in other applications with removal efficiencies of 60 to 90%. (Ref. 2, pp. 99-102) Despite the relative lack of experience with such experimental systems on resource recovery plants, several facilities equipped for non-catalytic reduction of flue-gas NO_x (e.g. the Commerce project which includes an ammonium injection system - the Exxon Thermal DeNox process) have been planned for the State of California, to prevent aggravation of the high levels of ozone (which NO_x helps to create) and acid deposition. (Ref. 2, p. 29) In addition, as shown in Table I, maximum resource recovery emission limits for NO_x (ranging from 100 to 300 ppm) have been adopted by a number of states.

Products of Incomplete Combustion

Emissions of organic matter, such as the toxic dioxins and furans, carbon monoxide, hydrocarbons and PAH's (polycyclic aromatic hydrocarbons) are all produced as products of incomplete combustion (PICs) of carbon compounds as are some particulate emissions. Furnace conditions that result in ineffecent combustion, for example, low temperatures, wet refuse, large or discontinuous influxes of refuse, insufficient or too much oxygen, insufficient turbulence, and insufficient residence time. For the most part these compounds, particularly dioxins and furans, are thought to be created by the furnace and/or near the boiler outlet at low temperatures (roughly 300°C). (Ref. 60) While hydrocarbons and carbon monoxide are emitted in the gaseous form, toxic organics, such as dioxins and furans, and their precursors may exit the stack either in the vapor phase or condensed or adsorbed onto fine particulate matter which can be easily inhaled deep into the lungs.

In order to minimize formation of PICs, most researchers agree that the most efficient technologies involve design of the stoker, grate and furnace so as to allow optimization of combustion conditions. In fact, the level of CO emissions relative to CO_2 emissions is often used to indicate the efficiency of combustion in a furnace. Though a perfect relationship between good combustion (as measured by CO emissions) and dioxin emissions has not been firmly established, data does seem to show that inefficient combustion and high dioxin emissions are related, though efficient combustion usually, but may not always, be correlated with low dioxin emissions. (One example of the latter case was recently reported by the California Air Resources Board in a test of a hospital solid waste incinerator -- CO emissions never exceeded 50 ppm, quite a low figure, indicating good overall combustion efficiency, but total dioxin and furan emissions were well over 1,000 ng/m^3, a moderately high figure. -- Ref. 34) Thus, other factors (e.g. waste composition [e.g. 30% plastics], transient upsets, etc.) in addition to average combustion efficiency may influence the level of dioxin emissions.

One common design feature, the auxiliary burner, usually located in the furnace well above the grate, is installed for the purpose of maintaining a minimum temperature (often 1500 to 1800°F) throughout the furnace, particularly during the start-up and shut-down procedures and during upset conditions, for example, when the BTU value of the refuse falls or is inconsistent, due often to moisture content. (Application of auxiliary burners to resource recovery plants is required by a number of regulatory authorities in their guidelines and permits (see Table I).)

Three furnace design features which allow for more precise optimization of combustion conditions and which are typically used on modern resource recovery plants are (1) the capability to vary grate speed, so that the quantity and BTU value of refuse being burned at any particular time stays at a reasonably constant level, and (2) the capability of controlling the quantity of air injected under the grate (underfire air) and above the grate (overfire air), so that complete oxidation of PIC's can occur, residence time of the flue gases is optimized, and entrainment of fly ash from the unburned refuse on the grate into the flue gases can be controlled.

Another design feature commonly used in resource recovery plants is the ability to charge refuse on a continuous or near-continuous basis, so that a constant volume of refuse is incinerated at all times. Also fairly common on small waste incinerators is batch or ram-feeding of refuse. Batch fed processes have the major drawback that as each plug of refuse is charged into the incinerator, a transient upset condition, caused by rapid devolatilization of waste materials, momentarily depleting or lowering local levels of oxygen in the furnace, causes heavy transient loadings of unburned gaseous and particulate matter, often referred to as "transient puffs". This phenomenon has been documented on a batch-fed rotary kiln incinerator (Ref. 36) and at the Pittsfield, MA batch-fed, two-chamber, heat recovery units. In the latter case, continuous measurements of temperature and CO in the primary and secondary chambers showed periodic excursions which coincided with the frequency of charging (every ten minutes). Though the upsets were quite short in duration, and the overall average for CO was reasonably low (roughly 100-200 ppm), the short-term spikes were anywhere from two to ten times the average value (Ref. 41). As a result of this and other observations of this phenomenon, some researchers have hypothesized that transient puffs might be responsible for much of the PICs emitted by otherwise efficient furnaces. This underscores the importance of selecting a continuous feed system which maximizes the uniformity of the refuse fed into an incinerator as well as other designs and operation modes which minimize upsets.

Another common design feature of resource recovery plants which reduces the moisture content of the refuse before it enters the combustion zone is a preheater or inclusion of drying zones where preheated air is injected under the first part of the grate system, positioned prior to the burning zone. The rationale for improving the uniformity of the moisture content of the refuse is that wet refuse (or low BTU refuse) is more difficult to burn efficiently, and that fluctuations in refuse moisture (e.g. wet refuse following dry (or high BTU) refuse) requires more manipulation of the underfire and overfire air controls than if the BTU level remained constant. This situation also introduces a greater likelihood of error or upset in control of combustion efficiency.

In addition, a recent study of a municipal solid waste incinerator (Ref. 61, p. 5) indicates that the presence of water vapor in the flue gases at normal oxygen conditions (10%) results in a vastly increased production of dioxin and furan over dry conditions, with much greater quantities of the lower chlorinated tetra, penta and hexa forms produced at the same time that hepta and octa forms were reduced. Thus, there is evidence that preheaters and grate drying zones, designed to remove water from the waste prior to its entering the combustion chamber by utilizing some of the heat generated by the combustion process can improve combustion efficiency and result in lesser PIC production. Since the amount of research on this issue is meager, new studies, such as the ASME Pittsfield research project, which is designed, in part to determine the effect of water vapor (refuse moisture) on dioxin emissions, are eagerly awaited.

Another design feature used in certain, usually small, incinerators of solid and hazardous waste involves multiple combustion chambers or post-combustion chambers (sometimes referred to as afterburners), to permit greater control of temperature, oxygen and residence time. In Italy, for example, national legislation which came into effect at the end of 1986 required all municipal waste incinerators to be retrofitted with post-combustion chambers to improve combustion efficiency. This regulation, stipulating retrofit of post-combustion chambers designed to operate at 950-1050°C, 2 seconds residence time, 6% O_2 measured downstream, and 10 m/s through the chamber inlet has resulted in the shutdown of about 50 incinerators of large and small size, leaving only four in operation capable of meeting the requirements. (Ref. 37, pp. 2-3)

Research tests have been conducted on two Italian municipal solid waste incinerators to demonstrate the efficacy of using post-combustion chambers. In one case (Busto Arsizio) test results showed that the total PCDD (4-8) emitted by the plant in 1979 before retrofit of a post combustion chamber was 1030.2 ng/Nm^3, whereas after retrofit, 1984 test results showed total PCDD emissions of 12.3 ng/Nm^3, a decrease of almost 99%. In both cases the primary combustion chamber was operated at 800-1000°C, and in the second case the postcombustion chamber was operated at 950-1050°C and 2.5 - 3 seconds residence time.

The other incinerator tests were performed on an pilot plant incinerator equiped with a post combustion chamber, designed by the Italian Research Council to test the efficiency of using a post-combustion chamber. Two tests were performed, one which determined the efficiency of dioxin reduction with the post-combustion chamber on and the other with it off. In both cases, the primary combustion chamber was started up at 600°C, reached 950-1000°C and fell to 750°C by the end of the four hour test. In the first case, the pilot plant with the postcombustion chamber off (600-950°C) emitted 0.456 ng/Nm^3 after the primary chamber and 0.1164 ng/Nm^3 after the postcombustion chamber, a reduction of 74%. With the postcombustion chamber on (1100-1200°C), the initial reading after the primary chamber was 0.785 ng/Nm^3, falling to 0.186 ng/Nm^3 after the postcombustion chamber, a reduction of 76%. Thus, it appears that postcombustion chambers provide a considerable further destruction of dioxins, if they are operated even at suboptimal temperatures (possibly a result of the additional residence time at temperatures capable of destroying these compounds). (Ref. 6)

In some cases (e.g. large, excess air, mass burn units), in lieu of designing additional closed chambers positioned after the furnace, one or more bull noses (projections of the furnace wall) or arches are designed into the furnace to improve combustion efficiency by serving the dual function of (1) narrowing, somewhat, the passageway for flue gases from the grate area to the region in which overfire air is injected and (2) increasing turbulence in the overfire region which increases to some degree, the residence time in both the primary and overfire regions. New tests being conducted by Environment Canada on a mass burn incinerator in Quebec City after its furnace was redesigned to improve turbulence and maximize combustion efficiency will be compared with tests done prior to the redesign. Preliminary results, though not yet published, appear promising.

Though many researchers in the field agree that design and operation of incinerators to maximize combustion regulation is the best method of minimizing emissions of toxic organics, the destruction of all dioxins and furans in resource recovery emissions cannot presently be assured by these means alone. Fortunately, new research indicates that further reductions in these emissions can be effected by means of properly operated emissions control devices, such as a scrubber/baghouse or scrubber/ESP. New research on this subject is discussed in a later section.

Heavy Metals

Heavy metals emissions are created as a result of combustion of solid waste containing metals. As a result of the high temperatures and turbulence in a furnace, metals are released in both solid particulate and in vapor form, often as metal oxides, chlorides and sulfates. Depending on the metal compound involved (and its condensation temperature), it is theorized that in an uncontrolled incinerator, a vaporized metal begins to condense mostly on the surfaces of fine solid particles in the flue gas (since fines have the greatest surface area). This occurs at normal flue gas temperatures after heat recovery in modern incinerators (about 235°C and below) and essentially totally at temperatures below 100°C. (Ref. 32 p. 61) As many of the condensation points of metal compounds emitted by resource recovery plants, (lead, cadmium, chromium, zinc) are well above 300°C, the percentage of these metals that condense, and are thus capable of being removed by a particulate control device in a resource recovery plant can be quite high (close to 100% in many cases). The recent Quebec City scrubber/baghouse tests reported that over 99% of the heavy metals were removed at either 110°C or 204°C (with the exception of mercury). (Ref. 21) The Tsushima scrubber/baghouse also demonstrated a removal efficiency of over 99% for a total of 12 heavy metals at a baghouse outlet temperature of about 210°C (also with the exception of mercury). (Ref 1)

The spray dry scrubber/ESP-equipped plant at Munich-North achieved a 98% removal of cadmium, lead and zinc. (Ref. 5)

Mercury, however, has a lower condensation point, and is hence more difficult to extract than the other metals. Also, since much of the mercury emissions are in the form of mercury chloride, it had been theorized that removal of mercury compounds is accomplished based on both reaction (e.g. with lime) and condensation mechanisms. As is the case with condensable organics, removal of mercury has been demonstrated in resource recovery plants equipped with properly operated scrubbers for condensation and reaction and either ESP's or baghouses for collection of the mercury-laden particulate.

OPERATING PRACTICES/MODES TO MINIMIZE EMISSIONS

In the foregoing sections stoker, grate, furnace and air pollution control device designs and the removal efficiencies they are capable of achieving for various pollutants have been described. It is increasingly understood, however, that having well-designed, efficient equipment is only part of minimizing emissions from a waste-to-energy plant. To have the lowest achievable emission rate from a resource recovery plant also requires plant operators well trained in the operation of the furnace and related equipment as well as the emissions control devices to minimize emissions. For example, a resource recovery plant equipped with the latest, most efficient furnace and emission control devices is only as good as the people operating it. If, for example, the weigh scale operator and tip floor personnel permit dumping of refuse with unacceptable wastes (e.g. hazardous waste, white goods, automobile parts -- chrome bumpers and lead batteries, etc...), or if the crane operator alternates feeding small, wet loads with smaller, larger, dry loads high in combustibles, or if the control room operator permits excursions of CO or other indicators of combustion inefficiency, then even a well designed plant could generate high emissions.

In recognition of the increasing need for trained operators for all the new waste-to-energy plants coming into operation, a number of organizations are exploring training and/or certification programs for resource recovery plants operators. To address this need, an ASME committee comprised of individuals from a diversity of interested groups has been charged with designing universally applicable and transferrable qualification and certification requirements for operators of resource recovery facilities involving combustion processes, and has recently begun deliberations.

In the following sections are some operating practices that have been shown to be effective in minimizing various emissions.

Materials Separation To Prevent Emissions

As was mentioned earlier, certain emissions depend on the level of precursor elements or compounds in the solid waste itself. Acid gases are emitted from resource recovery facilities primarily as a result of combustion of heterogeneous refuse containing chlorine, sulfur, nitrogen and fluorine, usually in such forms as plastic, textiles, rubber, yardwastes and paper. A somewhat similar situation exists with respect to any household hazardous wastes and heavy metals in the waste stream. Much of the lead, nickel, mercury, and cadmium in batteries, for example, will vaporize in the combustion zone, later exiting the stack in the vapor state, and/or condense on fine particulate in fly ash, later collected on an ESP or fabric filter. The fraction of metals remaining, unburned, on the grate becomes bottom ash. (Disposal of fly ash and bottom ash adds to the cost of resource recovery and poses an environmental dilemma since this ash is often disposed of in landfills, and may, thus, result in a leaching problem affecting groundwater quality.) The presence of these metallic components in the waste stream also causes wear and tear on the stoker and grate equipment of a resource recovery plant.

It has been theorized that if, before solid waste ever enters the resource recovery plant to be burned, certain components (e.g. batteries, mercury thermometers, cans, household hazardous wastes, PVC plastics, etc...) were removed from the waste stream, then the emissions of certain pollutants would likely be reduced proportionately (e.g. heavy metals emissions from batteries and cans, chlorinated organic emissions from certain household hazardous wastes, solvents, and possibly from PVC, and HCl emissions from PVC). This theory is supported by the Swedish government which contends that removal of mercury and cadmium-containing items from the waste stream would reduce emission of these pollutants. Swedish statistics of interest regarding the metallic content of various refuse items include the following: Of the total cadmium in solid waste, 26% comes from plastics and 60% from metals -- most is said to come from cadmium batteries. Of total chromium, 42% comes from rubber and leather while 43% comes from metals. Of total mercury, 10% comes from plastics, 13% is found in paper, and 60% is in metals - much contained in alkaline batteries. The Swedes are already targeting mercury batteries and other items for separation from the waste stream for the expressed purpose of reducing emissions. (Ref. 16)

One way of removing unwanted wastes from the waste stream is already incorporated into the operating permits of most resource recovery facilities in the U.S. Certain bulky wastes such as large appliances and automobile parts, etc. are required to be removed prior to incineration. Large volumes of hazardous wastes must also be removed. Good operation of a resource recovery plant thus, already entails a certain degree of effective screening of incoming waste by vigilant personnel at the weigh scales and the tip floor as well as a careful crane operator.

However, with respect to acid and other emission precursors present in ordinary municipal solid waste (noncombustible heavy metals present in batteries and metal cans, for example), there is generally no such prior separation requirement. This may be true because little research has been done to validate the theory that prior separation of noncombustibles, or other specific waste components in which emission precursors are concentrated, would reduce certain emissions cost-effectively. A new research program, sponsored by the ASME Dioxin Committee and undertaken an the Pittsfield resource recovery plant should shed some light on the effects of separation or addition of PVC to normal refuse (PVC is roughly 50% chlorine), since test runs have been done with varying amounts of PVC in the waste stream to determine the effect on dioxin emissions.

In Japan, on the other hand, separation of waste components is used to a considerable extent. For example, in response to a blanket, retroactive, nationwide emission limit for HCl of 430 ppm, issued in the mid 1970s, half of the municipalities in Japan chose to institute plastic separation programs to achieve the limit. (Ref. 33). With respect to heavy metals, battery recycling occurs in Europe, and in Sweden, where the moratorium on constructing new waste-to-energy plants was replaced by stringent limits on, among others, emissions of mercury (.08 mg/dry Nm^3), it is stated in the guidelines that after appropriate products control measures have been imposed (i.e. organized collection of Hg batteries, etc.) it should be possible to decrease the statutory limit to 0.03 mg/dry Nm^3. (Ref. 3) One explanation for the Swedes' apprehension about mercury emissions: Mercury emissions from waste incineration plants accounts for 55% of the total emission of mercury from all sources in Sweden. This figure compares with 3% for cadmium, 1.5% for lead and 0.1% for chromium. (Ref. 16)

Recycling of batteries as well as thermometers and cans is done on a large scale in Japan with the intended purpose of reducing emissions of mercury and other heavy metals, such as lead, nickel, cadmium and zinc. One research study indicating the positive relationship between the number of mercury batteries in the waste stream vs. heavy metal emissions was undertaken in 1984 in Japan by the Tokyo Metropolitan Government, which reported that when several mercury dry cells were dumped in an urban incinerator in operation, the mercury emission level was observed to jump almost ten times from the usual level. (Ref. 47)

The separation/emissions reduction relationship has also been tested in a resource recovery plant in Gallatin, Tennessee. By utilizing a materials recovery system (NRT) to remove moisture, aluminum, steel, glass, dirt and other inert, noncombustible materials from municipal solid waste, substantial emission reductions were demonstrated for combustion of this waste over the emissions from normal MSW combustion. The reductions were most notable for certain metals (lead - 52%, chromium - 64%, cadmium - 73%) and PICs (complex hydrocarbons - 75% and carbon monoxide - 63%). In addition, the amount of ash and inerts in the NRT separated waste stream contained less than half the ash content of normal MSW. (This probably explains the decreased metals emissions, and indicates that less bottom ash would be produced, requiring disposal.) Also, incinerating various mixtures of preseparated and normal MSW showed that not only was reliability not sacrificed, but that plant availability improved as greater proportions of preseparated waste was burned over a period of 50 months. (Ref. 51)

Despite the potential feasibility of employing materials separation as an emission control technology, (and the savings both in terms of cost and equipment reliability, as well as costs and impacts of ash landfilling to be gained by prior separation of metals, for example) there has unfortunately been insufficient research to define with better precision, the relationship of emissions to the percentage of particular components in any given the waste stream, or the expected reductions of various emissions as a result of a given materials separation strategy, or the cost-efficiency of such alternatives. Thus, though it is not possible, at this time, to compare the efficiency of emissions reduction via materials separation with other BACT emissions reduction technologies, this is an area ripe for future research.

Grate and Furnace Operation to Maximize Combustion and Minimize Emissions

Proper operation of a furnace is increasingly recognized as being an essential component of control of certain emissions, particularly products of incomplete combustion, from resource recovery plants. In general, good furnace operation involves (1) provision of optimal refuse feed rate (so that the BTU value of the refuse, or fuel, does not fluctuate excessively), (2) optimal temperature (sufficient to ignite the refuse, but not so high as to increase formation of NO_x, increase vaporization of metals, or exceed the melting point of fly ash causing fouling of boiler tubes), (3) injection of the correct quantities of overfire and underfire air (to provide sufficient oxygen and turbulence to permit complete reaction of unburned matter with oxygen), (4) uniformly low moisture content in the refuse, etc...(such that sufficient furnace temperature can be maintained), supplemented with (5) use of a properly designed and operated particulate control device and scrubber.

Figure 3 shows the relationship between destruction efficiency of unchlorinated dioxin and other organic compounds in a laboratory. In order to obtain excellent destruction of these compounds (i.e. 99.99%), under well oxygenated conditions, temperatures in excess of 750 - 850°C are required -- the higher temperature applies to chlorinated organics. Further increases in temperature result in further increases in destruction efficiency.

Probably as important as the average tmperature maintained in a furnace is the minimum temperature below which refuse combustion is either brought to a halt or at which point an auxiliary burner commences operation. Dioxin emission tests recently performed on a number of Italian incinerators of various furnace design showed a significant correlation between PCDD and PCDF concentration and the minimal combustion temperature occuring in the furnace during a given sampling period. (Ref. 37.) Thus, transient upsets where the furnace tmperature temporarily goes below 800°C or so may account for much of the dioxin and other PICs emitted from incinerators.

Temperature is not the only parameter affecting PIC emissions. Figure 4 shows that the amount of oxygen present in combustion of pentachlorophenol, one of the dioxin precursors, considerably affects the temperature required to achieve a particular destruction efficiency. To achieve a 99% destruction efficiency, for example, 40% and 20% oxygen conditions will require about 725°C (1350°F), 2.5% oxygen present will require over 800°C (about 1500°F), and 0% oxygen conditions will require 950°C (1800°F). Increased destruction efficiencies will, of course, require greater temperatures.

In a real resource recovery plant, however, combustion conditions cannot be held constant as in the above examples based on laboratory tests. This is due in large part to variation in the moisture content and BTU value of the refuse, and to the fact that refuse charging is usually not perfectly continuous and uniform, as individual crane loads of varying quantity, density, BTU value, etc.. fall through the hopper to the grate. In light of this reality, it is difficult to maintain an optimal degree of mixing of temperature, oxygen and PICs in the furnace chamber at all times.

The presence of moisture in the refuse has a dampening effect on the temperature that can be achieved by combustion, as does an overly generous amount of excess air provided (sometimes due to air leaks in the furnace), and the cooling effect of the waterwalls of the furnace. Figure 5 shows the relationship between the temperature of combustion gases which can possibly be achieved by combustion vs. the amount of excess air provided for a number of solid wastes containing a variety of moisture contents. Since, as the previous graphs show, it is critical to the destruction efficiency of PICs to maintain adequate temperature and oxygen conditions, this graph underscores the importance of accurately adjusting the rate of overfire and underfire air to the continually changing characteristics of the waste. Figure 5 also shows that maintenance of both an excess air condition and a temperature of 1800 to 2000°F in burning refuses with varying moisture contents will require overall excess oxygen to be 7 to 11% or 50 to 100% excess air. If more air or oxygen is provided, this has a dampening effect on the temperature and residence time.

Another possible means of reducing dioxin and furan formation via furnace operations was discussed and supported by data in the recent paper by Vogg and Stieglitz (Ref. 61). In an experiment conducted on a municipal waste incinerator, fly ash exposed to synthetic flue gas (1000 mg HCl, 300 mg SO_2, 11% O_2, and 150 g H_2O per std. m^3) spiked with 300 mg of ammonia/std. m^3 showed a substantial suppressive effect on the formation of dioxins and furans of all homologue groups (roughly one-sixth for dioxins and furans) when compared with fly ash exposed to unspiked synthetic flue gas under the same temperature conditions. The explanation suggested by the authors is that ammonia serves to poison the metal halide catalysts ($CuCl_2$ in particular) thought to play an important role in dioxin formation. Additional evidence of this dioxin reduction mechanism has been shown in certain RDF pyrolytic systems via the mechanism of ammonia gas reactions which scavenge available chlorine, reducing the chlorination reactions (Ref. 35). As an added benefit to using ammonia injection to controlling dioxin, this technique may also prevent NO_x formation to some degree, since thermal De-Nox technology employs ammonia injection. Thus, though this data on ammonia's role in dioxin reduction is limited, the results, if validated in future studies by these and other authors, point to ammonia injection as another potential method of reducing dioxin formation via optimized furnace operations.

Thus, based on the above discussion, specific operations for optimizing combustion and minimizing emission of PIC's such as dioxins and furans in a mass burn, excess air incinerator are thought to involve

(1) subjecting the refuse being charged into the incinerator to a sufficiently long period of drying to reduce moisture content of the refuse to uniformly low levels prior to commencement of combustion by varying the rate of charging and the speed of the grates. This will be facilitated by continuous feeding of refuse to the grates in such a manner as to maximize uniformity in quantity and type of refuse, to the extent feasible, and

(2) subjecting all flue gases created by the combustion process to (a) a furnace temperature of 1800°F to 2000°F (greater temperatures can have deleterious effects) by varying grate speeds and overfire and underfire air, and by use of an auxiliary burner, if necessary, (b) roughly 7 to 10% oxygen, as measured after the furnace, (c) residence time of the flue gases for at least one and preferably two seconds at these temperature and oxygen conditions, and (d) sufficient turbulence to distribute the heat and oxygen evenly throughout the furnace.

In recognition of the fact that proper furnace operations are capable of producing more efficient combustion, most state resource recovery guidelines and permits include specific requirements regarding minimum furnace temperature, oxygen content, residence time, combustion efficiency, carbon monoxide level etc... These are presented in Table I.

Operations to Minimize NO_x Production

Generation of NO_x depends to a large degree on the availability of nitrogen and oxygen in the flue gas as well as the temperature. An increase of these factors serves to increase NO_x emissions. The three combustion technologies to control refuse-generated and thermal NO_x mentioned above as facility design modifications (low excess air operation, staging of combustion, and flue gas recirculation) also involve specific operations to minimize generation of NO_x. Preventing the temperature from exceeding about 2000°F will lessen formation of thermal NO_x, and regulating the amount of excess air provided as overfire and underfire air will also help achieve this effect.

Boiler Operation

New research conducted on an operating municipal solid waste incineration plant by Vogg and Stieglitz (Ref. 61), indicates that fly ash depositing on the boiler tubes in the cooler section might be a site of dioxin formation, and that the longer the residence time, up to six hours, of the ash in optimal atmospheric conditions for formation (300°C with constant exposure to typical incinerator flue gases), the greater the quantity of dioxins and furans formed. If these preliminary data are subsequently validated, it might eventually be demonstrated that an increased frequency of sootblowing of the boiler tubes, and possibly an improvement in cleaning techniques (e.g. by using ultrasonic devices) is warranted so as to minimize the opportunity for dioxins and furans to form there. Another technology, employed for the purpose of removing large flyash after the furnace and primary boiler and prior to the waste heat (cooler section of the) boiler, involves a cyclone precollector installed at the Malmo resource recovery plant in Sweden. Yet another technology to address this potential dioxin formation problem is in place at the Hogdalen facility: vertical economizer tubes designed to reduce accumulation of fly ash. (Ref. 48) Minimizing the degree of particulate buildup on boiler tubes should, in any event, improve the ability of particulate control equipment (especially ESPs) to function at optimal efficiency, since the rate of particulate loading into the control devices would be more constant.

ESP Operation

ESP efficiency has been shown to increase via improvement of operating procedures. Isolating sections of the ESP's during cleaning to avoid reintrainment of fly ash, is one method currently in use. Another involves passing the flue gases through the ESP with even distribution and at lower velocities, so as to maximize the residence time in the ESP and improve the ability of the ESP to remove particles. A third operating technique involves recirculation of flue gas, which increases the likelihood of the fly ash particles in the flue gas being collected by the ESP on subsequent passes.

Also, in recent studies of the influence of plant design and operating procedures on emissions of PCDD's and PCDF's, a number of solid waste incinerators of different design were examined and found to have ESP temperatures often higher than necessary to avoid acid condensation, creating unnecessarily high vapor phase PCDD/F concentrations, reducing collection efficiency ofthe ESP for those compounds. Additionally, the research found that airflows through ESPs were not uniform and rapping rates wre often not ideal to prevent particle carry over. The authors recommend fitting transmissometers to monitor the performance of the plant, enabling operation practices to be optimized. (Ref. 63, p. 18)

Baghouse Operation

As experience with operating baghouses has increased over the last several years, improvements in removal efficiency have resulted from optimizing the vigor with which and frequency at which baghouses are cleaned (i.e. leaving the bag cake on long enough to increase the filtering capacity, but not so long that the power requirements are driven up and filtering becomes difficult).

In addition, as recently promulgated state standards suggest (Table I), operation of baghouses at low temperatures can also effect improvement in removal efficiency of the equipment. As have been shown in a number of slipstream and full facility tests, baghouses, when operated properly at low temperatures (below the condensation points of the various constituents of the flue gas), are capable of reducing overall particulate emissions to less than 0.01 -- and, in a number of cases, as low as .001 to .005 gr/dscf. (see Table III)

Scrubber Operation

Scrubber efficiency is optimized by maintaining uniform gas dispersion, atomization, sufficient mixing of flue gas throughout the scrubber, injection of sufficient alkaline material to react with the acid present (stoichiometric or lime/water ratio) (see figures 6 and 7) and by allowing sufficient residence or drying time at the low temperatures. In addition, it appears that the lower the temperature in the scrubber, the better the reaction and removal efficiency, probably due both to increased condensation of such pollutants as organics, heavy metals and acid gases, as well as to the decreased flow rate of flue gas caused by the lowered temperature, which results in longer flue gas residence times, allowing greater reaction efficiency. Figure 8 shows the influence of spray dry scrubber outlet temperature (or approach to adiabatic saturation temperature) and equivalence ratio (or lime consumption) on HCl removal using a single pass with lime absorbent. Since the lime consumption required for 90% HCl removal almost doubles when the outlet temperature is increased from 140°C to 170°C, it becomes apparent that operation of the spray dryer at a lower outlet temperature has its advantages. (Ref. 10)

In order to maintain uniformly low acid gas emission levels as waste composition and conditions in the furnace are constantly changing, a new automatic response control system has been developed by NIRO which is purportedly capable of both fast response and reagent savings. Such a device would obviate the need for constant operator monitoring and adjustment of reagent and water. One spray dryer equipped with this feature has been installed and others will be in operation in the next year. (Ref. 43, p. 5)

RECENT RESEARCH INTO THE RELATIVE EFFICIENCIES OF VARIOUS DESIGNS AND OPERATIONS

Considering the array of combustion and emission controls and modes of operation currently available for use in a resource recovery plant, a municipality contemplating the decision of which technologies to employ must first decide whether cost or efficiency will be the primary controlling factor. If it is decided that the goal is the lowest achievable emission rate and least environmental impact, with cost as a secondary consideration, then it would follow that the most efficient configuration of stoker, grate, furnace, and emission control devices would be chosen, and that priority would be given to having plant personnel highly trained in the operations which would enhance to the greatest extent the emissions reduction capability of the plant. It would also follow that municipalities planning a number of resource recovery plants, and whose primary consideration is the lowest achievable environmental impact, would keep abreast not only of new designs and devices in the fields of plant and emissions control design and and best operations practices, but also of tests of the destruction and removal efficiencies of these technologies in actual practice.

The debate over whether baghouses or ESPs are a superior choice for particulate control in a resource recovery plant has, in the last year or so, taken a new twist with the advent of the multi-field ESP. The data in Table III and Figure 9, a graph of test results listed in Table III, illustrates the greatly improving trend in the control of particulate emissions by both ESPs and fabric filters since 1970. These data demonstrate the overall superiority in particulate emissions achieved by baghouses vs. a two-field ESP. Figure 1 also indicates that, at least for two-field ESP's, the removal efficiency for fine, submicron particles is considerably less than that achieved in a fabric filter. However, for larger ESP's very little removal efficiency data is available, especially with regard to particle size. In a recent test at the Baltimore RESCO plant, equipped with a three-field ESP, however, the removal efficiency for particulate is well over 99%, close to three orders of magnitude (Ref. 15). Despite the excellent performance of this installation, the figures for overall particulate emission rate achieved by 3- and 4-field ESP's given in Table III show that fabric filters tested today are still somewhat superior on average to even larger ESPs.

More specifically, the test results in Table III indicate that half of particulate emission measurements were less than 0.015 gr/dscf, and about 40% of the plants emitted 0.01 gr/dscf or less -- most sampled since 1983. At stark contrast, the current federal limit for particulate emissions is 0.08 gr/dscf and some states' limits are 0.03 gr/dscf. Some forward-looking states, listed in Table I, have recognized the improvements in particulate control technology and have promulgated particulate emission limits of as low as 0.01 gr/dscf and the Swedish particulate matter limit is now 0.008 gr/dscf calculated on a monthly average. The data in Table III also show that, on average, the emissions of fabric filter-equipped plants has always been and continues to be lower than that from even the best new plants equipped with multi-field ESPs. For example, of the plants emitting at or below 0.01 gr/dscf, 17 were equipped with fabric filters, two were equipped with 3 or 4-field ESP's, and 3 were 2-field ESP-equipped plants.

Monitoring new developments in technology and operations and the quality of performance of new plants has become especially important in recent years, as the correlations between dioxin and other PIC emissions and design and operation of baghouses, dry scrubbers, and furnace operations have been investigated and practical experience on resource recovery plants has increased. For example, just a few years ago the resource recovery industry generally considered that the best control equipment available for control of dioxin emissions (those of greatest interest to the public, and hence, to municipalities and industry) was a modern mass burn, waterwall, excess air incinerator of European design, in combination with a two-stage ESP as was the case in the Chicago, N.W. and Zurich Josefstrasse plants. This contention was supported by test data which showed that these plants achieved dioxin emission levels of 42 to 113 ng/m^3 respectively, over one order of magnitude lower than other plants in operation then (e.g. Hampton, Va. 2300 ng/m^3 (Ref. 30) and Hamilton, Ont. 3680 ng/m^3 - personal communication - Kay Jones).

However, just in the last few years, the reduction of acid gas emissions has increased in importance, and plants in Europe and the U.S. designed with baghouses or larger ESP's, as well as dry scrubbers have been tested. The results show even greater emissions reductions, not only for dioxin and furan, but also for particulates and acid gases. Table IV provides a comparison of total dioxin and combined dioxin and furan emission data from the old-style Chicago and Zurich mass burn plants with that from newer mass burn municipal solid waste incinerators. The data show that, in general, as new plants are built with the latest efficient technologies and experience with operating these plants increases, lower total emissions of dioxins and furans are achieved. For example, with respect to total dioxin and furan, in terms of ng/m^3, Chicago emitted 505, (Ref. 8) and Zurich Josefstrasse 202 (Ref. 17), whereas Westchester and Tulsa, both 3-field ESP-equipped plants, emitted 77 and 34 respectively (Refs. 14, 19), and Wurzburg and Marion County, both spray dry scrubber/baghouse-equipped, emitted 50 and 2, respectively (Refs. 18, 27). In terms of total PCDD only, the difference was also on the order of an order of magnitude less, except for Marion, which was another order of magnitude lower. It is not insignificant that the baghouse temperature at Marion County during these tests was on the order of 260°F (125°C). (Ref. 18)

A comparison of old Italian incinerators without post-combustion chambers were compared with modern incinerators both with and without these devices, showing similar results. The older plants emitted a range of 19 to 189 ng/Nm^3 of TCDD -- average 65 -- (quite high figures when one considers that the figures in the previous paragraph are for PCDD). The newer plants without post-combustion chambers emitted 0.2 to 20 ng/Nm^3 TCDD (average 12.2) and the newer plants with these devices emitted a range of 0.1 to 20.9, with an average of 4 ng/Nm^3, over an order of magnitude below the average for older plant emissions. (Ref. 37, p. 9)

Technological developments have not been confined only to improving the performance of new plants; retrofitting of new technologies and application of new, improved operating techniques to older incinerators is also proceeding, showing promising results in most cases. One example of a plant which has been successively redesigned and retrofitted with new and better designs of furnace, grates and emission control devices is the Avesta plant in Sweden. After this small waste-to-energy plant, equipped with old ESPs was first measured for dioxin and furan emissions in 1984, and found to emit about 100 ng/dry Nm^3 TCDD equivalents (Eadon method), a modified grate system was installed, the furnaces were rebuilt and the air leaks into the furnace closed. After these improvements were made, new measurements indicated emissions of 4-6 ng/dry Nm^3 equivalents, a 95% reduction. Still not satisfied, the plant management ordered that operations be routinely performed which would optimize the efficiency of the controls. This lowered dioxin emissions to 1.8 ng/Nm^3 equivalents, another 64% reduction. The final improvement, discussed earlier, was the trial of a pilot plant equipped with a flue gas condenser which reduced emissions to 0.4 ng/Nm^3 equivalents (within the new Swedish goal for dioxin emissions from existing plants), another 77% reduction. (Ref. 3) The total reduction in dioxin emissions achieved by the improvements to the design and operation of the grate, furnace and emission control systems amounted to 99.6%, almost three orders of magnitude. That such great reductions in dioxin (and probably all other) emissions from an older solid waste plant have been demonstrated via retrofitting and better operations should provide quite a bit of encouragement to those municipalities that still have such plants in operation, and that would like to improve them for improved long-term operation.

Also in the past couple of years, some data has been generated to address the theory that major reductions in dioxin and other organic emissions, over and above that achieved by good combustion design and practice, can be achieved by use of a properly operated scrubber and baghouse. This theory, first proposed by Teller and Lauber in 1983 (Ref. 55), suggested that 99% of toxic organic compounds can be removed by passing flue gas first through a spray dry scrubber which would provide cooling, preferably to about 120°C, thereby condensing the dioxins onto particulate in the flue gas. The organics-laden particulate would then pass through a baghouse which would remove them from the flue gas. The New York State DEC Technical Guidance Document for operation of resource recovery plants supports the theory, suggesting that the lower the temperature of flue gases entering the pollution control devices below about 300°F (150°C), the greater the amount of phenols and benzenes which will be condensed and collected on the particulate, along with dioxins and other organics. In addition, the more efficient the collection device, the more efficiently condensible products of incomplete combustion will be removed from flue gas. (Ref. 32, p. 31) The Swedish government also recognizes the important role of flue gas condensation. In their recent paper both direct (humidification) and indirect (heat exchanger) methods of flue gas condensation as well as dry scrubbing with lime are cited as useful in reducing dioxin, mercury and HCl emissions as well as other organics. (Measurements of dioxin equivalents below the new plant emission limit of 0.1 ng/Nm^3 have been recorded on four installations in Sweden using these devices.) (Ref. 4, p. 5)

A number of pilot and full-scale incinerator studies have been undertaken in the last year or two which demonstrate the validity of the condensation and collection theory. Both the NIRO pilot test of a spray dry scrubber/baghouse in Copenhagen and the Flakt pilot tests in Quebec City of both dry lime powder injection and spray dry scrubbers all demonstrated that under optimal conditions (temperatures as low as possible), removal efficiencies of 99% or more were achieved with lesser removal efficiencies at higher temperatures. (Refs. 21, 35)

Similar studies of dry or wet scrubber/older ESP-equipped incinerators also demonstrate the achievement of significant removal efficiencies, particularly when flue gas temperatures are less than 150°C. However, it appears that scrubber/baghouse-equipped plants may have greater dioxin removal efficiencies at any given temperature than do the older ESP-equipped plants, possibly because of their superior particulate removal efficiency, and/or the capability of adsorption of vapor phase dioxins on the bag cake. Figure 10 illustrates the relationship of flue gas temperature in the collection device to dioxin removal efficiency based on preliminary data from a number of incineration plant tests. In the coming years as more new resource recovery plants come on line and are tested, more data will undoubtedly become available to prove or disprove this theory.

An additional explanation for the temperature dependency of dioxin removal efficiency by emission control devices is based on a recent article by Vogg and Stieglitz (Ref. 61). Their most recent studies of dioxin formation and destruction in municipal solid waste incinerators, demonstrates that the formation of dioxins and furans in the boiler fly ash takes place at temperatures between 220 and 400 °C (this same result had been found in laboratory experiments on incinerator fly ash in 1985). This might explain why the temperature vs. dioxin removal efficiency relationship seems to fall off at higher temperatures (say 300°C or so).

As is the case for organics, it has been demonstrated that resource recovery plants equipped with efficient particulate and acid gas control devices and operated to maximize reaction, condensation and collection in the emission control devices can reduce mercury emissions by as much as 99%. For example, the Quebec City tests demonstrated 0% removal of mercury at 204°C, but over 90% removal at temperatures below 140°C. (Ref. 21) Incinerators equipped with ESP's and scrubbers also have demonstrated high removal efficiencies of mercury at low temperatures (e.g. 50% removal was achieved at a temperature of 150°C at Munich-North) (Ref. 5) and at the recently retrofitted Zurich Josefstrasse, (spray dry scrubber and large, 2-field ESP) a removal efficiency of 94% was achieved at a temperature of 120°C by injecting a small amount of dry additive (proprietary) upstream of the spray dryer for the purpose of enhancing mercury removal. (Ref. 9)

One reason for this is the lower condensation points of mercury and its salts relative to the other metals (around 300°C). Thus, as is illustrated in Figure 11, the removal of mercury varies considerably, depending both on type of collection device and the temperature at which the device is operated, with superior removal efficiencies, in general, at temperatures below about 150°C and using both a scrubber, and a baghouse rather than an ESP. These results would have been expected, since, at a given lower temperature, scrubbers would provide the capacity to condense and adsorb the gaseous mercury chloride and other mercury salts and because the baghouse has a greater capacity to entrain the finer particulate on which the mercury compounds preferentially adsorb. Another possible explanation for the baghouse's relatively greater mercury removal efficiency is that ESP's tend to suffer a considerable decrease in particle removal efficiency at and near temperatures of 175°C. (Ref. 54)

NEW YORK CITY'S EXPERIENCE/ GENERAL CONCLUSIONS

It seems clear from the data presented, that due to the continuing advances in control technology design and operation, removal efficiencies for the particulates and acid gases have been improving over recent years. It is now recognized that the use, both of optimal furnace and emissions control designs and operating techniques, serves successfully as a "belt and suspenders" approach in minimizing emissions. The array of emission control equipment designs available today for use on resource recovery plants, including simple 2-field ESPs, larger 3-, 4- and 5-field ESPs and fabric filters for control of particulate and certain heavy metals, various kinds of scrubbers (dry lime injection, spray dry, spray dry with agglomerating agent, wet, and condensation) for control of acid gases as well as condensables -- organics and mercury, and ammonium injection and other NO_x control technologies presents a large menu of devices suitable for meeting varying requirements influenced by political, regulatory, economic and other factors. Optimal stoker, grate and furnace designs, involving the use of continuous feed systems, preheaters or drying zones, variable grate speed, variable overfire/underfire air injection, bull noses and/or post-combustion chambers have also been shown to be important in achieving high removal efficiencies. In addition, research has shown that the use of combustion regulation techniques, such as proper excess air control, drying of refuse, use of the auxiliary burners, etc... to improve furnace efficiency and also proper operation of emissions control equipment (e.g., maintaining low temperatures and optimal pollutant loading and cleaning cycles in the case of particulate removal devices, and using sufficiently high stoichiometric ratios of lime and residence times in the case of scrubbers), are critical to attaining optimal destruction and removal efficiencies. In tests conducted over the past two years or so, it has been demonstrated that properly operated, efficient emissions control devices achieve removal efficiencies of as much as 99% for particulate (overall and fines), HCl, SO_2, organics, and heavy metals, particularly if a scrubbing device is used in tandem with a baghouse, and thus, the relative impact of such plants on human health and the environment should eventually become insignificant in comparison with the many other uncontrolled (or less well controlled) pollution sources in the industrial and urban environment.

In this climate of fast paced, new research and plant testing, evolving theories about the causes of emissions from resource recovery plants and the effect of plant design on emissions, improving control technologies, new developments in operating procedures to optimize combustion and minimize emissions, the City of New York has been formulating and proceeding with its citywide resource recovery program. In step with the above developments, and out of recognition of the City's physical environment, demographics, and regulatory requirements (e.g. high ambient background levels for certain pollutants, the City's nonattainment status for CO and ozone, predominance in certain areas of elevated receptors and canyons caused by the skyscraper landscape, etc...), the City's resource recovery program has been evolving, giving major priority to choosing reliable and efficient technologies to meet any standards or guidelines imposed upon it by state or federal regulatory authorities and to minimizing emissions of the pollutants of concern (and particularly dioxins) with cost considerations as secondary.

In the case of the City's first proposed plant, to be at the Brooklyn Navy Yard, the initial plan, several years ago, was to use modern, mass burn, waterwall, excess air units of a reliable European design, and for emission control was a two-field ESP -- equivalent to the best available at the time: the Chicago, N.W. and Zurich Josefstrasse plants, as evidenced by their, then superior, dioxin emission concentrations. However, a few years ago, as a result of new research and upon the suggestion of the project's Citizens

Advisory Committee, the decision was made to expend more money to improve the emission control design for the plant to include and spray dry scrubber and fabric filter in lieu of the old-style ESP. (This decision was made well before the draft New York State resource recovery guidelines were even announced.)

Specifically, the present plan for the Brooklyn Navy Yard plant includes such environmentally sound designs as (1) barge-fed (rather than truck-fed) refuse delivery and storage, (2) a volumetric feeder in which the speed is continuously modulated by a control system based on steam demand, (3) a steam heated combustion air preheater to heat air to about 250^{o}F, (4) a three-zone reciprocating grate system, (drying, combustion and burnout zones) inclined to 18^{o} from horizontal, with fifteen primary air zones arranged according to the configuration of the grate modules, and a high-pressure-drop design to ensure uniform air distribution throughout the fuel bed, (5) an automatically controlled, preheated primary air system with the air to come from the refuse area to minimize odors, (6) an overfire air system with nozzles in all four walls to promote turbulence and complete combustion, (7) an auxiliary burner for each boiler for start-up, shutdown and temperature maintenance in the overfire air zone, (8) superheater tube cleaning by mechanical rapping, and steam-generating and economizer section cleaning via a steam soot blowing system to allow for different cleaning cycles as required, (9) for acid gas control, a spray dry absorber for each boiler, designed for a 240^{o}F normal outlet gas temperature which is automatically controlled to an adjustable setpoint, (10) for particulate control, a 10-compartment fabric filter with a guaranteed outlet particulate loading of 0.015 gr/dscf for each boiler, and (11) an induced draft fan located downstream of each fabric filter.

The proposed operating practices for the Brooklyn Navy Yard plant would involve (1) optimal operation of the refuse feed rate, stoker system and preheater to assist burnout of high moisture MSW, (2) optimal control of primary combustion air and grate motion to suit quantity and heating value of refuse fed onto the grates, (3) maintenance of total combustion air at a pre-determined excess air value measured by an O_2 monitor at the boiler flue gas exit stream, (4) maintenance of a temperature profile in the furnace such that temperature in the grate region would be about 2200^{o}F, in the overfire air region would range from 1875 to 2000^{o}F, and would be about 1350^{o}F at the furnace exit, (5) use of temperature monitoring devices so as to optimize use of the auxiliary burners to maximize the destruction of PICs, and (6) use of SO_2 monitors to allow for proper adjustment of the ratio of dilution water and absorbent for the lime slurry to the scrubber. (Ref. 25, section D-13).

Considering the variety of options available for municipalities in terms of furnace and emission control devices and operating modes, the City of New York has taken and continues to take a forward-looking approach to making its resource recovery plants as environmentally acceptable as is feasible while maintaining reliability, keeping itself up-to-date on the latest lab research, incinerator test results and new technologies and operating techniques which show promise for reducing emissions, and choosing the most efficient, proven options available to minimize environmental impact on this densely populated metropolitan area. While it is a certainty that the environmental needs and political, economic and regulatory framework of every municipality is unique, each will, hence, have a different set of influencing factors in choosing a pollution control strategy (i.e. either efficiency first, cost second, or vice versa); and even those communities who choose the same pollution control strategy may decide to choose different combinations of overall design technology (mass burn or RDF), furnace design, emission control design, operating practices, etc. depending on a myriad of factors (including local regulatory requirements, the levels and mix of background pollutants, local landscape topography and wind/stability patterns, and public attitudes towards burning, landfilling and participating in recycling programs). One thing is fairly certain; progress will continue to be made in development of new and more efficient designs and operations, mysteries regarding the causes of emission formation and destruction will continue to be resolved as new laboratory, pilot-scale and full-scale incinerator research is completed, and performance tests of efficiently designed and operated equipment will continue to show improvement over time. Whether the lessons learned in the resource recovery industry regarding the optimization of pollutant destruction and removal efficiency are subsequently applied to reducing emissions from other, possibly worse, combustion sources of dioxin and other troublesome pollutants in the environment (incineration in old units, hospitals, apartments, schools, etc..) is still a question.

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63. Woodfield, M.J., et. al., "The Influence of Plant Design and Operating Procedures on Emissions of PCDD's and PCDF's", presented at ISWA/WHO-EURO seminar on Trace Organics Emissions from Incinerators, Copenhagen, Jan. 20-22, 1987.

TABLE 1

RESOURCE RECOVERY EMISSION REQUIREMENTS FOR VARIOUS STATES

Pollutant	New York Guidelines 12% CO_2	California Guidelines 7% O_2	San Marcos Permit 12% CO_2	Penn. BAT Criteria 7% O_2	Erie, PA Permit 12% CO_2	New Jersey Guidelines 7% O_2	New Jersey Essex Cty Permit 7% O_2	Conn. Bristol Permit 12% CO_2	Maine Portland Permit 7% O_2	Mass. Rochester Permit 12% CO_2	Michigan Jackson Permit 12%CO_2
Particlte gr/dscf	.02	.01	.01	.015	.015	.015	.02	.015	.010	.03	.015
(sub- 2 micron)		.008	.008				.03 sootblw		.008		
HCl	50ppm/8 hr or 90% red	30ppm	30ppm/8 hr	30ppm/1 hr or 90% red.	50ppm/1hr or 90% red	50ppm/ 1 hr or 90% red.	50ppm/ 1 hr or 90% red.	50ppm or 90% red	30ppm	50ppm or 90% red.	71ppm
HF	--	--	3 ppmv/8hr	--	--	--	.82 lb/hr	--	--	--	--
SO_2	--	30 ppm	30ppmv/8hr	50 ppmv/1hr or 70% red.	50 ppmv/1hr or 70% red.	50ppmv/1hr or 80% red.	100ppmv/1hr or 70% red.	130ppm --	30ppm --	65ppm --	86ppm --
H_2SO_4	--	--	--	--	--	--	4 lb/hr	5.3ppm	--	--	--
NO_x	--	140-200ppm	200ppmv/8hr 425ppmv/1hr	--	--	300ppm/1hr 200ppm/3hr	300ppmv/1hr 95 lb/hr	339 ppm	100 ppm	196 ppmv	311ppm
Hydrocarbons	--	70 ppm	30 ppmv/8hr			case by case	70ppmv/1hr	--	--	--	26mg/m^3
VOC	--	--	--	--	--	--	--	70 ppmv	28 ppm	--	--
CO	--	400 ppm	400ppmv/8hr	400 ppmv/8hr 100ppmv/4day	250ppmv/1hr 120ppm/1day	400ppm/1hr 100ppm/4day	400ppmv/1hr 126 lb/hr	--	100ppm/8hr 80ppm/24hr	322 ppmv	400ppm/1hr 113ppm/24h 63ppmv/1yr
Dioxin	--	--	--	--	2ng/nm^3 toxic eqv		1 E-5 lb/hr 2378 TCDD			1.1pg/m^3 ambnt part 2.2pg/m^3 ambnt vapor	.52ug/dscm
Furan											.50ug/dscm
Furnce Temp Desgn	1800°F	--	--	--	--	1800°F	--	1800°F	--	--	--
Min. Temp. Furn	1500°F over 15min	1800°F +/- 200 F	avg 2000 F +/- 200°F	1800°F		1500°F	1600°F	1500°F	1800F/1sec 1500F/3sec	1800°F	1800 F/1hr
Min Res Time Furn	1 sec	1 sec	2 sec/1800F	1 sec		1 sec	1 sec	1 sec	1sec/3 sec	1 sec	1 sec
Min Res. Time Scr	--	--	10 sec	--	--	--	--	--	--	--	15 secs
Max. Baghse Temp	--	--	265°F	--	under consideratn	--	--	245°F	--	--	--
Combustn Effncy	99.5%/8hr 99.8%/7day	--		99.9%/4day	99.8%/2hr	--	--	--		--	--
CO/CO_2			.0033						.002		
Min. excess O_2	--	--	30% var.lim		3%	case-by-case	6%	3%	--	--	7%
Opacity	10%/ 6 min	--	10% sub 0, 3min 1 hr	30% sub 10% 3min 1 hr	30% sub 10%3min 1 hr	20%	20% sub 40% 3min 30min	10%	10%	20%	10% 76 min
Aux. Burner Rqd?	yes		yes	yes	yes	yes	yes	yes	yes		yes

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TABLE 2

RESOURCE RECOVERY CONTINUOUS EMISSION MONITORING/TESTING REQUIREMENTS FOR VARIOUS STATES

Pollutant CEM/ Parameter	New York Guidelines	San Marcos Permit	Penn. BAT Criteria	Erie, PA Permit	New Jersey Guidelines	New Jersey Essex Cty Permit	Conn. Bristol Permit	Maine Portland Permit	Mass. Rochester Permit	Michigan Jackson Permit
Opacity	x	x	x	x	x	x	x	x	x	x
HCl	x		x	x	x	x	x	x	x	
SO_2	x	x	x	x	x	x	x	x	x	
NO_x		x		x	x		x	x	x	
CO	x	x	x	x	x	x	x	x	x	x
CO_2	x	x	x	x			x			x
O_2	x	x	x	x	x	x	x	x	x	x
Furnace Temp	x	x	x	x	x	x	x	x	x	x
Combustion Effcny	x		x							
Other	ESP/FF conditions	Organics Flow rate Volume				ESP Conditn flow rate Volume	Pressr Drop VOC, H_2SO_4			
Telemetering	no	x	no	no	x	no	x	daily reprt	no	no
Stack Test Freqncy	18 mo.	12 mo.	6 mo. exc. PCDD/F 1 yr	6 mo. except PCDD/F 1 yr		3 mo. metals 1 mo. lead 5 yr. others	24 mo.	indeterm.	not specif. exc. PCDD/F 3 mo. if lmt is exceeded	12 mo. HCl
Operator Cert. Rqd	x	no	no	no	no	no	x	no	no	no
Ambient Monitoring Required	no	Must Pay fr Downstrm Monitors	no	no	no	no	no	Must Pay TSP, metals Ambient Mon	DEQE Reserves Right to Require	no
Noncompliance	Rept. to DEC w/in 1 day	Shutdown if T < 1800F	Shutdown if T < 1600 F O_2 < 3% CE < 99.5% Opacity > 10%	Shutdown if T < 1450F/5min O_2 < 3%/5min CE < 99.8%/2hr Opacity > 10% CO > 250ppm/2hr PrsrDrp > 25"/5min		Shutdown if T < 1500F O_2 < 6% Opacity exceeded	Shutdown if TSP > .02gr dscf	Shutdown if *	If PCDD/F **	Shutdown if T < 1600 F

* Shutdown if total dioxins exceed 24.5 x 10^{-6} lb/ton or if total furans exceed 16.5 x 10^{-6} lb/ton.

** If Dioxin and Furan emissions exceed 608 ng/m^3, 1) must reduce RDF firing by 10%, 2) build 350 ft. stack, 3) remove dioxin precursors from waste, 4) conduct dioxin emission tests at a 3 mo. frequency, 5) conduct ambient monitoring at three locations.

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Table IV

DIOXIN EMISSIONS FROM MASS BURN PLANTS
1967-1987

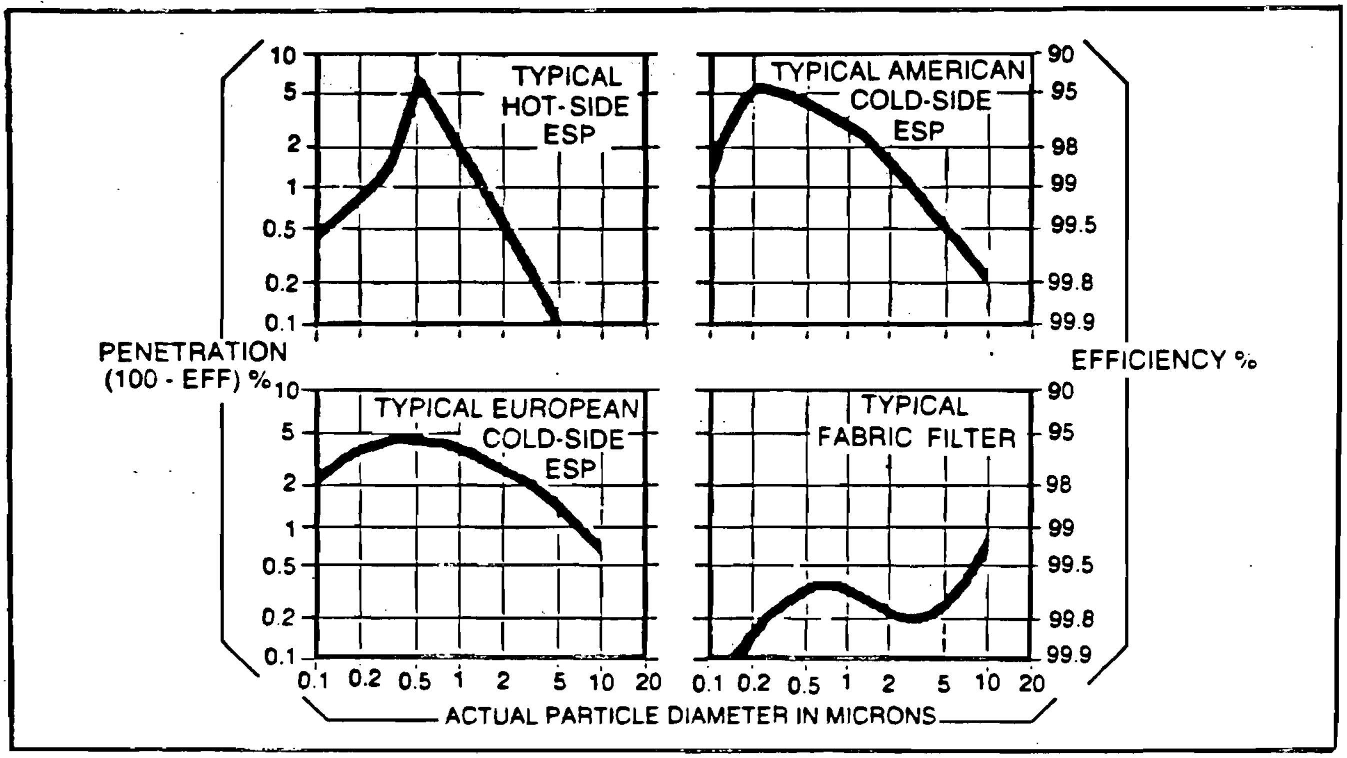
Plant	Start Date	Vendor, Incineration Technology	Emission Control Devices	PCDD ng/m^3 (4-8)	Reference
<u>EARLY PLANTS</u>					
Borsigstrasse	1967	Martin, MB, WW	Spray Scr/ESP	151 (3-8)	Nottrodt
Stellinger Moor	1972	Martin, MB WW	Spray Scr/ESP	114 (3-8)	Nottrodt
Stapelfeld	1979	Steinmuller, MB, WW	Wet Scr/ESP	42 (3-8)	Nottrodt
Umea, Sweden	1970	Von Roll, MB, WW	2-field ESP	189.6	Marklund
Saugus, MA	1975	Von Roll, MB, WW	2-field ESP	169.3 267.6	Radian
Chicago, N.W.	1971	Martin, MB, WW	2-field ESP	45 (3-8 w/o 5)	MRI
Zurich, Josefstr	1978	Martin, MB, WW	2-field ESP	113.1	Swiss EPA
Stuttgart	pre '80	VKW, MB, WW	2-field ESP	119.8	Hagenmaier
Hampton, VA	1980	J.M. Kennith, MB, WW	2-field ESP	2300	Haile
<u>LATER PLANTS</u>					
Pittsfield	1981	Vicon, MB, 2-stg/Mod	Gravel Bed Fltr	27.64	Weston
Cattaraugus	1983	MB, Modular	none	151.9	NYSDEC
Prince Edward Is.	1983	Tricil, MB, 2-stg/Mod	none	107	Env. Canada
N. Andover	1985	SES/Martin, MB, WW	3-field ESP	114.1	Radian
Tulsa, OK	1986	Martin, MB, WW	3-field ESP	18.9	Ogden
Westchester	1984	Von Roll, MB, WW	3-field ESP	17.94	NYSDEC
Wurzburg	1984	Martin, MB, WW	Dry Inj. Scr/FF	22.1	Hahn
Hogdalen, Sweden	1986	Martin, MB, WW	Dry Inj Scr/FF	5.25	Hahn
Marion, OR	1986	Martin, MB, WW	Teller Scr/FF	1.38	

PRELIMINARY TRENDS/CONCLUSIONS

- Dioxin Emissions Lower By Average of One Order of Magnitude in Most Plants Built Since 1980
- Degree of Variation in Dioxin Emissions Among Plants is Far Less Since 1980
- Emissions from Dry Scrubber/FF and 3-field ESP-equipped plants are lower than those from 2-field ESP-equipped plants
- Dry Injection or Teller Scrubber/Fabric Filter-equipped plants produce lowest emissions

Figure 1

Typical Fractional Efficiencies For Existing Collectors



SOURCE: Electric Power Research Institute. Economics of Fabric Filters vs. Precipitators, Denver, CO June 1978.

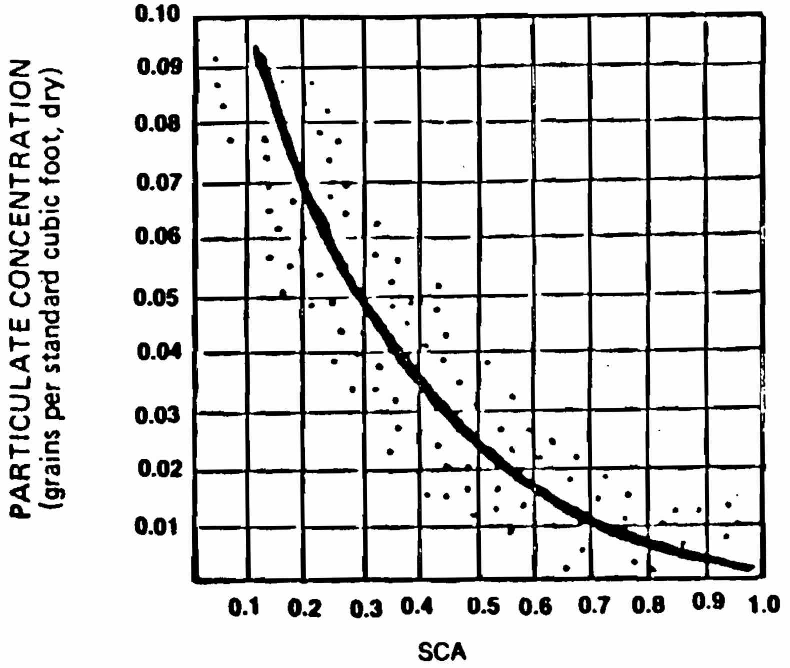
Figure 2

McGILL PRECIPTATOR DESIGN CURVES

"SCA CURVE"

(at common inlet conditions for a particular process)

The SCA Curve is a form of presentation of actual test data used in sizing a precipitator. It enables the selection of different plate areas for different requirement outlet conditions.



SPECIFIC COLLECTION AREA (SCA-PA/Q)

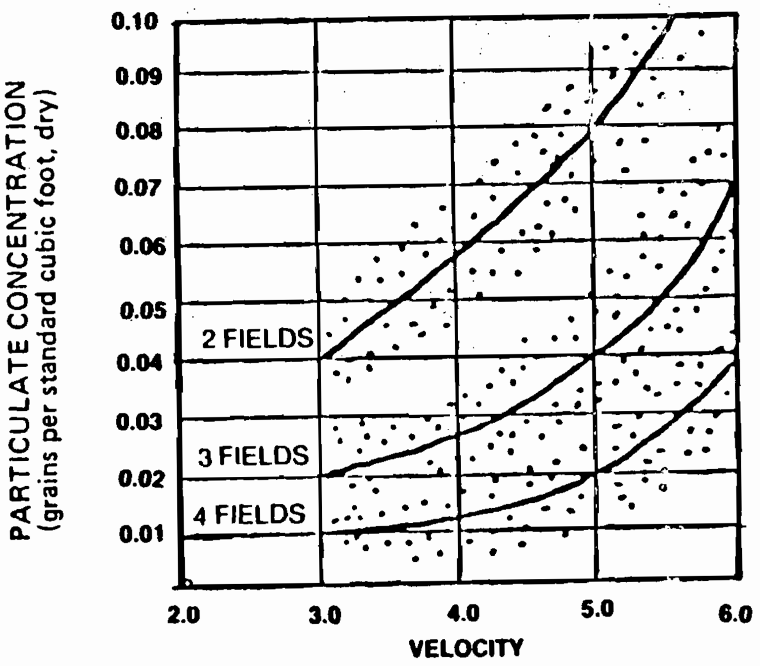
(Plate area divided by actual Volume Flow)

(ft^2/ft^3/min)

"VELOCITY CURVES"

(at common inlet conditions for a particular process)

The Velocity Curve is another form of presentation of actual test data used in sizing a precipitator. To have any value, the velocity effect must be considered with the total collection area (i.e. number of fields for a particular ESP design) therefore, in the sample below, curves are fitted for ESP's 2, 3, and 4 fields in series.



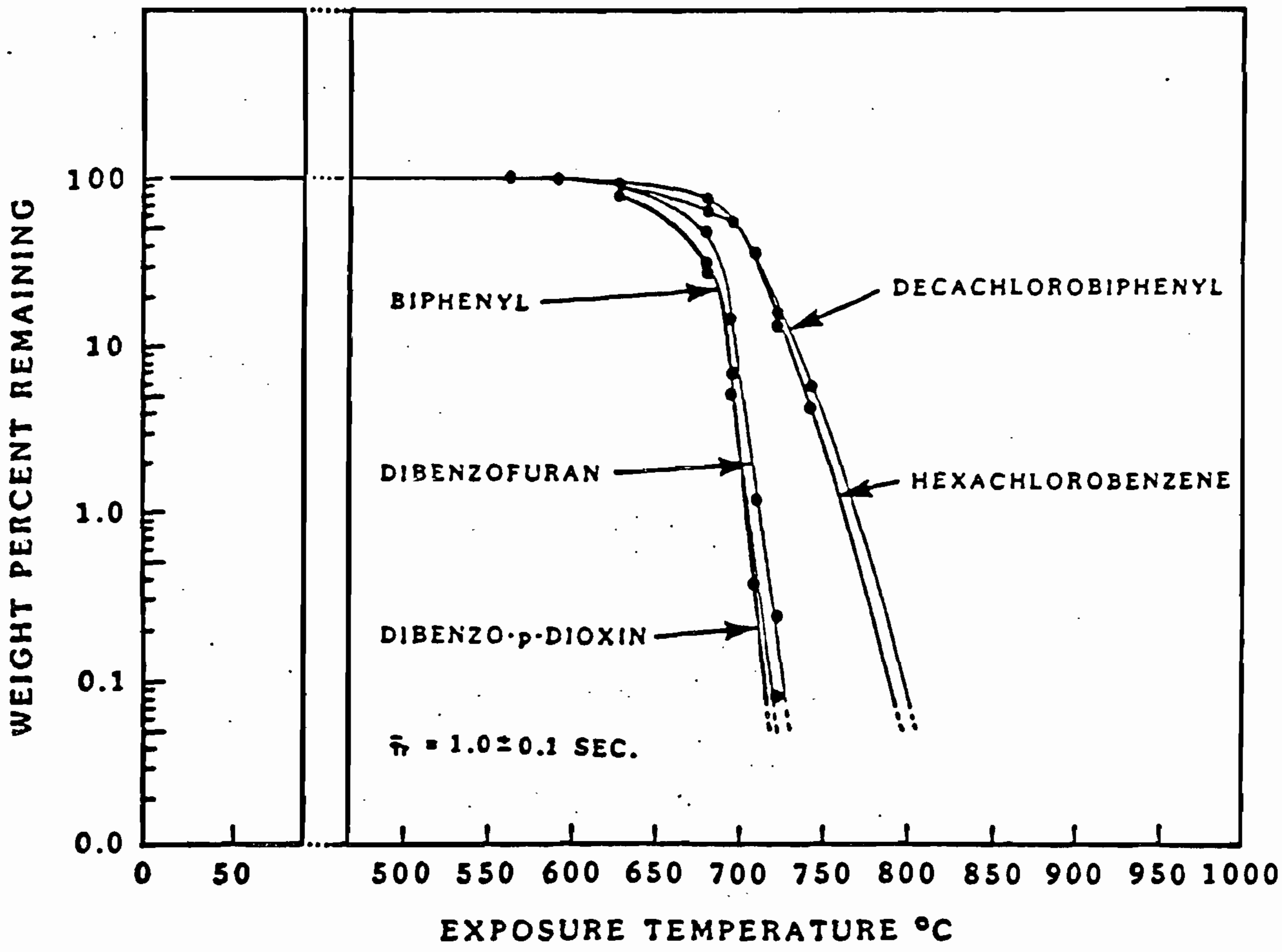
Flow-through Velocity (V = Q/A)

(Actual Volume Flow divided by effective Cross-Sectional Area)

(ft. per sec)

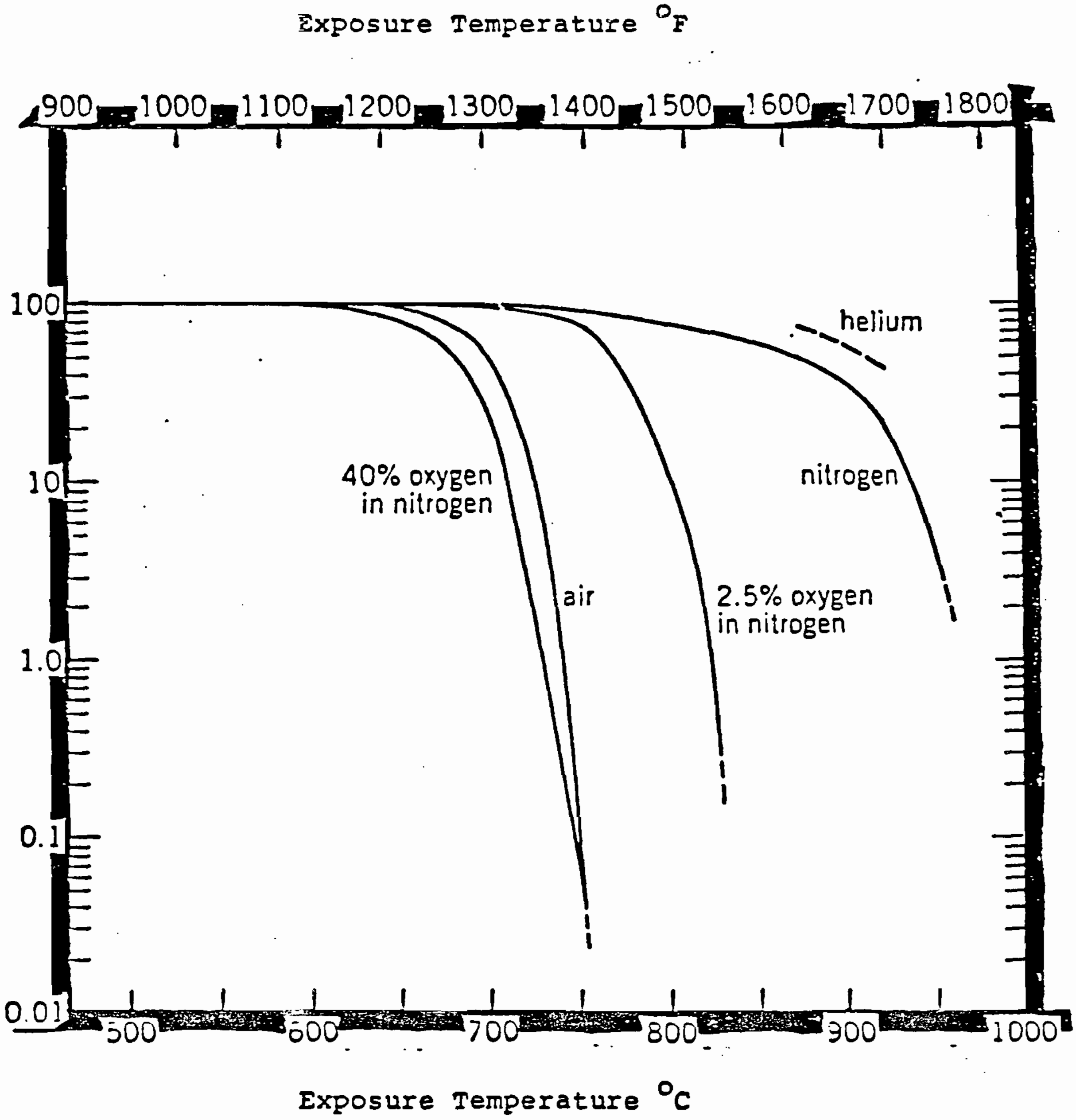
FIGURE 3

Thermal Destruction Profiles for Selected Organic Compounds



Source: Duvall, D.S., and Rubey, W.A., EPA, Laboratory Evaluation of High-Temperature Destruction of Polychlorinated Biphenyls and Related Compounds, Report No. 600/2-77-228, December 1977.

FIGURE 4

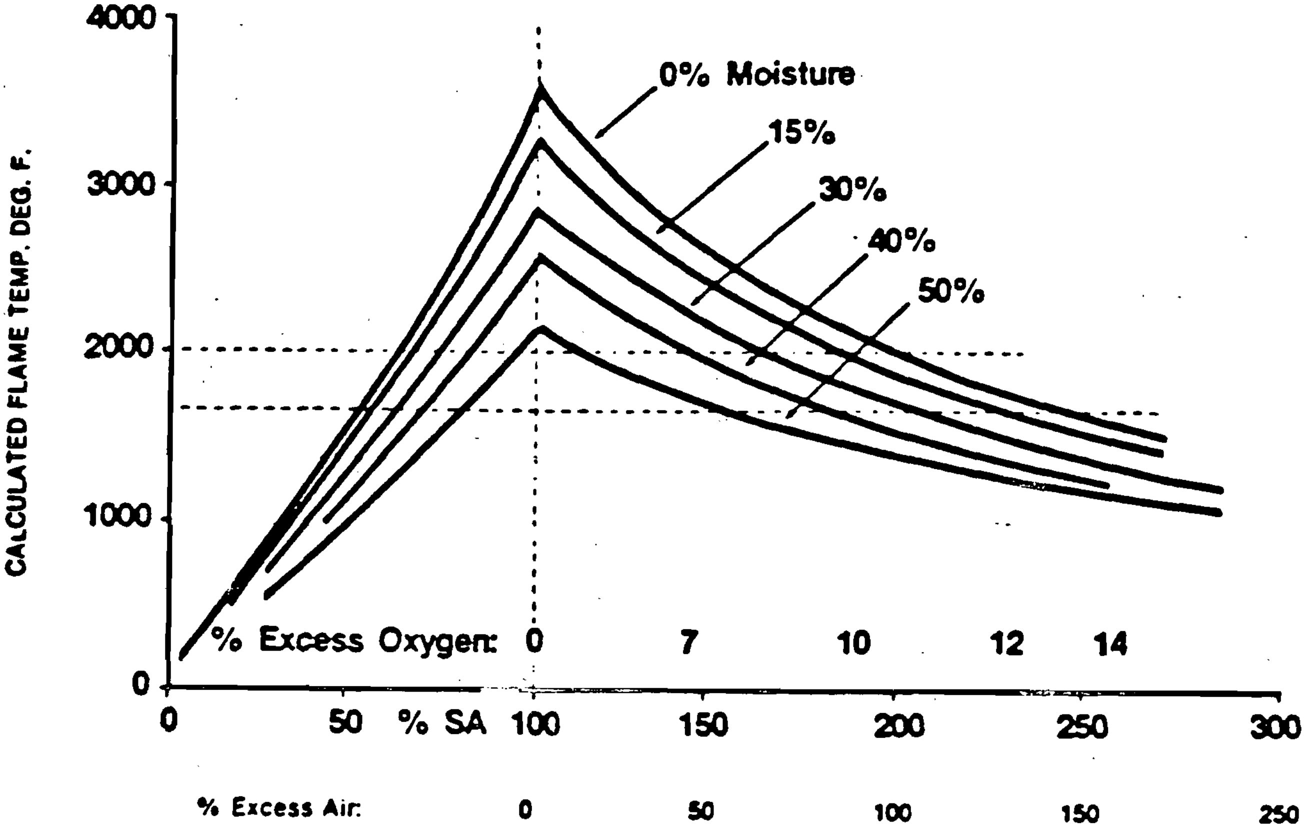


Effect of Oxygen Concentration on Destruction of Pentachlorobiphenyl

Source: Floyd Hasselriis, "Waste Energy Recovery" in <u>1985 EST Yearbook</u>, McGraw Hill, New York.

FIGURE 5

CALCULATED FLAME TEMPERATURE AS A FUNCTION OR REFUSE MOISTURE AND EXCESS AIR OR OXYGEN



Hasselriis

Figure 6

Comparison of HCl removal efficiencies of semi-dry and all-dry acid gas control systems, versus stoichiometric ratio of lime to acid.

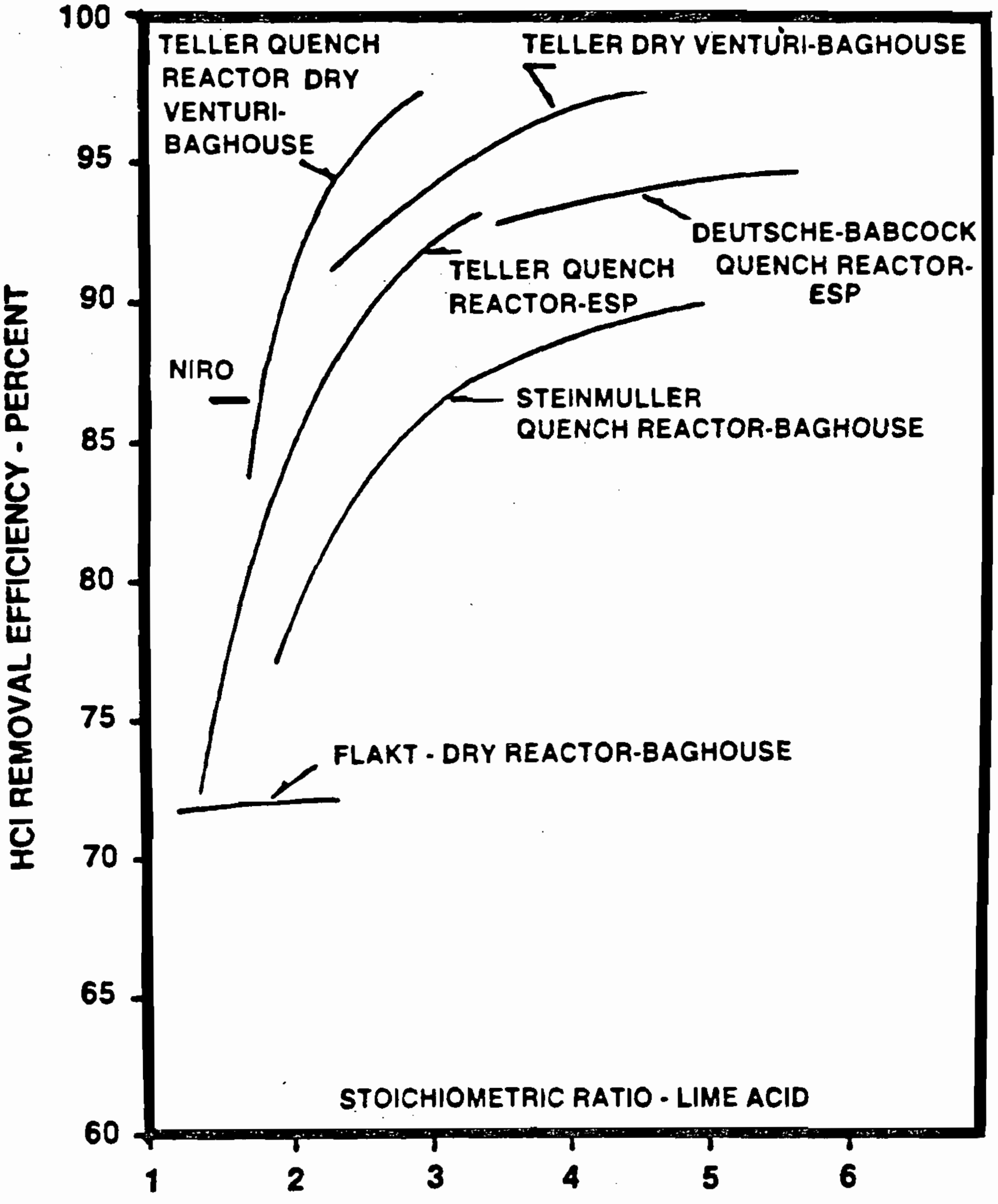


Figure 7

Comparison of SO_2 removal efficiencies of semi-dry and all-dry acid gas control systems, versus stoichiometric ratio of lime to acid.

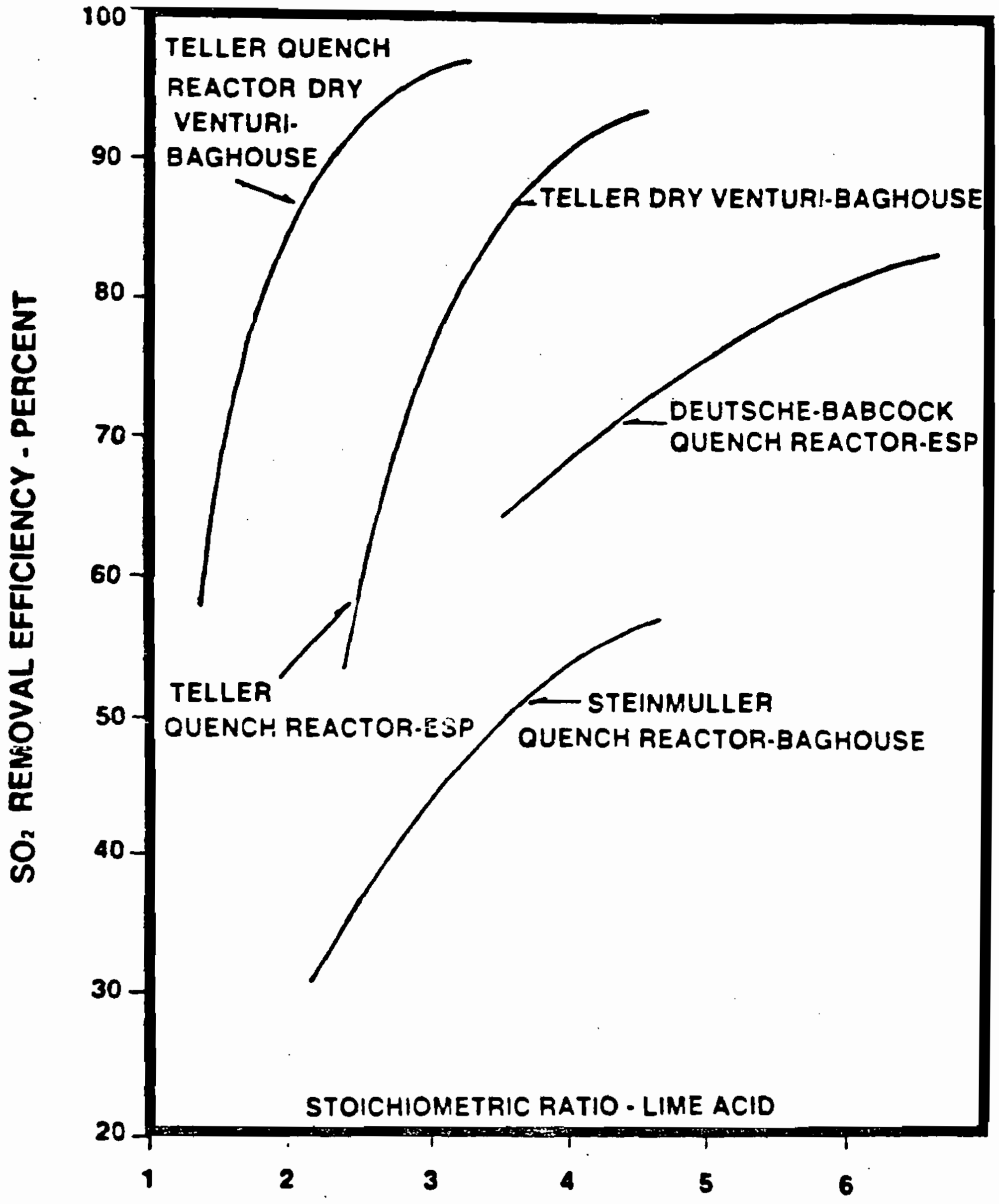
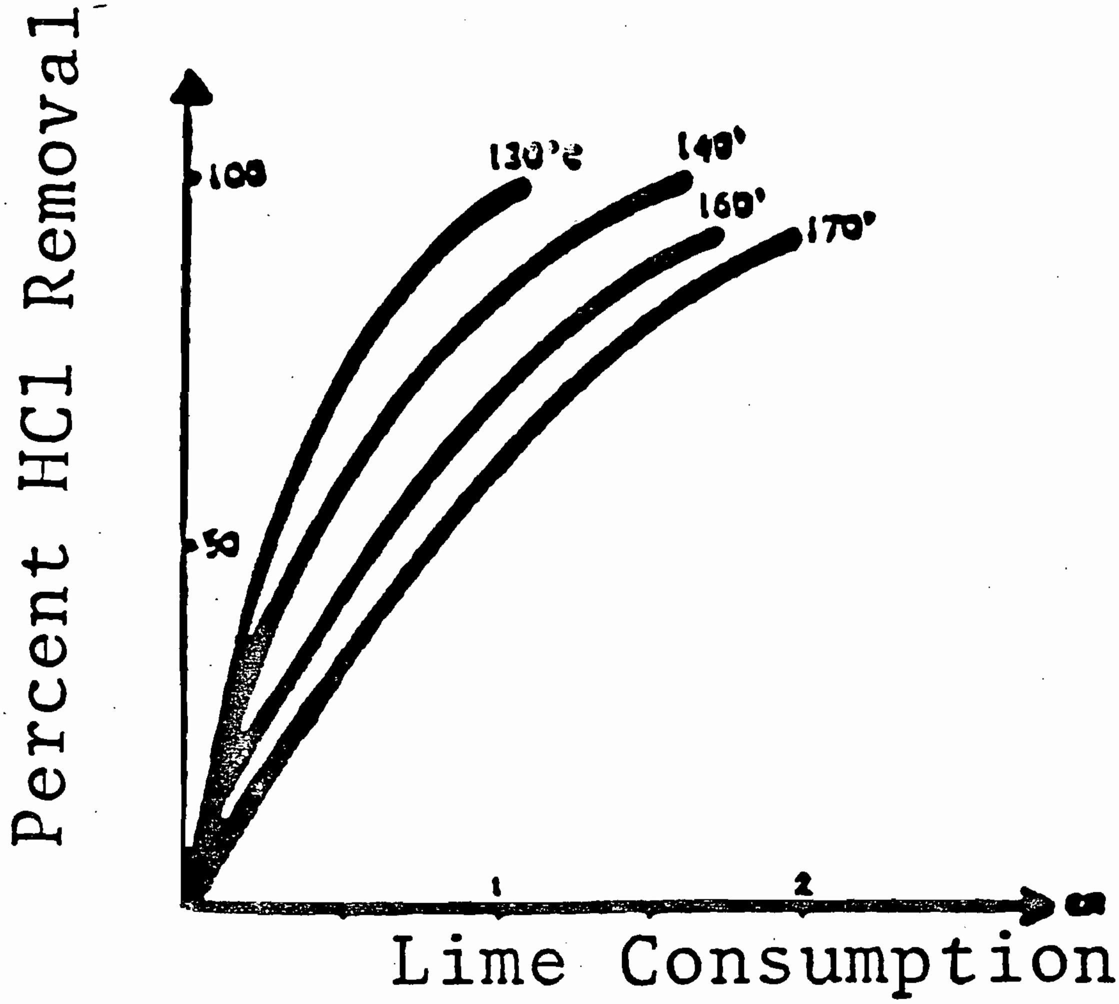


Figure 8
The Influence of Lime Consumption and SDA Outlet Temperature on HCl Removal



Source: Donnelly, James R., "SDA Data Base", November 1986
Seminar, JOY/NIRO, Key Largo, FL

Figure 9
Improvements In Particulate Emissions From MSW Incineration
1970 – 1986

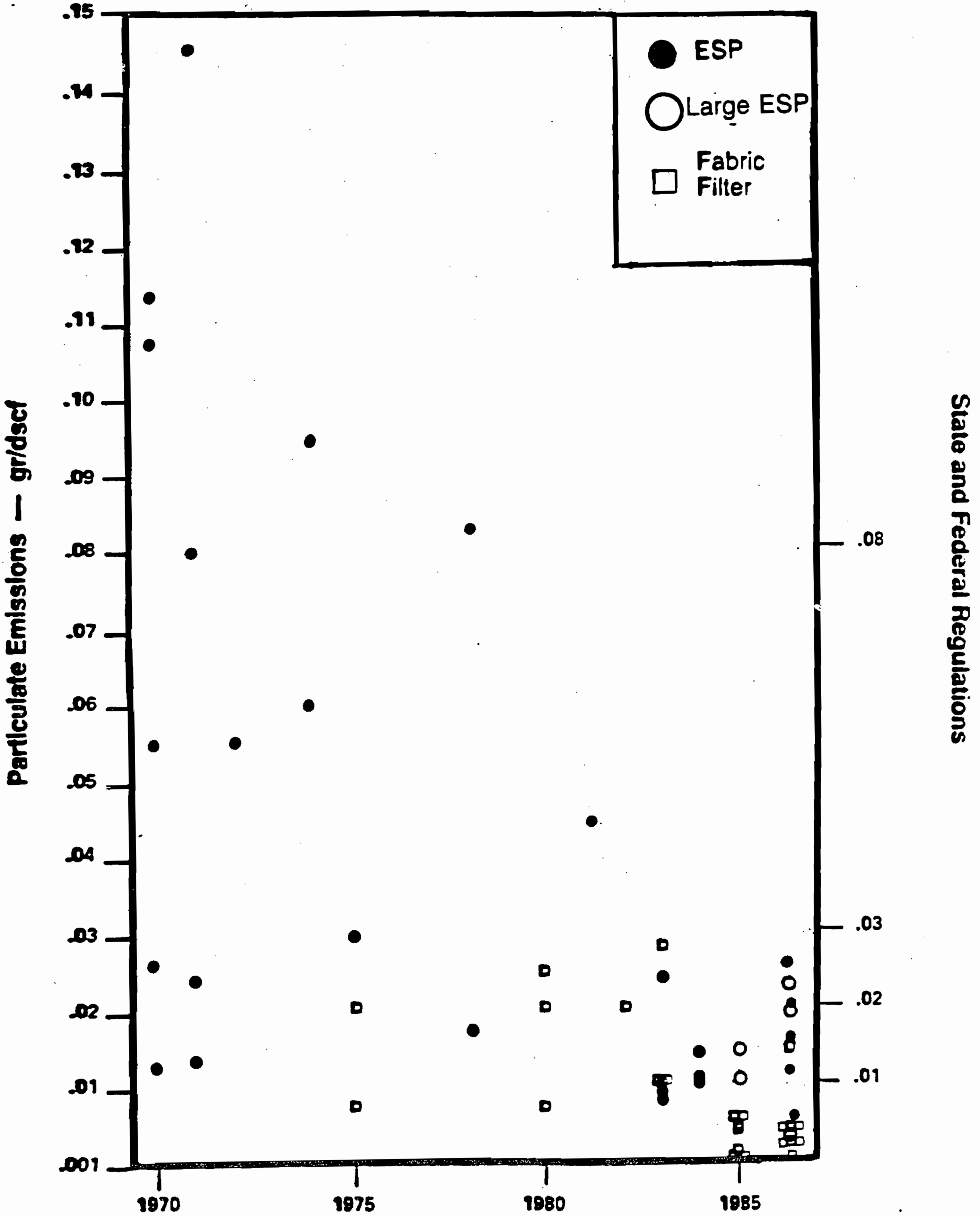


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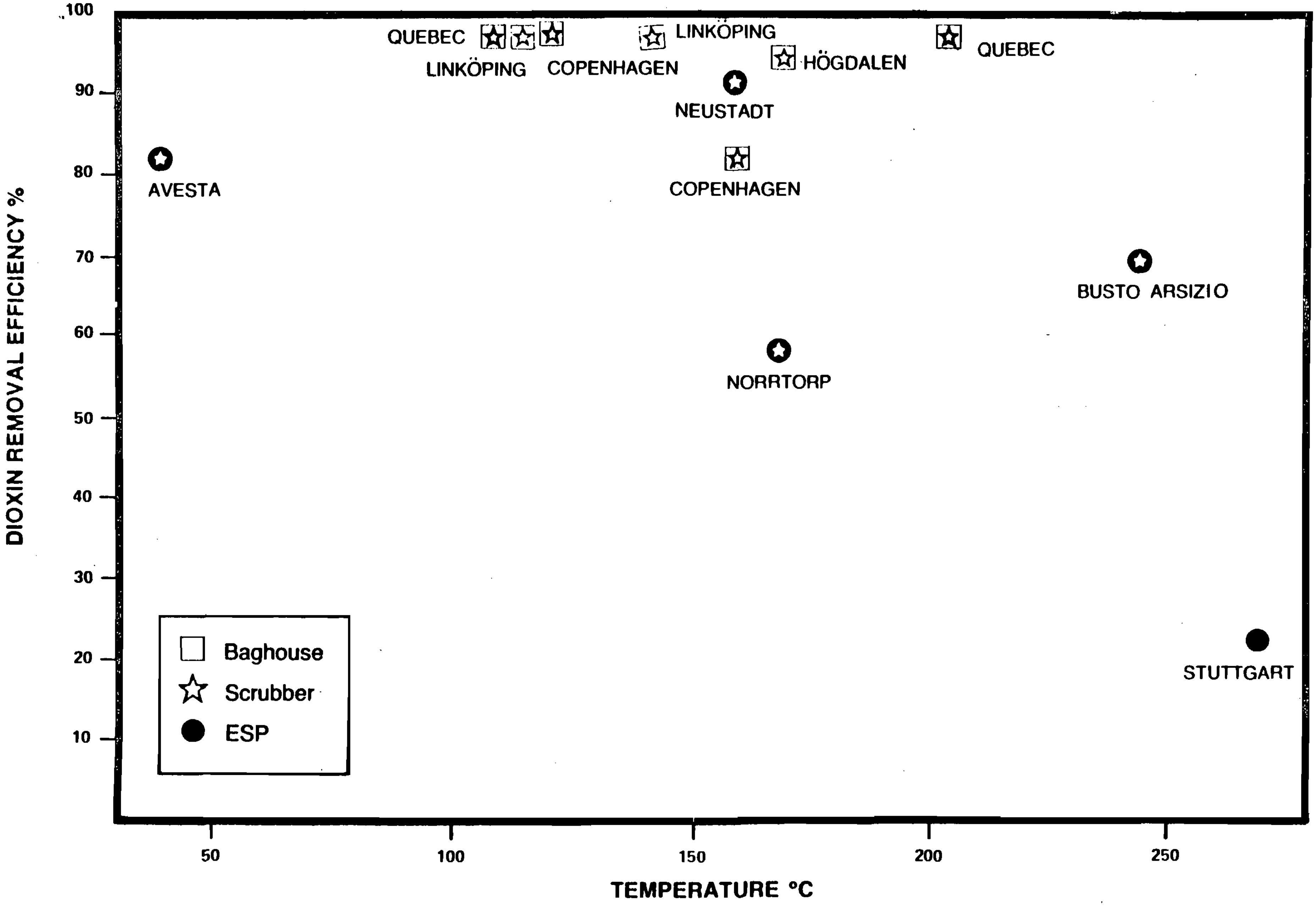
Figure 10
The Relationship of Temperature and Control Device On The Removal of Dioxin



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