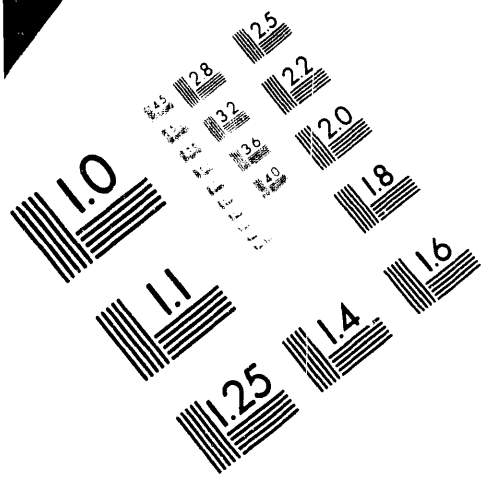
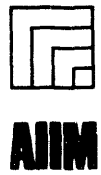




AIIM

Association for Information and Image Management

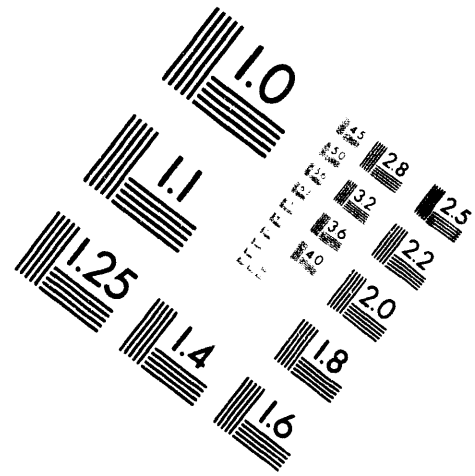
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

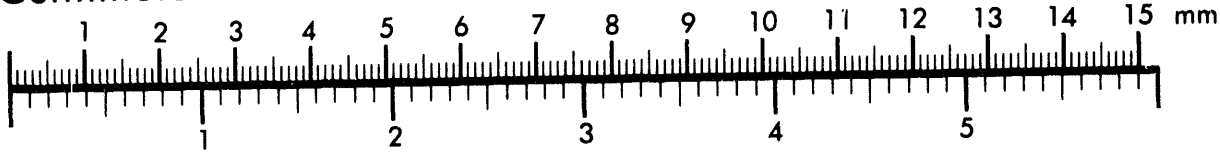
301/587-8202

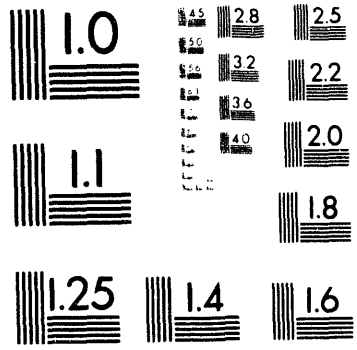
Centimeter

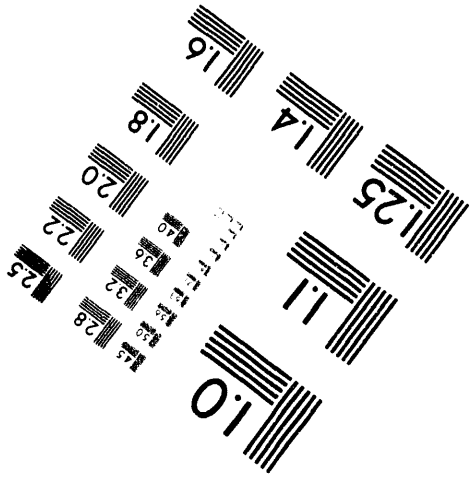
Inches

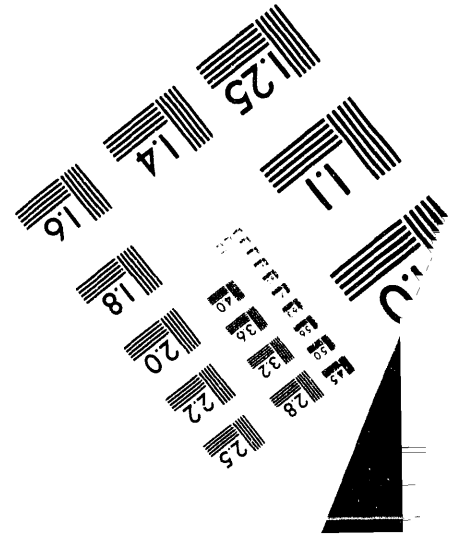
MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.











1 of 1

CONF-930364--6

A COMPARISON OF WET AND DRY SCRUBBING SYSTEMS FOR CONTROL OF METALS AND DIOXIN/FURAN EMISSIONS FROM INCINERATORS

RECEIVED
JUL 26 1993
OSTI

Paul S. Farber and Hann S. Huang
Energy Systems Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Paper presented at the

National Meeting
American Institute of Chemical Engineers
Houston, TX
March 29-April 2, 1993

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

A COMPARISON OF WET AND DRY SCRUBBING SYSTEMS FOR CONTROL OF METALS AND DIOXIN/FURAN EMISSIONS FROM INCINERATORS

Paul S. Farber and Hann S. Huang
Energy Systems Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

ABSTRACT

In Europe and the United States, both wet and dry (including semidry) scrubbing systems are being used for control of emissions from all types of waste incinerators. In terms of the effectiveness of controlling particulates and acid gases, both types of scrubbing systems are capable of meeting U.S. Environmental Protection Agency and European Community limits. Two of the more difficult emissions requirements for an incinerator air-pollution-control system to meet are the metals and the dioxin/furan limits. The dioxin/furan emissions requirement is especially stringent, calling for levels below 1 ng (10^{-9} g) per cubic meter toxic equivalency. The differences between wet and dry scrubbing systems are discussed in this paper, as well as the advantages and disadvantages of each in its application to the control of emissions from incinerators. Particular attention will be paid to control of metals and dioxin/furan emissions and to the sampling and analysis techniques used to measure these emissions. Toxic equivalency factors will be explained, and in particular, the international toxic equivalency factor proposed as the U.S. and European standard will be discussed. This paper will also address some of the techniques being employed to minimize the emissions of toxic compounds and discuss the use of combined wet and dry scrubbing systems for increased assurance of compliance.

INTRODUCTION

Regulations in the United States controlling the combustion/incineration of hazardous wastes in boilers and industrial furnaces (BIF regulations), as well as existing and planned regulations for hazardous, industrial, and municipal waste incinerators, are aimed at minimizing the emissions of certain metals and organic compounds (primarily di-benzodioxins and di-benzofurans). The BIF regulations, for example, control metals emissions by allowing industry to utilize a three-tiered approach.

Tier I metals restrictions are based solely on limiting the metal feed rates to the combustion unit. Tier I does not require the user to perform any emissions testing as a part of its final permitting

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so for U. S. Government purposes.

process. This tier does not allow any credit for metals partitioning to the bottom ash of the facility, nor does it allow any credit for metals removal in the air-pollution-control (APC) system.

Tier II controls metals emissions by setting mass per unit time emissions limits. These limits are seemingly more generous than Tier I limits and allow credit for metals partitioning to the ash and for metals removal in the APC system. Tier II, however, does require the user to perform metals testing (air emissions and levels in the ash) as part of the overall permit testing. The emissions levels called for in this tier also take into account the height of the exhaust stack and the exit-gas temperature. A spreadsheet model can be constructed to simplify the determination of allowable emissions and feed rates.[1]

The final tier, Tier III, has the most latitude for the owner/operator of the combustion system in terms of metals emissions (hence, the amount of regulated metals in the feed material). However, this tier requires all of the testing that must be performed in the Tier II permitting process and also requires that a full air-dispersion study be performed. Consequently, this tier is the most expensive (in terms of acquiring a permit) and the most complicated to comply with, but it may allow the largest amounts of metals to be fed to the system. (Note: The metals emissions regulations actually allow some regulated metals to be controlled under one tier while others are being controlled under another tier.[2] A full discussion of these regulations is not within the scope of this paper, but further investigation by the reader may be worthwhile.)

The U.S. Environmental Protection Agency (EPA) is implementing many of these regulations through the Omnibus Provisions within the Resource Conservation Recovery Act (RCRA) and applying them to hazardous waste incinerators and municipal waste-to-energy plants. The BIF regulations also address the emissions of polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF). Although not listed as regulatory limits, the suggested levels of emissions for these compounds are both set at 0.1 ng/Nm^3 (2,3,7,8 tetrachlorodibenzodioxin [TCDD] equivalent).

In Europe, the regulations governing the emissions of metals, PCDDs, and PCDFs are the European Community (EC) Directives for the Incineration of Hazardous Wastes.[3] Unlike regulations governing hazardous waste incineration in the United States, the EC directives pertaining to emissions are strictly mass emissions standards (mg/Nm^3 for metals and ng/Nm^3 for dioxins and furans). As with the emissions levels for dioxins and furans in the United States, the EC directives also utilize the concept of toxic equivalency factors and, hence, the dioxin level (measured over a sample period of a minimum of 6 hours and a maximum of 16 hours) should not exceed a guideline value of 0.1 ng/Nm^3.

Table 1 shows the EC directives metals emissions limits, which are determined by sampling emissions over a period of not less than 0.5 hour to a maximum of 4 hours, and include emissions of the gaseous, vapor, and particulate forms of heavy metals as well as their compounds. With regard to dioxins and furans, toxic equivalency factors are used to determine emissions. This equivalency factor relates the mass, speciated, dioxin and furan emissions to their toxic equivalent to 2,3,7,8 TCDD. These equivalency factors are known as the international toxic equivalency factors (ITEF) and were developed by a NATO task force. The method used to

Table 1. EC Directive Limits for Metals Emissions

Metal	Limit
Cadmium and its compounds, expressed as cadmium (Cd)	total of 0.05 mg/m^3
Thallium and its compounds, expressed as thallium (Tl)	
Mercury and its compounds, expressed as mercury (Hg)	0.05 mg/m^3
Antimony and its compounds, expressed as antimony (Sb)	total of 0.5 mg/m^3
Arsenic and its compounds, expressed as arsenic (As)	
Lead and its compounds, expressed as lead (Pb)	
Chromium and its compounds, expressed as chromium (Cr)	
Cobalt and its compounds, expressed as cobalt (Co)	
Copper and its compounds, expressed as copper (Cu)	
Manganese and its compounds, expressed as manganese (Mn)	
Nickel and its compounds, expressed as nickel (Ni)	
Vanadium and its compounds, expressed as vanadium (V)	
Tin and its compounds, expressed as tin (Sn)	

determine these ITEF factors is to multiply the mass concentrations of the speciated dioxins and furans by their equivalence factors and then summing the products to develop the toxic equivalent (TE). Table 2 gives the TE factors for several common dioxins and furans.

SAMPLING AND ANALYSIS

The EPA has developed a set of rigorous procedures for sampling flue gases from waste-combustion systems for the presence of metals and dioxins/furans. Procedures for determining the presence of these emissions are rather complex and require a very high level of quality assurance and quality control. Procedures to sample for either emission use some modification of the classic EPA Method 5 (Particulates) sampling train. In this sampling procedure, a portion of the flue gas

Table 2. Equivalence Factors For Dioxins and Dibenzofurans

Species of Dioxin or Furan	Toxic Equivalency Factor
Mono, Di, or Trichlordibenzodioxin	0
2,3,7,8 Tetrachlordibenzodioxin (TCDD)	1
1,2,3,7,8 Pentachlordibenzodioxin (PeCDD)	0.5
1,2,3,4,7,8 Hexachlorodibenzodioxin (HxCDD)	0.1
1,2,3,7,8,9 Hexachlorodibenzodioxin (HxCDD)	0.1
1,2,3,6,7,8 Hexachlorodibenzodioxin (HxCDD)	0.1
1,2,3,4,6,7,8 Heptachlordibenzodioxin (HpCDD)	0.01
Octachlordibenzodioxin (OCDD)	0.001
Mono, Di, or Trichlorodibenzofuran	0
2,3,7,8 Tetrachlorodibenzofuran (TCDF)	0.1
2,3,4,7,8 Pentachlorodibenzofuran (PeCDF)	0.5
1,2,3,7,8 Pentachlorodibenzofuran (PeCDF)	0.05
1,2,3,4,7,8 Hexachlordibenzofuran (HxCDF)	0.1
1,2,3,7,8,9 Hexachlordibenzofuran (HxCDF)	0.1
1,2,3,6,7,8 Hexachlordibenzofuran (HxCDF)	0.1
2,3,4,6,7,8 Hexachlordibenzofuran (HxCDF)	0.1
1,2,3,4,6,7,8 Heptachlorodibenzofuran (HpCDF)	0.01
1,2,3,4,7,8,9 Heptachlorodibenzofuran (HpCDF)	0.01
Octachlorodibenzofuran (OCDF)	0.001

Source: Reference 3.

(generally about 1 m^3) is isokinetically drawn into a quartz-lined heated probe, and from there, into the sampling assembly.

For metals sampling, the heated gas stream is passed through a filter assembly that removes all of the particulates. The gas then passes through a series of gas-liquid impingers filled with chemicals designed to react with, and separate out from the gas stream, vaporous metals. These impingers are immersed in an ice-water bath, which also ensures that all of the water in the gas stream is removed along with the metals. Finally, after passing through one empty impinger and one filled with silica gel, the gas goes through a dry gas meter for accurate measurement of the gas volume sampled. The glass-fiber filter, along with a distilled-water wash of the probe, is treated with chemicals that are analyzed for metals content by means of either an atomic adsorption spectrometer or an inductively-coupled argon plasma spectrometer. The liquids in the impingers are combined, treated, and then analyzed in a similar fashion. These two sample sections are referred to as the "front catch" and the "back catch," respectively, by the EPA. The front-catch metals are those metals in the flue-gas exhaust that exist as particulates, whereas the back-catch metals are those in the vapor state.

Sampling for dioxins and furans is similar to sampling for metals in equipment and procedure. The main difference is the addition of a canister of highly purified resin (XAD-2™) immediately following the glass-fiber filter. This resin filter is designed to absorb all of the organic material in the gas stream and, in some cases, will be used in testing a hazardous waste incinerator for simultaneous dioxin/furan and principal organic hazardous constituent (POHC) emissions. Following the gas extraction, the resin from the canister, as well as the liquids from the impingers, are extracted with solvent and analyzed. Analysis of dioxins and furans is accomplished using a high resolution gas chromatograph/mass spectrometer combination, so that speciated results may be obtained.

For more detailed information as to sampling and analytical procedures, the complete descriptions for metals and dioxins analysis may be found in "Compliance Methods for BIF Regulations," issued by the EPA in March 1992. The sampling and analytical procedures for metals and dioxins/furans are sensitive and require a high degree of precision. Accordingly, it is recommended that if such testing is to be performed, an emissions testing firm familiar with these methods should be used.

EMISSION CONTROL

Controls to minimize emissions of metals and dioxins/furans from incineration systems can take three forms: (1) precombustion, (2) combustion, and (3) post-combustion. The choice of application of controls depends on whether these controls are considered during the design phase of a project or are implemented on a facility already in operation. Obviously, when the control of these materials is considered during the design phase of an incineration system, there is much more flexibility for the owner/operator than there would be after the system has been granted a design and construct permit, or is already in operation.

Precombustion Controls. Precombustion controls generally involve restrictions on the amount of metal-bearing or dioxin-forming compounds allowed in the feeds, or on the preferred physical state of some (metal-bearing) materials in the feedstream. This is particularly important for metals where no destruction in the incineration system occurs, and the emissions, therefore, have a strong dependency upon the feed. The exit points for metals in an incineration system are the incinerator ash, the APC system residuals, or the stack. Some materials, such as mercury, partition themselves entirely into the APC system and are not apparent in the incinerator ash or slag. Others, such as chromium, make up 60% or greater of the inlet feed mass in the ash discharge and only minor amounts to the APC system.

Since, in general, liquids and sludges are dispersed when feeding an incinerator, metals in the pumpable portion of a feed will show up in the APC system in greater percentages than metals introduced in a solid form. Similarly, the chemical form of the metals in the feed has an influence upon emissions. For example, metals fed as nitrates will decompose into basic metals and/or oxides in an incineration system more readily than, for instance, sulfides.

Feed restrictions to limit the emissions of dioxins and/or furans generally center around dioxin precursors, such as benzene, and concentrations of highly chlorinated materials, such as trichlorobenzene. In addition, there is evidence that certain metals (such as copper) can act as catalysts for formation of dioxins and furans.[4]

Combustion Controls. As is the case with nitrogen oxides, some control of metals and dioxin/furans emissions is possible with careful operation of the combustion system. When remediating contaminated soils, for example, the use of a burner capable of producing a long stable flame will tend to leave more metals in the soil matrix than will a short bushy flame, which will have a very intense temperature region close to the burner. This intense temperature region will cause vaporization of the bulk of the metals, as well as other operating problems.

Incinerator owner/operators will attempt, in many cases, to operate their units with as little excess air as is necessary to meet destruction and removal efficiency and CO/hydrocarbon limits. This is generally due to operating permits having maximum flowrates of flue gas in the exhaust stack and a desire to maximize the throughput through the incinerator. Unfortunately, the low concentration of oxygen tends to aid the formation/reformation of dioxins and furans. In general, it is recommended that outlet oxygen concentrations >5% (dry basis) be a goal when there is concern about the formation of such air toxics as dioxins and furans.

Post-Combustion Controls. Metals and dioxins/furans emissions after the combustion zone are controlled in two areas: (1) flue-gas quenching and (2) flue-gas scrubbing.

Rapid quenching of flue gases, as would occur in the direct entrance of these gases into a wet or dry scrubbing system will reduce the tendency of dioxins and furans to form. The reason for this phenomenon is relatively simple: as the gases exit the combustion zone, the bulk of organics remaining exist as free radicals. If the gases cool slowly, as would occur if a waste-heat boiler was in place at the exit of the combustor, these free radicals have a greater opportunity (i.e., greater reaction time and temperature) to undergo the ring closure and chlorination necessary to produce dioxins and furans. An additional factor that aids in the formation of these compounds is the large

surface area presented by boiler tubes and membrane walls and the presence of catalyst metals (copper and iron) to promote the Deacon reactions. Rapid cooling of the gases below temperatures believed to promote the dioxin-forming reactions (about 400°C) has resulted in lower dioxin/furan emissions than in similar systems where a waste-heat boiler is present.

After cooling/quenching the flue gases, control of metals and dioxin/furan emissions is accomplished through flue-gas cleaning (scrubbing) systems. Either wet or dry gas-cleaning systems can be used to reduce emissions of metals and dioxins/furans, and both have advantages and disadvantages.

The EPA, in publishing the procedures for Tier II metals emissions evaluations, has evaluated data from 20 different types of APC systems. These systems, listed in Table 3, represent the range of APC systems used on incinerators, boilers, and furnaces combusting hazardous wastes either

Table 3. Selected Air-Pollution-Control Devices

1.	Simple Wet Scrubber
2.	Calvert/HydroSonics Scrubber (CS)
3.	Spray Dryer/ Fabric Filter (SD/FF)
4.	Ionizing Wet Scrubber (IWS)
5.	Venturi Scrubber 20"delP
6.	Venturi Scrubber 60"delP (VS-60)
7.	Electrostatic Precipitator - 1 Stage
8.	Electrostatic Precipitator - 2 Stage
9.	Electrostatic Precipitator - 4 Stage
10.	Wet Electrostatic Precipitator (WESP)
11.	Fabric Filter
12.	Dry Scrubber/Fabric Filter (DS/FF)
13.	Fabric Filter/Wet Scrubber (FF/WS)
14.	Electrostatic Precipitator-1 Stage/Wet or Calvert Scrubber
15.	Electrostatic Precipitator-4 Stage/Wet or Calvert Scrubber (ESP-4/WS/CS)
16.	Venturi Scrubber 20"delP/Wet Scrubber (VS-20/WS)
17.	Wet Scrubber/Ionizing Wet Scrubber (WS/IWS)
18.	Wet Electrostatic Precipitator/Venturi Scrubber/Ionizing Wet Scrubber (WESP/VS-20/IWS)
19.	Cyclone/Dry Scrubber/Electrostatic Precipitator or Fabric Filter (C/DS/ESP/FF)
20.	Spray Dryer/Cyclone/Electrostatic Precipitator

singly or in conjunction with a premium fuel. For each system, the EPA has issued a "preliminary" metals removal for each metal regulated under RCRA, which can be used in the initial determination of allowable feed rate. Some of these expected reductions, as published in the BIF regulations, are shown in Table 4. The test information shown in Table 4 indicates that wet scrubbing systems, especially the simpler types (venturi scrubber and fabric-filter/wet-scrubber), generally are less efficient in metals removal than are the dry scrubbing systems (spray-dryer/fabric-filter) or the combination wet scrubbing systems (wet-scrubber/ionizing wet-scrubber). In particular, use of wet scrubbing systems results in removals of 50-80% for mercury (due to its low boiling point [about 350°C]), while other metals are removed at the 95-98% levels.

This low removal of mercury has resulted in extensive research in Europe[5] and the United States[6] into means of capturing sufficient amounts of mercury emissions to meet environmental standards, without undue restrictions on the operation of the waste combustion system. Testing at the Swedish government's incineration system in Sakab (Table 5) has indicated that injecting activated carbon between the spray dryer and the fabric filter was an effective means of controlling mercury emissions. Without addition of carbon, the removal of mercury in a spray-dryer/fabric-filter system was 40-60%. With the addition of activated carbon, mercury removals of well over 80% were achieved. It should be noted that, while well over 90% removal of the mercury solids was achieved by the spray-dryer/fabric-filter system, the majority of the mercury entering and exiting the pollution-control system was in the gaseous state. Accordingly, without additives such as carbon to control the gaseous mercury, even a well-designed and well-operated fabric-filter system would be unable to achieve high degrees of mercury removal.

Table 4. Metals Removal Efficiencies of Selected Control Equipment[a]

	CS	SDFF	IWS	VS-60	WESP	DS/FF	FF/WS	ESP-4/ WS/CS	VS-20/ WS	WS/ IWS	WESP/ VS-20/ IWS	C/DS ESP/FF
Antimony	95%	95%	95%	40%	95%	98%	90%	95%	96%	95%	97%	99%
Arsenic	95%	95%	95%	40%	95%	98%	90%	95%	96%	95%	97%	99%
Barium	95%	99%	95%	98%	97%	98%	95%	99%	97%	95%	99%	99%
Beryllium	95%	99%	95%	98%	97%	98%	95%	99%	97%	95%	99%	99%
Cadmium	95%	95%	95%	40%	95%	98%	90%	95%	96%	95%	97%	99%
Chromium	95%	99%	95%	98%	96%	98%	95%	99%	97%	95%	98%	99%
Lead	95%	95%	95%	40%	95%	98%	90%	95%	96%	95%	97%	99%
Mercury	80%	90%	85%	40%	60%	50%	50%	85%	80%	85%	90%	98%
Silver	95%	99%	95%	98%	97%	98%	95%	99%	97%	95%	99%	99%
Thallium	95%	95%	95%	40%	95%	98%	90%	95%	96%	95%	97%	99%
Nonlisted	94%	96%	94%	63%	92%	93%	88%	96%	95%	94%	97%	99%
Hydrogen chloride	99%	99%	99%	95%	40%	98%	99%	99%	99%	99%	99%	99%

[a] Equipment abbreviations found in Table 3.

Table 5. Mercury Removal in the Presence of Carbon at the Sakab Incineration System[a,b]

Date	Hg Solids In	Hg Total In	Hg Solids Out	Hg Total Out	% Hg Solids Removal	% Hg Total Removal
9/25/90	0.35	14.2	0.01	2.0	97.14	85.92
9/26/90	0.53	11.8	0.01	1.73	98.11	85.34
9/28/90	0.26	10.1	0.01	1.65	96.15	83.66

[a] Powdered activated carbon injected at a rate of 9 kg/h.

[b] All concentrations in $\mu g/Nm^3$, dry corrected to 10% CO_2.

The EPA has performed a series of parametric studies in an attempt to quantify this adsorptive effect of carbon on mercury. Based on their work (and accepting that the r^2 fit was only 0.777), the EPA was able to develop a "best" predictive equation for mercury outlet concentrations:

$$\ln(HGOUT) = 5.66 - 0.963[(CFR)^{0.5}] + 0.000724[HGIN]$$

where

HGOUT = mercury outlet concentration ($\mu g/Nm^3$),
HGIN = mercury inlet concentration ($\mu g/Nm^3$), and
CFR = carbon feed rate (kg/h).

Control of mercury emissions with wet scrubbing systems can be achieved to the same degree as with dry scrubbing systems (about 60%). One drawback of wet scrubbing systems is the emission of aerosols that may contain mercury salts. These mercury salts can lower the overall effectiveness of wet scrubbing systems in the control of mercury emissions. The use of carbon as an aid to mercury removal is not effective for wet scrubbers. When "enhancement" of mercury removal is needed for compliance, then wet scrubber operators have been employing sodium sulfide (Na_2S). The Na_2S in the scrubbing solution will combine with mercury salts in the gas stream to form mercuric sulfide, which is extremely insoluble. When Na_2S is used as an additive in wet scrubbing systems, mercury removals are in the 80-90% range.

Dioxins and furans in the gas exiting an incinerator are from two sources: (1) the feed materials and (2) formation from free radicals in the hot gas stream as it cools. The faster the gas is quenched (below about 250°C), the lower the amount of dioxins and furans produced through reformation. Therefore, the presence of a waste-heat boiler, with its gradual cooling of the gas, will permit higher emissions of dioxins and furans than will the tempering chamber or quench unit found with dry or wet scrubbing systems, respectively.

The majority of work that has been published on dioxin/furan removal from scrubbing systems resulted from testing performed on dry systems,[7,8] although some work has been performed on the reformation of dioxins and furans in wet systems.[9] Tests run by the EPA (the MWC tests) on municipal waste incinerators equipped with either spray-dryer/electrostatic-precipitator (SD/ESP)

or spray-dryer/fabric-filter (SD/FF) emission control systems (Table 6) have shown the capability of these systems to achieve total dioxin/furan emission levels of less than 30 μg/Nm^3, with some of the systems attaining levels consistently below 10 μg/Nm^3.

Extensive testing has been performed at the Sakab, Sweden, hazardous waste incinerator to determine the effect on dioxin/furan removal of injecting activated carbon between the spray dryer and the fabric filter. The results of these tests are shown in Table 7 as data from the baseline (no carbon) tests and from the carbon injection tests themselves. As can be seen, only a 65-70% removal of dioxin/furan was achieved by the spray-dryer/fabric-filter system with no carbon injection. When carbon was injected, the overall removal of dioxins and furans was well over 97%. Similar results are seen in Table 8 for other related chlorocompounds (primarily chlorobenzene and chlorophenol), where 97-98% removal of these compounds were

Table 6. MWC Dioxin/Furan Test Data

Location	Control Type	Average Emission (ng/Nm^3)
Babylon	SD/FF	21.9
Biddeford	SD/FF	4.4
Mid-Connecticut	SD/FF	0.7
Stanislaus Co. #1	SD/FF	6.3
Stanislaus Co. #2	SD/FF	6.5
Honolulu #1	SD/ESP	9.9
Honolulu #2	SD/ESP	2.9
Millbury	SD/ESP	59.2
SEMASS #1	SD/ESP	9.3
SEMASS #2	SD/ESP	311.0

Table 7. Sakab, Sweden, Carbon Injection Test Results

Activated Carbon Addition (kg/h)	Dioxin/Furan Concentration[a]		Removal (%)
	Inlet Flue Gas	Stack Emission	
0	21	7.3	65.24
0	7.0	2.2	68.57
4.5	2.0	0.014	99.30
7.5	2.8	0.027	99.04
9	6.1	0.07	98.85
9	2.7	0.06	97.78
9	2.2	0.06	97.27
13	1.0	0.03	97.00
13	1.8	0.02	98.89

[a] Dioxin/furan concentrations are given in ng/Nm^3 toxic equivalent, dry corrected to 10% CO_2.

Table 8. Sakab Sweden Removal of Other Related Chlorocompounds

Activated Carbon Addition (kg/h)	Chlorocompounds Concentration[a]		Removal (%)
	Inlet Flue Gas	Stack	
9	8,109	107	98.68
9	6,181	102	98.35
9	4,206	102	97.57

[a] All concentrations in $\mu g/Nm^3$, dry corrected to 10% CO_2.

demonstrated. It is probable that the activated carbon is adsorbing all chlorocarbons and is not selective for dioxins and furans.

Not much data is available in the literature for wet scrubbing tests. It is known that with a wet scrubbing system, higher emissions of dioxins and furans (as compared with dry scrubbing systems) will result due to the materials contained within the emitted aerosols. Some research has been performed in Sweden which indicates that low-temperature (about 70-90°C) formation of PCDDs and PCDFs may be taking place in wet scrubbing systems when the proper precursors are present. These dioxin/furan precursors are hydrogen chloride (HCl), organic compounds, and particulates (to provide a surface area for reactions to take place). Effective particulates and acid-gas removal systems can eliminate the precursors from the flue gas entering the wet scrubber and minimize the reformation and emission of dioxins and furans.

CONCLUSIONS

Both wet and dry scrubbing systems have proven their effectiveness for minimizing emissions of particulates and acid gases from incinerators and other combustion systems. Testing by the EPA has indicated that for collection of most metals from flue gases, wet and dry scrubbing systems are equivalent. For situations where the collection of mercury is a concern, the dry scrubbing system has an advantage over the wet scrubbers, primarily because of the fabric filter. This advantage is enhanced when activated carbon in injected between the spray dryer and the fabric filter. The removal of mercury by wet scrubbers can be increased by the addition of Na_2S to the scrubbing solution, but aerosol emissions, which contain mercury salts, must be minimized. For dioxin and furan emission control, many of the reasons that dry systems have an advantage over wet systems in mercury removal also hold true. Therefore, in general, wet and dry scrubbing systems are equally efficient in controlling emissions from combustion systems, but the dry scrubbing system has a measurable advantage in control of mercury and dioxins/furans, primarily due to the presence of the fabric filter and the capability of holding sorbent materials in the filter cake.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy, Assistant Secretary for Fossil Energy, under contract W-31-109-Eng-38.

REFERENCES

1. Farber, P.S., "A Spreadsheet-Based System for Tier II Metals Calculations," Paper 90-135 presented at AWMA Annual Meeting, Pittsburgh PA, 1989.

2. U.S. Environmental Protection Agency, Workshop Notes on the Implementation of the Regulations for the Control of Emissions from Boilers and Industrial Furnaces, 1989.

3. Proposal for a Council Directive on the Incineration of Hazardous Waste, Commission of the European Communities, COM(92) 9 final - SYN 406, Brussels, Belgium, 19 March 1992.

4. Guillete, B., EPA, "Influence of Copper on the Formation of Halogenated Ring Compounds," presented at AWMA/EPA Municipal Waste Combustion Conference, Tampa FL, 1991.

5. Feldt, K.G., "Electrostatic Precipitator vs. Fabric Filter for Dioxin/Furan Emission Control on Hazardous Waste Incinerator at Sakab, Sweden," Paper #91-34.4 presented at AWMA Annual Meeting, Vancouver, B.C., 1991.

6. Brna, T.G., Kilgroe, J.D., and Miller, C.A., "Reducing Mercury Emissions From Municipal Waste Combustion With Carbon Injection into Flue Gas," presented at ECO WORLD '92, Washington, DC, June 1992.

7. White, D.M., and Nebel, K.L., "Review of SD/FF versus SD/ESP System Performance for Acid Gas, Particulates, and CDD/CDF Control," presented at AWMA/EPA Conference on Municipal Waste Combustion, Tampa, FL, 1991.

8. Christiansen, O.B., and Brown, B., "Control of Heavy Metals and Dioxins from Hazardous Waste Incinerators by Spray Dryer Absorption Systems and Activated Carbon Injection," Paper #92-41.06 presented at AWMA Annual Meeting, Kansas City, MO, June 1992.

9. Stromberg, B., "Low Temperature Formation and Minimization of Chlorinated Hydrocarbons," *Chemosphere* 23(8-10):1515-1525, 1991.

DATE
FILMED
9/22/93

END