UPGRADING EXISTING MWCS WITH ESPS: THE CONTRIBUTION OF COMBUSTION IMPROVEMENT VERSUS APC TEMPERATURE REDUCTION

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This paper makes a number of interesting points which may be true, but are not supported by the information provided. For example, the paper does not distinguish between the contributions of combustion improvement and APC temperature reduction to upgraded particulate, acid gas, metals, PCDD/F, carbon monoxide or oxides of nitrogen emissions characteristics at existing MWCs equipped with ESPs. Consequently, these comments focus on identifying areas that need to be clarified to avoid potentially misguiding less experienced readers and conclusions that are not obviously supported by the data presented.

It appears that problems identified in the following discussion may simply stem from hasty editing. For example, the author discusses replacing an ESP with a SDA. Replacing an ESP with a SDA accomplishes nothing other than blowing lime and reaction products all over the landscape while allowing the previously controlled fly ash to escape as well. This is clearly not the author's intent, but it is the literal interpretation of his statement. A SDA is added between the incinerator and an existing ESP to absorb acid gases. The reaction products are then removed along with the fly ash by the ESP.

The Emissions Guidelines signed by the Administrator on October 29, 1995 were available on the EPA Bulletin Board on November 3, 1995. They were promulgated when published in the December 19, 1995 Federal Register. While Table 1 does not provide averaging and sampling times, when read with these additional requirements in mind, the tabulated values are the current limits.

A reference for the stated incremental cost of retrofitting acid gas removal is needed. The regulatory preamble indicates that the average retrofit cost is around $3,500 per ton of acid gas removed. In fact, the preamble to the proposed regulation explained that EPA specifically decided not to require retrofit of SDA/ESP combinations to convert them into SDA/FFs because the retrofit cost was in excess of $10,000 per ton of acid gas removed. Hence, the author's estimate that this cost is in excess of $18,500 per ton of acid gas removed for an existing ESP equipped MWC may be incorrect. My experience indicates that this number relates to the cost of upgrading a DSI/ESP equipped MWC to a SDA/FF equipped system. A reference for the total PCDD/F to ITEQ ratio of 50 employed is needed. My analysis of the available data indicates that the ratio is around 40:1 when all the congeners are above detection limits and EPA's 60:1 ratio is not bad when there are a significant number of non-detects in the congener distribution.

My understanding is that when a facility fails a periodic recertification test, it is subject to fines— $25,000 per day per occurrence under the Clean Air Act citizen suit provisions. What benefit is there to a plant being in compliance on average, if it exceeds the standard when tested? It gets fined anyway! I agree that emissions limitations have to be set above the average. After all, the average is by definition the center of the data. That is, half the data are larger. How far you have to set the emissions limitation above the average is, among other things, a function of the data variability (i.e., standard deviation). The number of standard deviations an appropriate emissions limitation is located above the average is not a constant. Rather, it is a function of the type of underlying data distribution, the number of test points used to determine the average and standard deviation, how certain one wants to be of being in compliance (the statistical confidence level) and what proportion or number of future tests are to be contained by the limit. The problem is complicated (as if this isn't already complicated enough) when correlated emissions like particulates and semi-volatile metals each have their own limits. For MWCs where lead, cadmium and particulates are all regulated, the statistical confidence level moves from the 95 percent used in most of 40 CFR 60 Subparts to 98 percent for each co-contaminant regulated so that the entire regulation achieves the desired 95 percent statistical confidence level. As a consequence, while I agree that an appropriate emissions limitation must be greater than the mean, I am not aware of any justification for saying that it is four times the mean (this paper) or for EPA's traditional approach of setting permit limitations at 120 percent of the mean. Techniques exist for data based emissions limitation setting. The EPA used conceptually similar techniques to those found in my publications in the draft Hazardous Waste Incinerator and Industrial Furnace Rule signed by the Administrator in March 1996.

The reference to Pakrasi [and Davis] is an article that addresses sorbent utilization, not acid gas removal rate. To be specific, Pakrasi and Davis state that "the most important parameter in determining the rate and extent of sorbent conversion" (emphasis added) is relative humidity. Relative humidity affects the amount of unreacted reagent near the center of each particle. It does not necessarily follow that higher humidity produces greater emissions control for a constant reagent stoichiometry. While there is strong evidence that approach to saturation is a critical emissions control parameter, that evidence is not found in the reference or presented elsewhere in this paper. Further, I am aware of little evidence that the 25 percent relative humidity Pakrasi found is necessary or prudent for an economically efficient installation. In fact, SDAs typically operate between 17 and 22 percent absolute humidity (which equals the relative humidity when the temperature is above the boiling point of water). I am aware of two plants which were designed to operate at 285°F, but which must be operated at 325°F to avoid water extraction by desiccant materials like calcium chloride with the subsequent formation of mud and concrete in the ash handling system. Increasing humidity further can cause operational problems. This may not be a practical recommendation for commercial systems.

Arsenic, chromium and nickel are described as being criteria metals. Which regulations are referred to? These metals are Clean Air Act, section 112 Hazardous Air Pollutants [HAPs]; however, that does not make them criteria pollutants. My understanding is that lead, cadmium and mercury are the only criteria metals for MWCs.

References or data are needed to demonstrate that lead and cadmium are well correlated with particulate concentrations and that achieving large and small plant particulate emissions guidelines should result in compliance. While I do not generally disagree with the statement, I am unaware that this point has been demonstrated in this paper or any of the references.

My understanding is that mercury control system performance is adequately described by Langmuir thin film isotherm based formulations. In this case, control effectiveness is a function of mercury sorbent injection rate, temperature and uncontrolled mercury concentration. There is also evidence that moisture plays an important role, first increasing and then retarding sorption. As a result, additional information is needed before Figure 1 becomes meaningful. What were the reagent addition rates and what was the operating temperature? Also, the results in Figure 1 are not all comparable. Hence, any conclusions reached may be the result of data artifacts. Some of these facilities are European where both powdered activated carbon and activated carbon bed filters are employed. If any of these facilities use the carbon bed filters, space velocity and average carbon duration should also be provided in the filter information.

The author states that APCS temperatures between 400 and 450°F are too high for effective mercury and dioxin control with PAC. We now know that this is not true. At Davis County, for example, effective control was demonstrated during the November 1995 ASME/CRTD test program at temperatures between 420 and 430°F. The statement may be a carry-over from European practice where some types of activated carbon employed, such as HOC [hearth oven coke], can ignite at only slightly higher temperatures.

My understanding is that it is virtually impossible to successfully apply SNCR technology to refractory wall MWCs. Consequently, the promulgated guidelines exempt these units from regulation. What guideline is referred to when it is stated that these units need NO_x control or that they can meet emission limitations without control? Also, since many refractory wall incinerators exhibit NO_x emissions comparable to waterwall equipped MWCs, field data from several plants should be provided to verify the generality of the conclusion that refractory wall units meet the waterwall unit standards.

Boisjoly's Des Carriers incinerator experiment result—that furnace injection of hydrated lime "drastically reduced" PCDD/F—was not replicated by the EPA during their extensive testing at Montgomery County, OH or Dutchess County, NY. Furnace lime addition did not produce reductions in excess of data noise when all the then available data were analyzed by ASME (CRTD-36, 1995), including the infamous 1989 Horsholm test and other Danish experiments conducted as part of their emissions inventory exercise that allegedly show just such a relationship. The ASME study found that dioxin and chlorine are not correlated in commercial scale systems. The basis for the author's surprise that this unreplicatable finding did not become widely known should be presented.

Davis County met the percentage reduction assumptions for acid gases underpinning the plant's permit mass emission rate (lb/h) limitation. Unfortunately, the numerical lb/h limits could not be met and a revised set of emissions limitations was requested based on the cited Rigo report (1993).

Recirculation of fly ash and reaction products is common practice in some plants. It is done to increase reagent utilization in fabric filter equipped installations where the reagent can sit on the bags for long periods. Recirculation also increases the effective stoichiometric ratio without increasing overall reagent requirements. When an ESP is involved, however, recirculation is usually avoided since the extra mass flow can overload the ESP and increase particulate emissions. In the case of one facility with a 0.06 gr/dsft^3 @ 7% O_2 limitation, 2 of the 12 reagent addition tests exceeded the regulatory limit. Also, the surface of the partially reacted reagent is already saturated with acid gases and little additional removal is expected using partially spent reagent. Test results are needed to show that this suggestion is likely to be beneficial; absent such evidence, this should not be counted on to effectuate effective emissions controls at existing ESP equipped MWCs.

Figure 2 does not obviously support the author's conclusion. The information needs to be replotted so that total PCDD/F (or ITEQ) are contrasted against CO or some other combustion parameter. Also, the distinguishing characteristics of the referenced facilities need to be provided so that the validity of the conclusion can be verified by the reader. The 1993 EPA reference must also be incorrect since 1994 data are attributed to it. There are additional instances of impossible references that need to be corrected.

Is a continuous chlorobenzene [CB] monitor a commercially practicable technology? Even with a vendor promise of a 1 ppb detection limit based on similar equipment, the ASME/CRTD Davis County testing found each of the ten chlorinated chlorobenzene isomers present at concentrations between 0.02 and 0.4 ppb, so this is not good enough. Nor have any CB monitors been shown to provide Method 301 equivalent results to manual Modified Method 5 samples (Environment Canada or California Air Resources Board methodology since there is no EPA reference method).

Absent such an equivalency demonstration, any results should, at best, be used for process monitoring purposes only; the danger is that they might be used for enforcement by unknowledgable people. This could lead to a number of needless court cases under the citizen suit provisions of the CAA. Even if a practical CB monitor with sufficient sensitivity existed, what information would it give that a CO analyzer does not?

Pittsfield was a parametric experiment. A number of different conditions were tested, so the data must be analyzed using techniques that account for these designed experimental effects.

Otherwise, any conclusion drawn can be easily assigned to the wrong cause. This is the "false positives" problem in statistical parlance.

How were the lines added to this and subsequent figures? They appear to be hand drawn guidelines. If this is the case, they can mislead readers, especially when there are other parameters varying. For example, look at the line drawn labeled "Hamilton '94" on one end with "Pulaski '90" with an arrow pointing to the other end. This line shows a reduction in TEQ with increasing CO. Which is right, this subset or the overall trend displayed by the majority of the data? Good science calls for going with the preponderance of the evidence. Exceptions to general patterns must be identified and discussed; they may point toward important break-throughs. The conclusion that TEQ and CO are highly correlated may only apply to special cases.

Figure 4 does not show a decrease in TEQ with CO. It appears that the totality of the data argues for no correlation. I believe that if the author were to look at PCDD/F concentrations entering the APCS, a correlation would probably be found, but that when the point of reference is the stack, no consistent relationship exists. Basing regulatory mandates on unproved theories, especially when the available information argues that the linkage is weak, will—at best—waste money. At worst, assuming there is a real problem, attention is misdirected and the problem left unresolved.

It should be confirmed that the only change made at Hampton, VA was over-fire air system modifications. Figure 5 shows that the ESP temperature was reduced from 700°F to 500°F. Either the explanation is incorrect or the data are misplotted.

The rest of the Pitttsfield data should be added to Figure 3; there is more shown on other figures in this paper. Also, individual run results should be used rather than averages to provide a visual indication of variability (data scatter). Inspection of the existing plot, Figure 3, indicates that the Pittsfield PCDD/F is probably all the same. The easiest way to see this is to hold the paper level and look across the graph from the end. If the data all seem to overlap, there is probably nothing there. Any interpretation under this circumstance is assigning causality to data noise. At best, Figure 3 shows that any relationship between PCDD/F and CO occurs at levels above 200 ppm$_v$. The author is requested to revisit his conclusion to determine if it is general or needs to be appropriately qualified. The data in Figure 5 should also be reanalyzed, accounting for the parametric nature of the test, and considered as the author develops a statement concerning the generality of his conclusion.

From Figure 5 (identified as 6 in the text) it is impossible to determine that oxygen changed or that the PCDD/F increase was predominantly in the furans. This is another oft-repeated hypothesis that may not be generally correct or even supported by the data acquired at the referenced facilities. Plotting total PCDD, total PCDF and total PCDD/F versus oxygen would show if the point is valid. Appropriate data and graphics are needed to support the conclusion reached in the paper.

Regarding the ash management procedure conclusion, why does having lots of landfill space have any bearing on prudent management techniques? RCRA waste characterization methods are intended to simulate management in Subtitle D (sanitary landfills). EPA's final guidelines on ash testing and characterizations recognize that RCRA requires the generator to characterize and manage in an appropriate manner the residues leaving a facility. Ash typically tests RCRA non-hazardous. Consequently, any management technique suitable for MSW is also appropriate for such ash. Land availability has nothing to do with it; not wasting society's resources chasing ghosts does.

Looking at Figure 5, discussed as Figure 6, I am unable to find any data identified as belonging to Tulsa or Pittsfield. In addition, that plot shows PCDD/F concentrations decreasing with ESP temperature at every plant. How can one conclude that Pulaski, Westchester (Peekskill) and Pinellas show something different since the hand drawn guidelines are all sloping down?

The strength of this temperature relationship emphasizes the need to account for ESP temperature changes when interpreting these data. It would be prudent to revisit all the CO plots to make sure that whatever conclusions are finally reached are assignable to CO and are not the result of changes in ESP temperature or some other confounding variable. Such confounding is what made the ASME/CRTD analysis of the relationship between dioxin and chlorine so challenging. No plots that show low precursors being related to low PCDD/F were found. The precursors being discussed should be defined and the relationship between the precursors and PCDD/F explained. Finally, it should be shown that once other variables like ESP inlet temperature have been controlled for, there is still a meaningful relationship—one that is not equally well explained by random chance. My understanding is that there are several modes of PCDD/F production in operating facilities. Under poor combustion conditions, flame formation and furnace carryover probably predominate. Once out of that mode, time-temperature profiles become very important. So do particulate loading and gas composition. If this is an important finding that can help plant designers and operators, it should be supported. To do otherwise could cause people to waste money on a demonstrably false premise.

How does measuring CO reduce the emissions of organics? While CO monitors provide valuable information concerning the quality of combustion, the mere act of measuring does not effect a change, much less an improvement.

The chlorobenzene data in Figure 7 only support a high correlation if the condition labeled "High-poor" is representative. Absent this point, no statistically significant correlation exists. At the ASME/CRTD Davis County testing, total chlorobenzenes were correlated with PCDD/F when powdered activated carbon [PAC] was not used. Once PAC was introduced, the correlation was statistically insignificant; the sign was negative indicating that more chlorobenzene produced less PCDD/D! Since Hartford is a spreader stoker, its fly ash has a lot of carbon and a no-relationship finding would be consistent with the ASME/CRTD study.

I am unable to locate any evidence in the figures provided that DSI equipped systems have PCDD/F concentrations that are independent of CO. The appropriate information should be provided, perhaps by identifying sets of points in the existing figures to support this conclusion or providing an additional graph. This statement is probably true since it is, in my opinion, true for all systems operating below a few hundred ppm CO. However, the conclusion must be supported and any necessary limitations on the generalization stated such as the confounding factors (e.g., ESP temperature) the author already identified.

I am unable to find evidence in this paper that ESP temperature affects acid gas and mercury emissions. On the surface the statement appears ridiculous since an ESP alone cannot affect acid gases; it is not designed to control acid gases. While lower temperatures undoubtedly help DSI and SDA systems work better, including those adding PAC too, the data have not been presented to support this conclusion.

I am unable to reach the conclusion that combustion technology determines absolute PCDD/F emissions from the data presented in this paper. I do not question that when furnace carry-over and flame formation predominate emissions, there is an effect; or that suspension firing increases fly ash carbon which can reduce emissions from a SDA/FF or SDA/ESP installation. Once past that regime and design feature, however, the linkage probably breaks down. Consider, for example, the data in Figure 4. Some units experience an increase in PCDD/F across the APCS, others a decrease. Clearly, the APCS has an effect as well. This conclusion needs to be supported and its limitations qualified.

I understand the traditional role of oxygen and CO in guiding furnace operating condition adjustments. For inherently low NO_x staged combustion burners like incinerators, a NO_x monitor may also indicate that something has changed and adjustments are needed. But, how is having a HCl or SO_2 monitor useful in optimizing combustion control? These are usually used to adjust reagent flow to a DSI or SDA system. It is not obvious that seeing a change in SO_2 or HCl should prompt the operator to adjust the overfire air flow, for example.

In summary, the author brings together a wealth of information and makes many interesting and potentially useful observations. Unfortunately, absent cogent responses to the questions posed in this discussion, this paper is misleading. It should not be distributed without the discussions and the author's response.

AUTHOR'S REPLY

The objective of this paper was to investigate the separate contributions of improvements in combustion and emission controls, in order to meet the newly published EPA guidelines. Due to the importance of the subject to owners and operators of facilities with ESPs, and their urgent need for guidance, I felt obliged to provide a broad perspective, including matters ranging from well understood to purely speculative, inviting further investigation.

Dr. Rigo is concerned that some of my statements could be misleading, promising false hopes or inviting failure. I appreciate his warnings and invite the reader to pay close attention to them.

While the title of this paper uses the word 'upgrading,' the paper focusses almost entirely on combustion and reduction of PCDD/F emissions from the stack, ignoring what are probably more critical problems in meeting the EPA Emission Guidelines, especially control of SO_2 and HCl. The subject of upgrading is incomplete without addressing the use of alkaline reagents to control acid gases, and the potential impact of the use of dry reagent injection on particulate emissions when an ESP is used.

Recognizing this deficiency, I displayed a graph during the presentation of the paper indicating that a stoichiometric ratio (SR) of 2.0 was likely to be needed to meet the EPA guideline for large MWCs of 95% HCl control and 85% SO_2 control. The ESP might not be able to meet the PM guidelines of 0.012 gr/dscf for large facilities when this quantity of reagent was employed unless a cyclone was used to reduce the particulate burden on the ESP.

I had hoped that research currently being completed would be available in time to provide and publish answers to the these questions. The paper by Rigo and Chandler "Retrofit of WTE Facilities Equipped with ESPs" (Page 1 of the Proceedings) unfortunately could not include the results of this research, carried out by the authors. This research was jointly initiated by the ASME Solid Waste Processing Division and the Research Committee on Industrial and Municipal Waste, and carried out by the ASME Center for Research and Technology Development under sponsorship by the DOE's National Renewable Energy Laboratory. This research has now been published by the ASME as CRTD-Vol. 30 and will be available from NREL.

The report states that "results of the tests indicate that the Davis County facility and other facilities using dry sorbent injection, powdered activated carbon (PAC) and ESP inlet temperature control can meet the small MWC category emissions limitations for all pollutants, and would likely meet the large facility guidelines for all regulated pollutants except for the acid gases."

The reason why the Davis County tests did not demonstrate ability to meet the guidelines for existing large facilities was that the tests was restricted to using only a stoiciometric ratio of about 1.0. The reader is referred to Appendix D of the report for an analysis of test results from European MWC facilities equipped with ESPs that use DSI, and which have demonstrated the ability to achieve high levels of HCl control during tests. Rigo calculates that emissions limitations based on data from the Edegem facility in Belgium might achieve 95% control with stoichiometric ratios in the range of 1.3 to 1.9 sodium-based reagents (sodium bicarbonate or trona). The tested facility incorporates a reactor column with 5-second retention, a cyclone, and reagent recirculation, in order to achieve these high levels of HCl control.

The clarifications which Dr. Rigo has provided should be useful to the reader. His discussion also provides me with the opportunity to elaborate on some deserving issues. I will try to respond to his major points.

1. The incremental cost of $18,500 per ton of acid remved is not far from the $15,725 which Dr Rigo suggested in his proposal for the Davis County study. In any case it is greater than the $10,000 per ton which the EPA suggested as being excessively high.

2. I used a ratio of 50:1 so that I, and the reader, could use the more convenient factor of 100/2 to make rough conversions.

This is not far off, since, as Dr. Rigo states, when all the congeners are above detection limits the ratio of PCDD/F to ITEQ is indicated to be close to 40, and that EPA's 60:1 ratio has some basis.

3. The mercury data used in Fig. 1, referenced to Marjorie Clarke, includes a variety of facilities, using various feed rates of activated carbon of various types, to meet various requirements. This graph shows the spread of the data in a given plant is typically 0.5 to 1.0 to 2.0, typical of a log-normal distribution, and in all cases the maximum was less than 80 mg/dscm.

4. Contrary to Dr. Rigo's statement regarding application of SNCR technology to refractory-wall MWCs, vendors of this technology pointed out to me that the lack of waterwall cooling of the gases, and the consequent close control and maintenance of furnace temperatures at 1600° to 1800°F should actually make it easier to control NOx when using urea or aqueous ammonia injection. My examination of the EPA data base shows that refractory-walled MWCs including the Pittsfield facility, generate much lower NOx levels, averaging below 180 ppm, corrected, probably due to their consistently lower furnace temperatures, making it hard to justify SNCR except perhaps for corrective action.

5. Dr. Rigo has provided me with some pages from the Des Carrierres report which I have previously cited. Tests were performed on Units 3 and 4 in November, 1982, having old 2-field ESPs, reporting extremely low PCDD/PCDF emissions. Tests of Unit 1, having a newer multi-field ESPs, performed in March, 1983 included four runs without lime injection, and four runs during which hydrated lime was metered into the MSW feed hopper. The PCDD/DF emissions of Units 3 and 4 averaged 40 times higher than those of Unit 1, and there was no difference between the averages of runs with or without carbon. That certainly settles the question as to whether or not lime feed to the hopper was beneficial. Fig. H (from Fig. 2 of the paper) presented herewith has been redrawn to include the Pittsfield and Des-Carrierre data, for comparison. The line connecting the March data seems to run parallel with the Pittsfield data. The November data show the bi-level characteristic of the Pittsfield data, and correspond with the emissions achieved with activated carbon injection. The reason why the Des Carrierre data are so much lower than other ESP data remains to be explained.

6. Regarding the range of emissions of particulates and volatile metals, I refer Dr. Rigo, and the reader, to my paper presented at this Conference, which provides the basis for my statement that the maximum emission level measured can be as high as four times the mean (page 83, Fig. 4), and Table 2, page 79. Actually, the maximum over a period of four years ranged from about 2.5 to 3.5 times the average in most cases, and as much as 5 times the average, depending upon the pollutant involved. The relationship between particulate and lead and cadmium is explored in this paper: the conclusion is that many factors are involved, including the behavior of different metals, the performance of different emission control technologies, and variations in their operation, all subject to the variations of the metals in the waste itself.

7. At the Hampton facility both ESP temperature and the over-fire air system were modified. As we have seen throughout this investigation, both factors can have a significant affect. The graph I published in 1984 showing the results of diagnostic testing of the Hamilton RDF-burning system clearly indicated the importance of optimizing the control of overfire air. See Fig. B.

8. The effect of oxygen on generation of foreknows is shown in Fig. C: with high oxygen levels (and relatively low furnace temperatures), PCDF exceeded PCDD by a factor exceeding 7, while being roughly equal below 7% oxygen. This contradicts my statement that low oxygen corresponds with high foreknows, and I stand corrected.

9. In regard to Fig. A, after plotting the data from these many different plants and technologies, including the three tests reported for each facility, I was struck with the tendency of the lines through the three tests to have a similar slope, in response to different ESP temperatures during each of the tests. This is likely the result of gradual fouling of the boiler surfaces. I suspected that the different levels indicated by different technologies were not a coincidence: there is a principle behind

this observed characteristic. I also noted a similar multi-level characteristic in Fig. E, showing the Pittsfield data with the furnace temperatures identified. This data indicates that the high temperatures correspond with low oxygen (as they must), and a corresponding increase in both dioxins and foreknows.

10. In regard to Fig. 4 in my paper (Fig. A herein), showing dioxins at the inlets and outlets of ESPs, it has been found that at certain temperatures the ESPs become generators of dioxins: this was demonstrated at Dayton (Montgomery County). High temperatures also result in higher dioxins levels leaving the baghouse than entering.

11. ESP temperature affects acid gas control efficiency only when alkaline reagents are used to control the acids. I would not claim that SO_2 or HCl monitors have any use in optimizing combustion control, but rather, as Dr. Rigo states, they can be used to adjust reagent flow to the DSI or SDA system.

12. Regarding the chlorobenzene data of Fig. 7, in this set it is not true that the high correlation depends upon a single high point. Actually, three separate tests performed under "poor" conditions fall on the same line as normal good and low good. "High good" is not consistent. Fig. G plots the data from the Pittsfield tests, which show an 84% regression coefficient (R^2). I have included only the runs burning MSW and PVC-free waste (commercial trash), since there was significantly more scatter in the tests with seeded PVC. The line marked 'Hartford' is repeated from Fig. 7. In Fig. 7 the relationship between CB and PCDD+PCDF remains more strongly linear at low CO levels than does that with CO. More research needs to done on these relationships.

13. Fig. A shows two data sets for Quebec. As it happens, these are from operation of the pilot installation in dry sorbent injection (DSI) operation which allows the temperatures to be varied more than with spray-dry lime injection. Those with spray-dry (SD) operation show the same characteristic, namely, that in spite of high inlet levels of dioxins, and high CO, the outlet conditions were roughly the same as those of Hartford, and essentially the same as the other facilities having baghouses (Marion and Commerce). Again we see that the outlet dioxin levels for the Quebec and Hartford data are essentially independent of inlet dioxins. Note that these data show that the efficiency of dioxin control is fairly constant (~99.9%), hence is sensitive to the inlet concentrations. The control efficiency of the Marion and Commerce plants was lower because the inlet levels were lower: this demonstrates the weakness in relying on control efficiencies when the outlet level is determined more by the operating temperature.

14. In regard to relative humidity versus HCl removal, Dr. Teller (Kreith, 1994) presents a graph based on parametric tests which shows that HCl removal is linear with RH below 18% RH, but exhibits logarithmic decay at higher humidities (diminishing effect). Rigo states that two plants that he knows of operate at temperatures above the design level of 285°F to avoid caking on the baghouse. Teller lists ten facilities having DI or SD scrubbers with baghouses: the stack temperature ranged from 243°F to 300°F, and averages 256°F. Usually plants have to stay close to the temperatures employed during compliance tests, but have some leeway to increase them. In the winter higher temperatures reduce the risk of condensation.

AUDIENCE QUESTIONS

Can you explain why different plants have different CO-PCDD/F relationships?

AUTHOR'S REPLY

This question is raised in connection with Fig. A (Fig. 4 of my paper), which shows toxic equivalent (TEQ) PCDD/DF emissions from a number of WTE facilities, some with ESPs and some with scrubber/baghouses. The top line, containing Pulaski '92 and Pulaski '94, the same line containing Hampton '86, '84 and '94 in Fig. 3) shows TEQ emissions measured at the entrance of the ESP, at temperatures generally greater than 450°F. Other facilities ESP facilities (not identified) are noted to have somewhat higher or lower emissions at the stack. The inlet to Quebec straddles the upper line. The inlets to the Hartford RDF facility are substantially lower, similar those of the other ESP facilities and also to the inlets of the Marion and Commerce WTE facilities.

The astonishing reduction in TEQ attained at Pulaski '94 was achieved by greatly increasing the effectiveness of overfire air jets, computer control of combustion, and reduction of the ESP temperature to 380°F. This result attests to the importance of both improving combustion and ESP temperature reduction. It also raised the question as to the contributions of these two approaches, hence the subject of this paper. (Hasselriis and Gaskin, 1995)

The stack emissions of the Marion, Commerce, Quebec and Hartford facilities, are well below to the line indicated as the EPA Proposed Standard of 0.5 ng/dscm. Quebec, employing dry lime injection shows outlet emissions which vary with the operating temperatures of 257°F and 284°F, respectively. The Marion and Commerce spray-dry (SD) scrubbers and fabric filters (FF) were operating at 260°F, whereas the Hartford SD/FF was operating at 245°F.

Fig. A shows that the inlet TEQ levels increase linearly with increased CO emissions, but that some facilities have lower TEQ to the ESP or scrubber/baghouse. TEQ entering the air pollution control devices (APCs) are seen to range from about 0.5 ng/Nm3 to 500 ng/Nm3 as CO ranged from about 2 to 1000 in the case of Pulaski, but range only up to 100 in the case of Hartford. Thus, different technologies have different relationships between the inlet TEQ and CO prior to the emission control system. Note that Marion and Commerce data **uncontrolled** are close to the EPA Guideline of 30 ng/dscm total PCDD/DF (0.5 ng/dscm on a TEQ basis) However, outlet emissions are clearly dependent on the temperature at which the air pollution control (APC) is operated.

This graph indicates that regardless of the inlet levels of TEQ and CO, outlet levels of facilities with temperature-reducing scrubber systems are roughly the same, largely because of the temperature at which the emission control system is operated.

The fact that ESP facilities showed either little control of PCDD/F, or even increases, led to the finding that the temperatures at which ESPs were operated had an important affect on these emissions.

To investigate the effect of stack (APC) temperature on TEQ emissions, Fig. B has been plotted (Fig. 5 in the paper). Here we see dramatically the effect of factors other than the APC operating temperature of both facilities having ESP and also SD/FF control, At any given APC temperature there is a wide range of TEQ emissions, ranging from less than 1 ng/dscm to 500 ng/dscm.

What is it about WTE facilities that accounts for these enormously different emissions? The Danish SD/FF could meet the EPA guideline of 0.5 ng/dscm for facilities with FF, only if operated at less than 320°F. The trends of the lines indicate that by reducing the ESP temperature to 450°F or even to 500°F the ESP facilities might achieve emissions below the EPA guideline of 1.0 ng/dscm. This extrapolation would of course have to be confirmed by testing. The linearity of the Danish graph indicates that a good surrogate for PCDD/DF emissions is the temperature at which the APC is operated. For ESP facilities, ESP temperature might be an indicator for a specific facility, but the variability of the ESP stack test data doesn't give much confidence in this assumption.

Dioxins and foreknows are generated in a variety of ways, partly the result of poor combustion, and partly the result of formation down the line as gas temperatures are reduced. CO is produced as the first stage of combustion, followed by completion of combustion to CO_2. The process of destroying organic matter is not that simple: trace organics leaving the combustion process are the result of imperfections in the process of volatilizing, and oxidizing the organics while passing through the flame region or bypassing it, quite independently of burning the CO. The organic matter must be volatilized then mixed with oxygen at sufficiently high concentrations and at high enough temperatures to complete the combustion. This mixing must take place at all locations and at all times. This requires proper provision of underfire and overfire air, and sufficient energy and placement of the overfire air jets. In addition, the combustion air supply must be continuously adjusted in proportion to the rate of combustion so that shortage of oxygen does not occur anywhere or at any time. Likewise, if combustion air is not properly controlled, temperatures can fall, slowing down the combustion process and resulting in products of incomplete combustion (PICs), including CO and trace organics.

In other words, destruction of trace organics appears to be related to the effectiveness of mixing of the reactants and maintaining optimum conditions **at all times and all places**. This is easier said than done..

The formation of PCDD/F after combustion requires the presence of precursors, and depends upon their concentration, which is reduced by good combustion. Boiler configuration and cleaning of tube surfaces influences formation; and finally, the emission control technology influences formation, destruction and condensation of PCDD/F, and their removal from the flue gases.

At high CO levels a strong trend has generally been noted between CO and furnace temperature, as expected from chemical kinetics, and with oxygen, since furnace temperatures are controlled by the use of excess air containing excess oxygen, and oxygen is necessary for the oxidation of organics. These variables are thus dependent upon each other. However, at low CO levels, corresponding with high furnace temperatures and associated low oxygen levels, effective mixing becomes more and more critical. Some furnace designs and methods of injecting overfire air are much more effective in reducing not only CO, but dioxins and foreknows.

Insight into the principles of attaining optimum combustion can be obtained from Figs. C, D and E based on the data obtained from the diagnostic research carried out at Pittsfield in 1987. Tests were performed over a wide range of furnace temperatures, by controlling combustion air and flue gas recirculation. This system was fed by a hydraulic ram on roughly a six-minute cycle. Uncontrolled PCDD/F were measured at the boiler outlet. In addition to tests burning normal MSW, trash (paper, cardboard and wood) were burned during specific tests. To reduce data scatter, only the runs burning MSW are plotted here.

Fig. C (revised from Fig. 6 of my paper) shows strong linearity between the logarithm of CO and furnace temperatures in the range from 1250°F to about 1650°F. As furnace temperatures were increased to 1850°F, CO did not fall further, but on the contrary, became erratic, with substantial increases. Although exhibiting a wide band of variation, PCDD+PCDF also decreased with temperatures up to 1650°F or so, then also increased erratically at higher temperatures. It is worth noting that so-called duplicate runs at the same temperature often showed points at both the upper and lower extremes. On the basis of this data, I have suggested that 1600°F may be a more ideal furnace temperature than 1800°F. However, the location at which this temperature is critical. The EPA guidelines which call for 1800°F as the ideal temperature state that this should be measured above the last point of overfire air injection, supposedly reflecting the flame temperature.

In Fig. D, PCDD and PCDF data points plotted against oxygen, also fall on declining and rising lines. PCDF data are about 50 times higher than PCDD when the oxygen exceeds 7% oxygen, but seem to follow PCDD at lower oxygen levels. Several test runs at about 7% oxygen show oddly different behavior: these points could be the average of oscillations between high and low oxygen caused by failure of the oxygen control system to function rapidly enough. This was noted in the diagnostic tests of a two-chamber waste combustor in Prince Edward Island, also fed by a charging ram.

Fig. E, PCDD and PCDF in which data are plotted against carbon monoxide (CO), shows that above about 20 ppmv of CO, PCDD and PCDF data fall on distinctive and separate lines, whereas below 20 ppmv they are scattered in a wide range, duplicate runs often falling on either extreme. Only the runs burning MSW were included here, since runs with paper-type and wood waste behaved differently. The trend of CO with PCDD/F observed at Pittsfield has also been noted in tests of other MSW combustion facilities, including the finding that as CO was reduced below about 10 to 20 ppm, PCDD/F levels have been noted to increase, radically.

The relationships between furnace temperature, oxygen, CO and PCDD/F, obtained by deliberately operating the furnace at a series of closely-controlled temperatures, provide a map of the range of conditions which can take place during normal operation. In a less than perfectly controlled combustion process, the operating conditions at any given time will oscillate to the right and to the left of the optimum point, and will vary from location to location in the furnace, as well as from time to time. Each fresh charge injected by the ram feeder will contribute to a displacement of the operating point, causing the need for combustion air adjustment.

Fig. F (a replot of Fig. 3 of my paper) shows toxic equivalent dioxins and foreknows (TEQ) plotted against CO for MSW combustors employing ESPs for emission control. The upper line is linear with CO. The other combustors (from the EPA data base) show a lesser slope, while the Pittsfield data shows the steepest trend with CO, but jumps up below 10 ppmv, as noted above. Furnace temperatures are shown.

In my judgement, a major reason for the differences between the different facilities lies in the effectiveness of the combustion in reducing precursors of PCDD/DF, achieved by effective mixing of combustible gases and combustion air, and maintenance by automatic control of optimum combustion conditions. This is well known to the technology developers who have over the years concentrated on improving the effectiveness of the overfire jets in providing turbulence (mixing) of the reactants as combustion is completed. Other factors are the carryover of flyash from the combustion chamber, the formation on boiler tubes, and the temperature at which the emission control system is operated, and even the design of the ESP.

While we have focussed on dioxins, limited data shows a relationship between dioxins and other products of incomplete combustion (PICs) such as chlorobenzenes (CBs) leaving the boiler and the emission controls. Fig. G shows that an 84% correlation coefficient was found between uncontrolled CBs and PCDD+PCDF data obtained from the MSW runs at Pittsfield. Higher levels were measured at Hartford, shown in Fig. 7 of the paper, exhibit a similar essentially linear trend with CB. While CO is useful as a continuous monitor, it is not directly related to the PICs such as CBs, hence CBs may be more valid precursors of dioxins and foreknows. I suggest that continuous measurement of CB could be a useful diagnostic for control and optimization of combustion conditions.

AUDIENCE QUESTION

Adding sorbent after humidification is sometimes better than adding it before water sprays. Please comment on your experience.

AUTHOR'S REPLY

Because most sorbents perform optimally at lower temperatures and higher humidities, adding the sorbent after humidification (water-spray cooling) is considered to be preferable. However, depending upon site considerations and the type of sorbent used, in a retrofit it may be preferable add the sorbent upstream of humidification. Hence, while there are advantages and disadvantages to both, practical considerations may force the decision.

When a new system is to be installed without space and configuration constraints, an attemperating tower plus a reagent reactor would preferably be installed prior to an ESP or baghouse. Thus adequate retention time can be provided for evaporation of the water as well as for dispersion and exposure of the dry reactants. This arrangement also allows for recirculation of the reagent and collected flyash to improve efficiency and utilization of reagent. dispersal and exposure of the reagent.

In retrofitting existing facilities the special site characteristics and the type of sorbent reagent must be taken into account, as well as the emission limits which must be met. In the case of the Davis County WTE facility it was advantageous to inject the trona reagent into the roughly 600°F gases entering the economizer, removing bound moisture characteristic of trona, while gaining the retention time of the economizer, and conserving retention time for evaporation of the water spray applied after the economizer. See the paper by Rigo and Chandler, page 1 of the Proceedings.

COMMENT BY JAMES KILGROE

You stated that in spite of high dioxin concentrations entering the APC, such as in the case of Hartford, the scrubber/baghouse removes it all, hence it doesn't matter whether or not the combustion is good and the CO is low. But these organics remain in the flyash, and are considered to be a problem in Europe. In addition, while we pay attention to dioxins, there are other trace toxic organics which may be emitted due to poor combustion.

AUTHOR'S REPLY

Mr. Kilgroe is right. Although the organics are apparently well absorbed or adsorbed by the particulate matter and carbon, we certainly should prefer that they be destroyed in the combustion process, so that even the flyash is essentially free of them.

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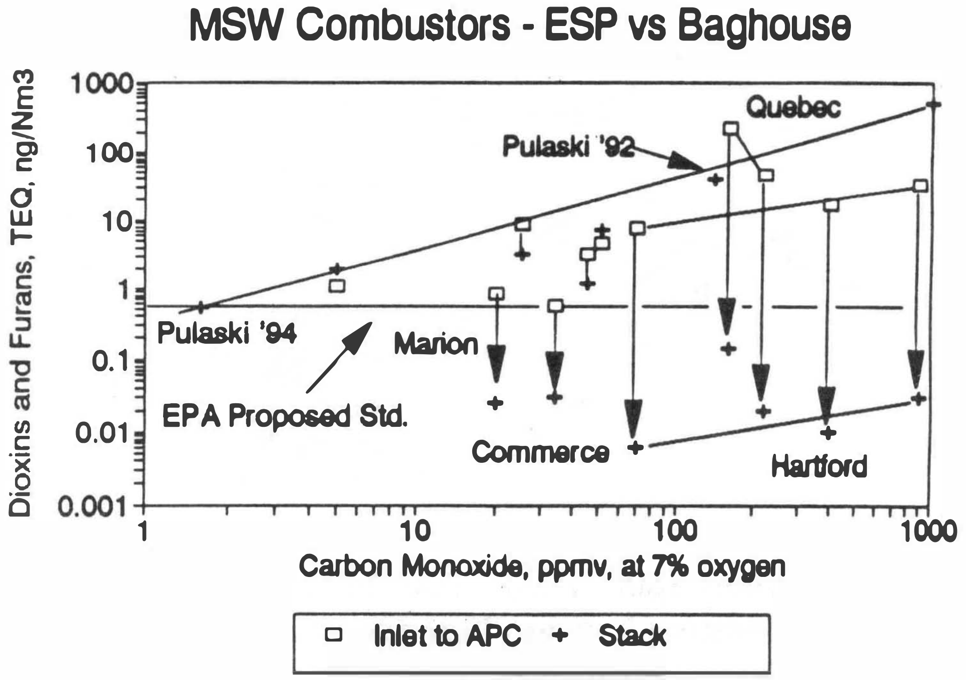

Fig. A Toxic equivalent (TEQ) TCDD emissions of MSW combustors versus carbon monoxide (CO)

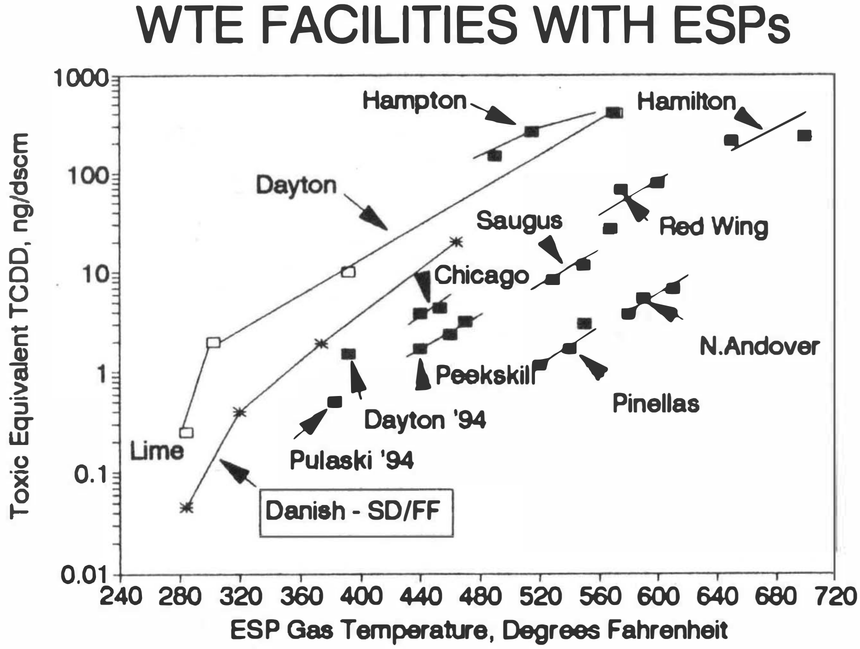

Fig. B TEQ emissions of WTE facilities versus stack temperature

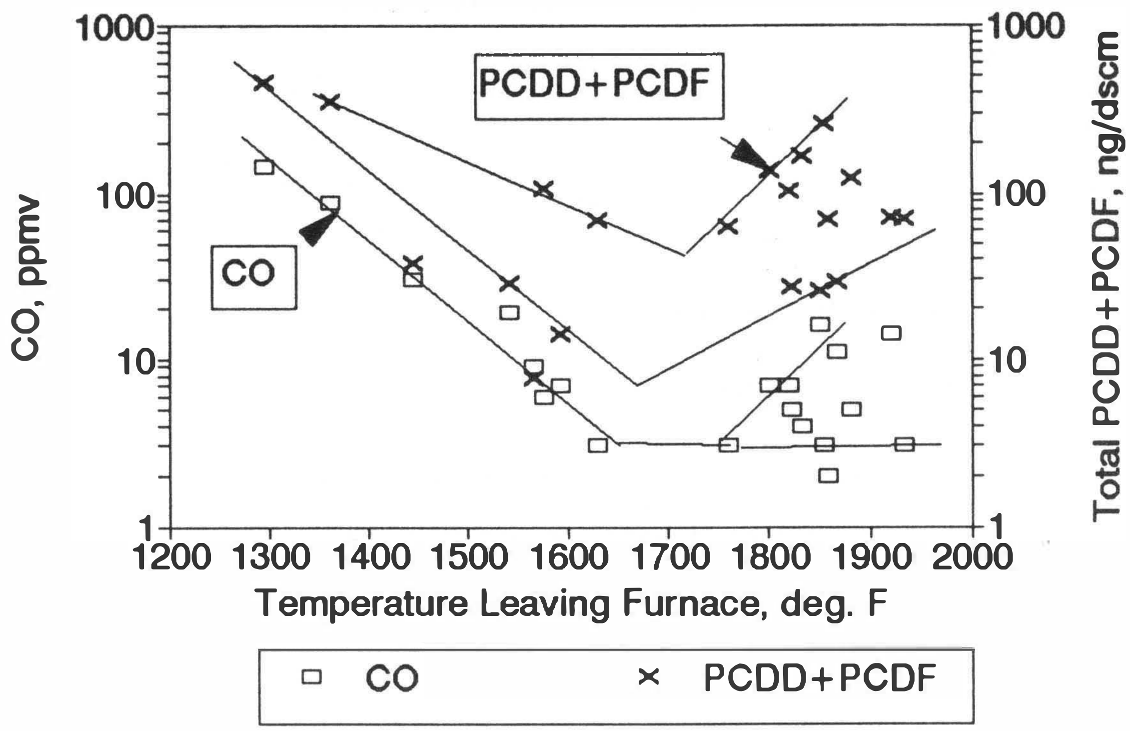

Fig. C Carbon monoxide and total PCDD+PCDF versus furnace exit temperature, Pittsfield data

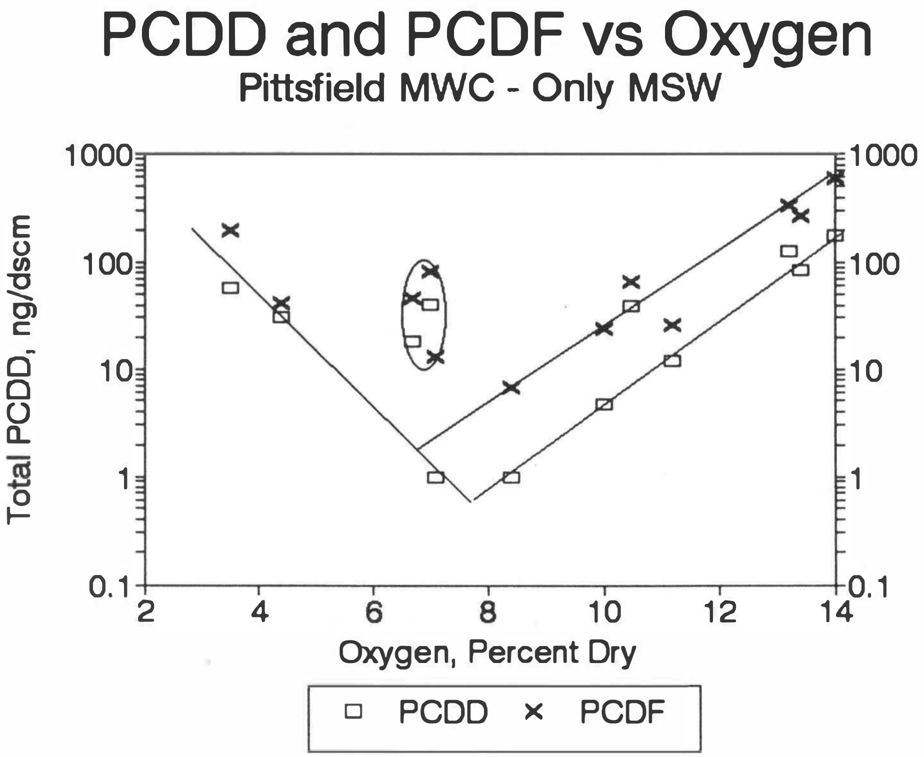

Fig. D Total PCDD and PCDF versus oxygen, Pittsfield data.

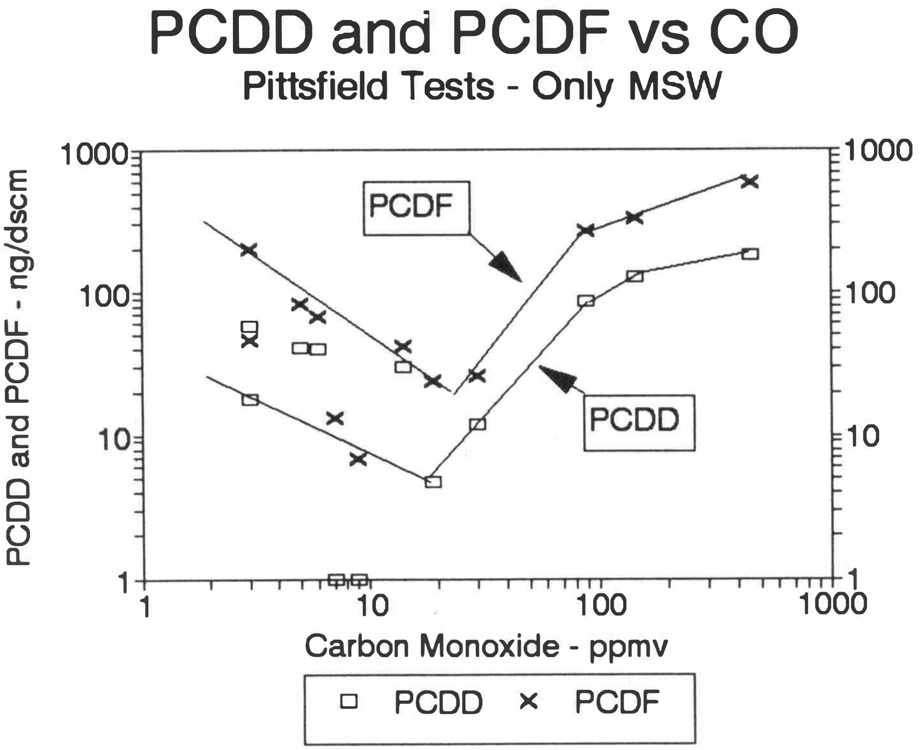

Fig. E Total PCDD and PCDF versus carbon monoxide, Pittsfield data.

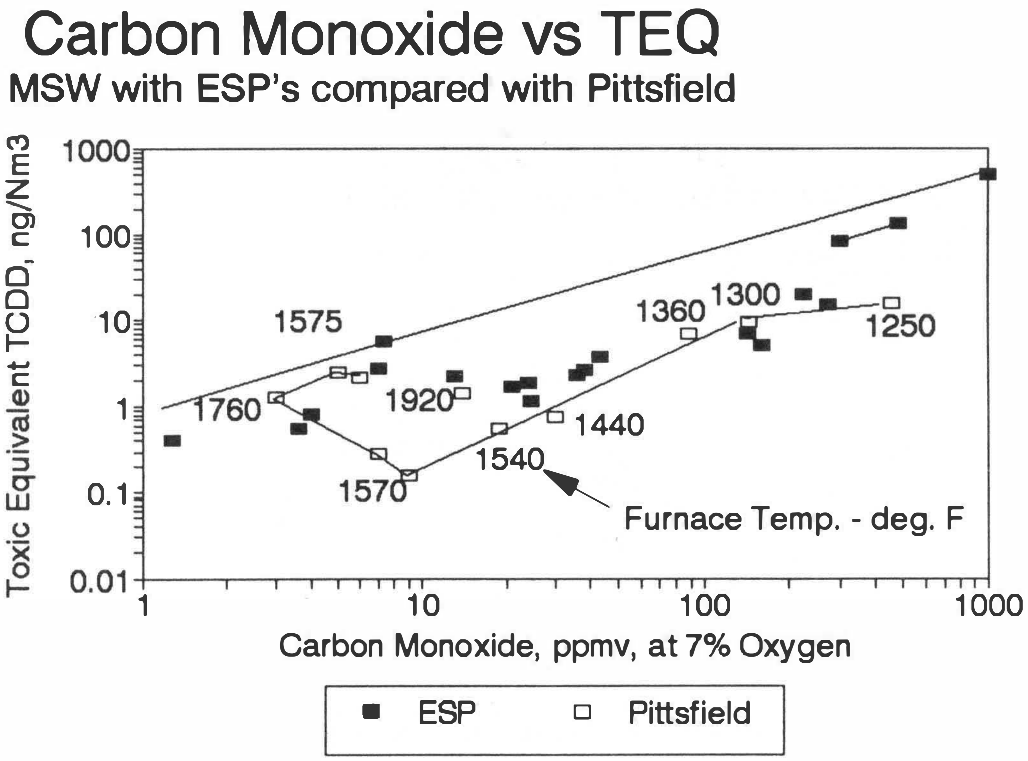

Fig. F TEQ TCDD versus carbon monoxide for facilities with ESPs, including Pittsfield data.

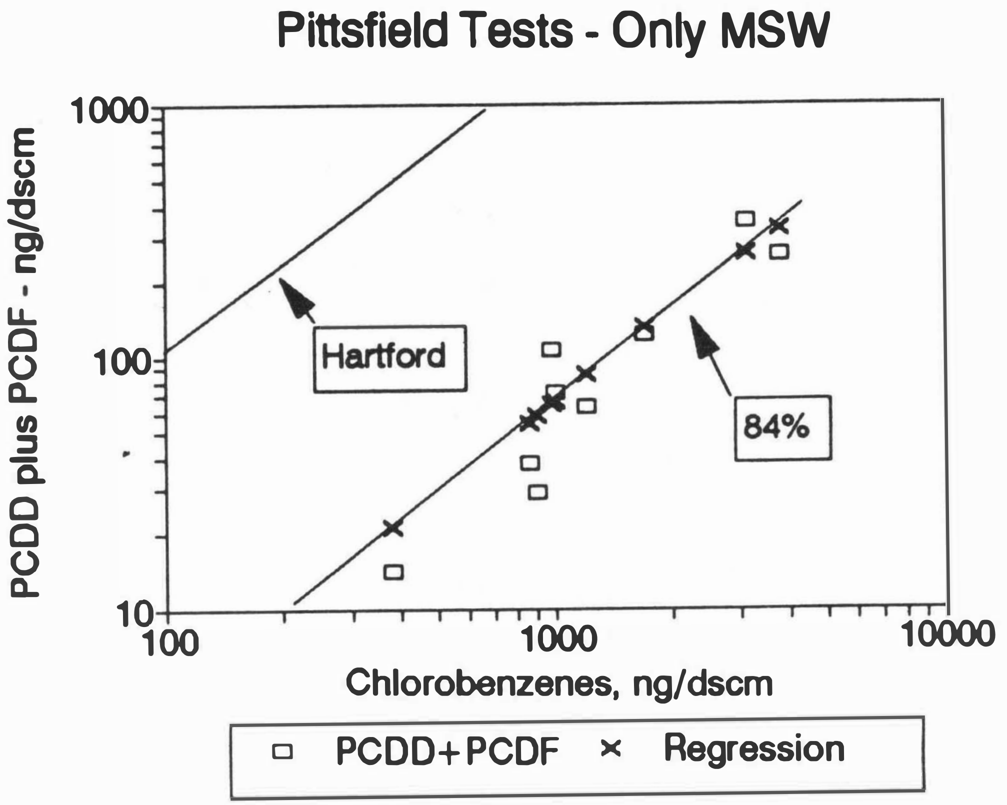

Fig. G Correlation between total PCDD+PCDF and chlorobenzenes, comparing Pittsfield with Hartford.

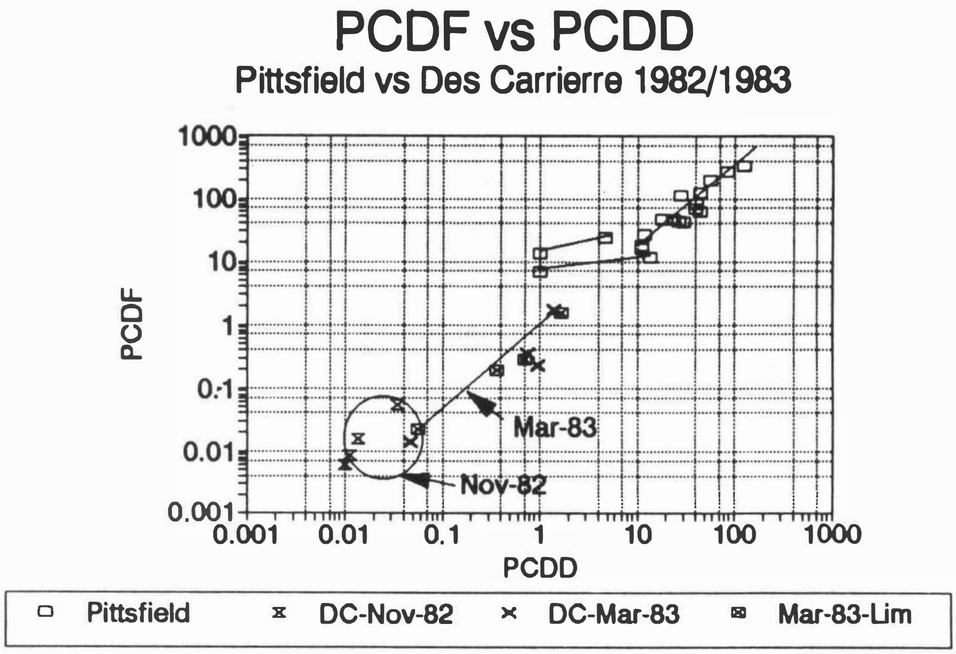

Fig. H Total furans (PCDF) plotted against total dioxins (PCDD) from tests of Pittsfield and Des Carrierres. (Boisjoly, 1984)

In conclusion, it has been demonstrated that emissions of dioxins and furans from existing MSW combustors can be reduced to regulatory levels by readily available methods: upgrading combustion by control of combustion air distribution, reducing the temperature at which the ESP is operated, and by injection of activated carbon.

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Please insert page 48 in the *Proceedings*. ASME-SWPD regrets the inadvertent omission.