Reducing Mercury Emissions from Municipal Solid Waste Combustion

(Results of Investigations and Testing at the Camden Resource Recovery Facility)

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Abstract: During the past year, the subject of mercury emissions from municipal solid waste combustion facilities has become a focus of investigation by federal and state regulators with regard to potential health effects, setting of regulatory limits on mercury emissions, and means of achieving those emission limits. A report has been prepared which presents an overview of the subject of municipal solid waste combustion mercury emissions. Through the authors' investigative studies as part of ongoing work related to the Camden Resource Recovery Facility serving Camden County, New Jersey, a discussion of the sources of mercury emissions which may be found in municipal solid waste, which through recycling and source separation could result in reduced mercury emissions, is presented. The paper also discusses powdered carbon injection as a technology based means of reducing mercury concentration in municipal solid waste combustion flue gas. The results of a recently completed USEPA test program performed at the Camden Resource Recovery Facility, which tested the effect and variability of results of powdered carbon injection, is discussed. The discussion provides a basis for predicting the achievable reductions in mercury concentrations through this technology.

The paper helps provide insight into the flue gas mercury emission levels or mercury removal efficiencies which are likely achievable through precombustion source separation and post combustion technology related means. The paper therefore provides valuable input into the regulatory data base upon which mercury emission regulations may ultimately be based.

REDUCING MERCURY EMISSIONS FROM MUNICIPAL SOLID WASTE COMBUSTION

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Introduction

The presence of mercury in municipal solid waste has become a matter of public concern with regard to potential stack emissions of mercury and mercury compounds from waste combustion facilities. The solid waste combustion industry, and industry regulators, can begin to address this issue by considering preventive measures such as source separation and product content limitations on mercury, or such corrective measures as technology based post combustion pollution control. Mercury emissions, although controlled to some degree by the combustion process itself, are not efficiently controlled by air pollution control equipment typically used at modern facilities. Experience in New Jersey operating plants, of which there are four, has shown that mercury emission limitations as contained within the individual facility air permits are being met, but by relatively narrower margins than other regulated metals emissions.

Other sources of airborne mercury emissions in New Jersey include coal burning utility boilers and sludge incinerators for example. Although the mercury content of the various types of coals used by utilities is lower than the mercury content of municipal solid waste as presently estimated, the amount of coal combusted in New Jersey annually is approximately 2.7 times as much on a weight basis as the amount of municipal solid waste combusted. In areas of the country where coal combustion is more prevalent than in New Jersey, utility boilers are often a far more serious concern for mercury emissions than are municipal waste combustors. Additionally, municipal solid waste mercury content is on the decline and the means for further reducing mercury content as discussed herein are not available for the reduction of coal mercury content.

Public concern regarding mercury emissions surfaced during our ongoing work at the Camden Resource Recovery Facility (CRRF) in New Jersey. In September of 1991, Camden County passed a resolution in this regard, essentially limiting the mercury emissions from stationary sources within the County to a level below that which could

reasonably be achieved on a regular basis from the Camden Resource Recovery Facility. Although stack emission testing at the Camden Resource Recovery Facility consistently resulted in mercury emissions below the limits set by the facility air permit, and mercury emission levels during stack compliance testing were approximately one-half the permitted limit, the facility could have faced periodic shutdowns as a result of exceeding the County's standard, had the New Jersey Department of Environmental Protection and Energy (NJDEPE) Commissioner allowed the resolution to stand without comment. The Commissioner ultimately used his authority to disapprove the ordinance on the grounds that the technical analysis upon which the proposed mercury emission standard was based was insufficient to support the resolution. This series of events gave rise to mercury as a highly visible solid waste combustion issue in New Jersey. The NJDEPE, under the direction of the Commissioner, assembled a mercury task force in an effort to develop a scientifically based statewide mercury emission standard for combustion facilities, among other task force goals. During the same time frame, the federal USEPA also set out to study the issue of mercury emissions so that a federal standard, able to be achieved by current technology, may be set as required by the 1990 Clean Air Act Amendments.

The Pollution Control Financing Authority of Camden County (PCFACC), the public sector agency responsible for overseeing the operation of the CRRF, and Camden County Energy Recovery Associates (CCERA), the owner and operator of the facility, initiated its own activities to determine how best to reduce mercury emissions, although permit limits were consistently met. PCFACC's and CCERA's activities which took place during 1992 with regard to the subject of mercury emissions included investigations concerning mercury content in the waste entering the Camden facility, investigations of the potential mercury removal possible through battery recycling, studies regarding the available technology for removing mercury and its compounds from the facility flue gas streams, and preparation of a health risk assessment report.

The health risks associated with mercury emissions, the estimation of which is essential to the development of state and federal policies for mercury emissions from combustion facilities, is an important element of the work performed at Camden, although not addressed in this report.

Discussion

Section 129 of the 1990 Clean Air Act Amendments requires USEPA to set mercury emission limits for all new and existing combustion facilities. USEPA is also required to set numerical emission standards for maximum available control technology (MACT) for municipal waste combustors which by definition are to be based on the operating performance of the best 12% of operating units in each category (i.e., mass burn, rdf, etc.). Carbon adsorption technology, is likely to be the preferred means of achieving the MACT numerical standard for mercury, since it is well established that the capture of mercury in flue gas is dependent on the amount of carbon present in the products of combustion and municipal waste combustion products are relatively low in carbon

content. NJDEPE standards limiting mercury emissions from combustion facilities will likely be adopted as part of the State Implementation Plans required by Title I of the Clean Air Act Amendments. Carbon adsorption technology is under study in the development of this standard. Although the federal and State of New Jersey limits are not yet established, present indications are that the NJDEPE regulations may be based on a relatively low mercury outlet concentration standard rather than a percent mercury removal standard. An outlet mercury concentration standard of 28 micrograms per dry standard cubic meter at 7% oxygen is under consideration by New Jersey's mercury task force, although most recently a staged approach to implementing this standard has been introduced. Based on discussions with USEPA, the federal numerical standard is likely to be less stringent, although at this time it is difficult to determine when the numerical standard will be promulgated, or what the final standard will actually be. As a basis for comparison, the CRRF stack mercury emissions, although variable, were measured during facility acceptance testing to be approximately 300 micrograms per dry standard cubic meter exiting the facility stack, and approximately 600 micrograms per dry standard cubic meter at the economizer outlet, which represents a mercury reduction of approximately 50% through the existing air pollution control equipment. It should be noted that the mercury being removed is captured within the ash and stabilized, which prevents any future possibility of leaching. Therefore, with present technology, existing MSW plants provide a process for actually removing mercury from the waste stream.

The major contribution to flue gas mercury originating in the municipal solid waste stream has been identified through various studies as mercury containing batteries. The USEPA has reported that according to its studies, approximately 88% of the mercury present in the municipal solid waste stream is attributable to batteries[1]. Other sources of mercury which may exist in municipal solid waste, are fluorescent and high intensity lamps, paint residues, thermometers, pigments, and coatings for example. Our waste stream analysis work in Camden County concentrated strictly on batteries of various types as the main contributor of mercury in the County waste stream. Since approximately 70% of Camden County's remaining waste after recycling, is disposed of at the CRRF, a program designed to reduce the volume of batteries in the waste stream was implemented.

An attempt was made to estimate the quantities of various types of batteries in the Camden County waste stream, and the resulting mercury contribution those batteries make to the waste which is ultimately combusted at the Camden Facility. Using the weights of each type of battery and the percentage by weight of the mercury in each type of battery, we were able to project the weight of mercury per hour entering each furnace on an average basis. Applying a mercury reduction factor for removal during the combustion process, as demonstrated during stack emission testing, we were able to reasonably correlate the amount of mercury in the waste as a result of battery

[1] "Characterization of Products Containing Mercury in Municipal Solid Waste in the United States", dated January, 1991, prepared by A.T. Kearney Inc. and Franklin Associates, Inc. for the USEPA.

disposal, to the mercury concentrations reported in the stack emissions testing program conducted during facility acceptance testing.

As a separate effort we investigated current technology based methods of reducing stack mercury emissions from the CRRF. Our investigations included discussions and visits with vendors of carbon adsorption systems and sodium sulfide injection systems in order to gather information regarding the effectiveness and costs of the available technologies. The available test and operating data for both systems indicated that carbon adsorption is preferable on the basis of emission data and operational problems associated with sodium sulfide systems.

During May and June of 1992, the USEPA, in cooperation with Foster Wheeler Power Systems, Inc., of which CCERA is a subsidiary, conducted a series of tests designed to determine the effectiveness of carbon adsorption technology in reducing mercury content in combustion flue gases, with particular emphasis on electrostatic precipitator equipped facility performance.

Flue Gas Mercury Reduction Through Materials Separation

In order to demonstrate the relationship between the quantity and types of batteries in the waste stream processed at the CRRF and the measured mercury emissions from the facility's stack, U.S. data on battery discards was assembled and analyzed. The U.S. battery discard data was obtained from the paper entitled Characteristics of Products Containing Mercury in Municipal Solid Waste in the United States previously referenced.

The annual sales of each type and each size of battery for the year 1989 was used in conjunction with data on the weight of mercury present in each type and each size of battery to estimate the total amount of mercury present in the annual battery discards in the U.S. The following assumptions were then made to estimate the amount of mercury entering each furnace of the CRRF and the projected amount of mercury exiting each flue of the facility stack:

- Batteries contribute 88% of the mercury in the municipal solid waste stream
- The quantity of batteries present in the Camden County waste stream is proportional to the quantity of batteries in the U.S. on a population basis
- 50% of the mercury entering each furnace is removed in the combustion process and the existing air pollution control equipment

The calculations made based on the available data and the above assumptions resulted in predicted stack emissions which were very similar to the average mercury emissions measured during acceptance period stack testing and subsequent quarterly stack testing. One important conclusion from this study was that mercury zinc type batteries

as well as other high mercury content batteries, although existing in much smaller quantities in the waste stream than most other types of commonly used batteries such as alkaline type, are the main contributor to the mercury emissions ultimately discharged from the facility stack.

The following information regarding the most commonly used types of batteries was used to estimate the mercury emissions from the CRRF.

Alkaline Batteries

The most commonly used category of household batteries is the alkaline type, which accounted for approximately 56% of all battery sales in the United States in 1989. Alkaline batteries are used in flashlights, radios, toys and various other consumer products. The total sales of alkaline batteries is increasing and the percentage of all household batteries sold in the United States which are of the alkaline type is increasing as well. Mercury is used in alkaline batteries as a corrosion inhibitor and as an inhibitor to hydrogen buildup. The amount of mercury used in alkaline batteries is quite small and battery manufacturers are under increased pressure to further reduce mercury content in batteries in the future. However, the contribution of mercury to the municipal solid waste stream by alkaline batteries has been significant, although declining, as a result of the large number of batteries of this type sold (estimated to be 1.9 billion in 1991) and disposed of annually. The various sizes and weights of alkaline batteries and the approximate amount of mercury contained in each type are as follows:

Type	Percent Mercury	Weight of Mercury (grams)
D Cell	0.136 %	.1926
C Cell	0.117 %	.0792
AA Cell	0.298 %	.0682
AAA Cell	0.164 %	.0190
9 Volt Cell	0.071 %	.0337
Button Cell	0.409 %	.0085

Mercury-Zinc Batteries

Mercury-zinc batteries account for approximately 1.8% of all household batteries sold in the U.S. The two basic types of mercury-zinc batteries are button batteries (approximately 60% of mercury-zinc batteries sold) and cylinder batteries (approximately 40% of mercury-zinc batteries sold). Button batteries are used in watches, pocket calculators, hearing aids and for various industrial applications.

Mercury-zinc batteries presently constitute approximately 30% of the button battery market. Cylinder batteries are used in medical applications such as fetal and EKG monitors, as well as in certain household applications such as smoke detectors. Mercury-zinc batteries of both the button and cylinder type are also used as a power source for industrial and scientific equipment such as measuring instruments, and have other laboratory and military equipment applications. Button batteries weigh less than two grams each, of which about 0.8 grams is mercury. Mercury-zinc cylinder batteries weigh approximately 36 grams each, of which approximately 14 grams is mercury. Mercury functions as an electrode in these types of batteries and is therefore an essential component which cannot be substantially reduced as is the case in other types of batteries, where mercury has a secondary function and can be reduced or substituted with other materials. Mercury-zinc batteries have recently been losing market share to other types of button batteries. The various sizes and weights of mercury zinc batteries and the approximate amount of mercury contained in each type are as follows:

Type	Percent Mercury	Weight of Mercury (grams)
Button	40%	.629
Cylinder	40%	14.26

Zinc-Air Batteries

Zinc-air batteries are beginning to replace mercury-zinc button batteries for uses such as hearing aids. As zinc air batteries become more cost competitive with mercury-zinc batteries, it is expected that mercury-zinc batteries will continue to decline in use thereby reducing mercury content of the municipal solid waste stream.

Other Types of Batteries

Other types of batteries, such as silver oxide, lithium, carbon-zinc, nickel-cadmium, and heavy duty batteries make up a relatively small percentage of the total battery discards in the U.S. and contain either very small quantities of mercury or no mercury at all. The batteries which should be considered for collection and recycling for the purpose of reducing waste stream mercury are therefore mercury zinc button and cylinder type batteries, and other types of specialty mercury batteries generally used for industrial and medical applications. However, since it is beneficial to reduce the quantities of other waste stream metals such as cadmium, zinc, lead, and lithium for example, diversion of all types of batteries from the waste stream should be considered.

Battery Legislation

The state of New Jersey adopted legislation aimed at the removal of hazardous materials in the manufacture of batteries. Under the bill, button type mercury batteries would be banned from sale beginning in 1996. Until then the batteries would have to be collected under a system developed by the manufacturers and approved by NJDEPE.

Other states have instituted similar legislative approaches to encourage hazardous material reduction in the municipal solid waste stream. Such legislative mandates along with municipal battery and hazardous waste collection programs, should result in reduced mercury emissions from waste combustion facilities.

Effect of Battery Collection Programs on Combustion Facility Emissions

Aggressive recycling programs have been in place in various counties throughout the United States for some time. A review of some of these programs indicates that the rate of recycling of batteries is low as compared to the projected total weight of batteries in the waste stream as a result of the lower than expected participation rates and the high cost of final disposal.

None of the battery recycling programs investigated appear to be highly successful in terms of the percentage of batteries which have been shown to be removed from each community's municipal solid waste stream, but the body of data on battery recycling is very small and not scientifically based. The direct relationship of mercury emitted from resource recovery facilities to mercury in the waste stream results in reduced emissions even at low battery removal rates. Therefore, a battery removal program may be considered successful even without a high degree of compliance, provided it is properly planned to target batteries with high mercury content.

Our recommendation with regard to Camden, was generally to institute a targeted battery recycling program. A 20% reduction in mercury-zinc batteries would result in measurable mercury emission reductions since it is estimated that about two-thirds of the mercury in the Camden County waste stream results from mercury-zinc batteries. Removal of mercury from the waste stream could be accomplished through battery recycling programs directed at industries and health care establishments, which are likely to use high mercury content batteries in their equipment and instruments. An industrial waste survey concentrating on battery use discards, could be performed, with emphasis on medical establishments (hospitals, clinics, doctors offices for example), laboratories, and other possible users of mercury-zinc batteries would be an initial step in establishing a recycling program.

The attached Table 1 shows the basis for estimating the annual mercury contribution from batteries in Camden County. The estimated battery sales and associated mercury contribution from each type is extrapolated on a population basis from the total U.S. data as obtained from the USEPA report previously referenced. The data

Camden Resource Recovery Facility
Estimated Mercury Contribution From Batteries

Alkaline

Total Annual U.S. Sales	2,064,250,000
U.S. Population	250,000,000
Camden County Population	550,000

Type	total sales	mercury content	battery weight (gm)	annual mercury contribution (pounds)
9Volt	7.92%	0.0710%	46.7	26
D	12.91%	0.1360%	141.9	249
C	16.11%	0.1170%	67.5	127
AA	55.28%	0.2980%	22.9	378
AAA	7.48%	0.1640%	11.6	14
Button	0.30%	0.4090%	2.09	0
Total Annual Mercury Contribution from Alkaline Batteries				795 total

Carbon Zinc

Total Annual U.S. Sales	317,400,000
U.S. Population	250,000,000
Camden County Population	550000

Type	total sales	mercury content	battery weight (gm)	annual mercury contribution (pounds)
9Volt	11.1100%	0.0074%	35.63	0
D	33.6900%	0.0088%	79.5	4
C	22.2200%	0.0076%	39.3	1
AA	32.9700%	0.0053%	15.06	0
Total Annual Mercury Contribution from Carbon Zinc Batteries				6

Heavy Duty

Total Annual U.S. Sales	495,650,000
U.S. Population	250,000,000
Camden County Population	550,000

Type	total sales	mercury content	battery weight (gm)	annual mercury contribution (pounds)
9Volt	9.5100%	0.0073%	36.47	1
D	23.9000%	0.0018%	95.4	1
C	23.4300%	0.0069%	43.7	2
AA	43.1600%	0.0051%	15.62	1
Total Annual Mercury Contribution from Heavy Duty Batteries				4

Mercury Zinc

Total Annual U.S. Sales	56,350,000
U.S. Population	250,000,000
Camden County Population	550,000

Type	total sales	mercury content	battery weight (gm)	annual mercury contribution (pounds)
Button	60.0000%	40.0700%	1.57	103
Cylinder	40.0000%	40.0700%	35.6	1,560
Total Annual Mercury Contribution from Mercury Zinc Batteries				1,663

Silver Oxide

Total Annual U.S. Sales	95,450,000
U.S. Population	250,000,000
Camden County Population	550,000

Type	total sales	mercury content	battery weight (gm)	annual mercury contribution (pounds)
Button	100.00%	0.0053%	0.92	0
Total Annual Mercury Contribution from Mercury Zinc Batteries				0

Zinc Air

Total Annual U.S. Sales	69,000,000
U.S. Population	250,000,000
Camden County Population	550,000

Type	total sales	mercury content	battery weight (gm)	annual mercury contribution (pounds)
Button	100.00%	2.4500%	1.56	13
Total Annual Mercury Contribution from Mercury Zinc Batteries				13

Table 1

base is for 1989, and the assumption is made that battery sales for 1989 equate to battery discards for 1990 (average 1 year life for all batteries). Using published data regarding the mercury content and distribution of battery types and sizes among the battery discards in the municipal solid waste stream in the United States and other assumptions as discussed above, the weight of mercury in the Camden County waste stream was estimated. Table 3 shows an estimate of the annual mercury contribution to the Camden County waste stream from various types of batteries. Table 4 shows the projected annual weight of mercury in the County waste stream derived from all mercury sources as well as the projected mercury weights entering the CRRF. Table 5 compares the estimated emissions based on the estimated mercury entering each of the CRRF furnaces to the mercury measured during the facility stack testing. Mercury zinc batteries, although a small percentage of all battery discards, is the largest contributor to waste stream mercury. Reductions in stack mercury emissions from the Camden Facility resulting from battery recycling is estimated in Tables 2(a), 2(b) and 2(c). As indicated below, Table 2(a) estimates mercury emission rates from the Camden Facility with no battery recycling. Tables 2(b) and 2(c) estimate the Camden Facility stack emission rates based on battery recycling rates as shown:

Table	Alkaline Batteries	Mercury-Zinc Batteries	Stack Emissions (#/hour)per flue
1(a)	0 %	0 %	0.036
1(b)	20 %	40 %	0.024
1(c)	20 %	60 %	0.019

As stated above, the calculated emission rates assume a 50% removal rate for mercury with no additional controls, as has been demonstrated during facility stack testing. The emission rates calculated in Table 2(a) are similar to those demonstrated during stack testing.

The predicted stack emissions demonstrate the close correlation between battery quantities in the waste stream, particularly high mercury content batteries, and stack emissions of mercury.

Mercury Reduction in Flue Gas Through Post Combustion Technology Based Means

Carbon Adsorption

In the spray drier absorption process for removal of acid gases, flue gas cooling takes place rapidly in a cloud of finely atomized droplets. Metals in the flue gas tend to condense or absorb onto the droplets. The metals are then removed along with dust and reaction products in the particulate removal device. This process works well for lead, cadmium, and other metals. However, much of the mercury present in the flue gas does not condense and remains in the vapor phase. In Camden's case

Estimated Battery Discards in Camden County, Effect on Waste Stream Mercury and Facility Mercury Emissions

Alkaline Battery Removal Rate=	***0.00%***
Mercury Zinc Battery Removal Rate=	***0. 00***

Type	Number*	Weight (lbs)*	Mercury Contribution (lbs)
Alkaline			
9Volt	359,675	37,037	26
D	586,288	183,443	249
C	731,611	108,891	127
AA	2,510,458	126,764	378
AAA	339,693	8,689	14
Button	13,624	63	0
total	4,541,350	464,887	795
Carbon Zinc			
9Volt	77,579	6,095	0.45
D	235,251	41,239	3.63
C	155,158	13,445	1.02
AA	230,223	7,645	0.41
total	698,210	68,424	6
Heavy Duty			
9Volt	103,700	8,339	0.61
D	260,613	54,822	0.99
C	255,488	24,618	1.70
AA	470,630	16,209	0.83
total	1,090,430	103,989	4
Mercury Zinc			
Button	74,382	257	103.18
Cylinder	49,588	3,893	1559.75
total	123,970	4,150	1,663
Silver Oxide			
Button	0	0	0.00
total	0	0	0.00
Zinc Air			
Button	0	0	0.00
total	0	0	0
TOTAL	6,453,960	641,451	2,468

Estimated Facility Mercury Emissions	
Pounds per Hour Mercury per Flue	0.036

* Based on data obtained from USEPA, January, 1991 report entitled "Charaterization of Products Containing Mercury in Municipal Solid Waste". Data prorated to Camden County on a population basis.

Table 2 (a)

Estimated Battery Discards in Camden County, Effect on Waste Stream Mercury and Facility Mercury Emissions

Alkaline Battery Removal Rate=	***20.00%***
Mercury Zinc Battery Removal Rate=	***40.00%***

Type	Number*	Weight (lbs)*	Mercury Contribution (lbs)
Alkaline			
9Volt	359,675	37,037	21
D	586,288	183,443	200
C	731,611	108,891	102
AA	2,510,458	126,764	302
AAA	339,693	8,689	11
Button	13,624	63	0
total	4,541,350	464,887	636
Carbon Zinc			
9Volt	77,579	6,095	0.45
D	235,251	41,239	3.63
C	155,158	13,445	1.02
AA	230,223	7,645	0.41
total	698,210	68,424	6
Heavy Duty			
9Volt	103,700	8,339	0.61
D	260,613	54,822	0.99
C	255,488	24,618	1.70
AA	470,630	16,209	0.83
total	1,090,430	103,989	4
Mercury Zinc			
Button	74,382	257	61.91
Cylinder	49,588	3,893	935.85
total	123,970	4,150	998
Sliver Oxide			
Button	0	0	0.00
total	0	0	0.00
Zinc Air			
Button	0	0	0.00
total	0	0	0
TOTAL	6,453,960	641,451	1,644

Estimated Facility Mercury Emissions	
Pounds per Hour Mercury per Flue	0.024

* Based on data obtained from USEPA, January, 1991 report entitled "Charaterization of Products Containing Mercury in Municipal Solid Waste". Data prorated to Camden County on a population basis.

Table 2 (b)

Estimated Battery Discards in Camden County, Effect on Waste Stream Mercury and Facility Mercury Emissions

Alkaline Battery Removal Rate=	***20.00%***
Mercury Zinc Battery Removal Rate=	***60.00%***

Type	Number*	Weight (lbs)*	Mercury Contribution (lbs)
Alkaline			
9Volt	359,675	37,037	21
D	586,288	183,443	200
C	731,611	108,891	102
AA	2,510,458	126,764	302
AAA	339,693	8,689	11
Button	13,624	63	0
total	4,541,350	464,887	636
Carbon Zinc			
9Volt	77,579	6,095	0.45
D	235,251	41,239	3.63
C	155,158	13,445	1.02
AA	230,223	7,645	0.41
total	698,210	68,424	6
Heavy Duty			
9Volt	103,700	8,339	0.61
D	260,613	54,822	0.99
C	255,488	24,618	1.70
AA	470,630	16,209	0.83
total	1,090,430	103,989	4
Mercury Zinc			
Button	74,382	257	41.27
Cylinder	49,588	3,893	623.90
total	123,970	4,150	665
Silver Oxide			
Button	0	0	0.00
total	0	0	0.00
Zinc Air			
Button	0	0	0.00
total	0	0	0
TOTAL	6,453,960	641,451	1,311

Estimated Facility Mercury Emissions	
Pounds per Hour Mercury per Flue	0.019

* Based on data obtained from USEPA, January, 1991 report entitled "Charaterization of Products Containing Mercury in Municipal Solid Waste". Data prorated to Camden County on a population basis.

Table 2 (c)

Annual Mercury Contribution

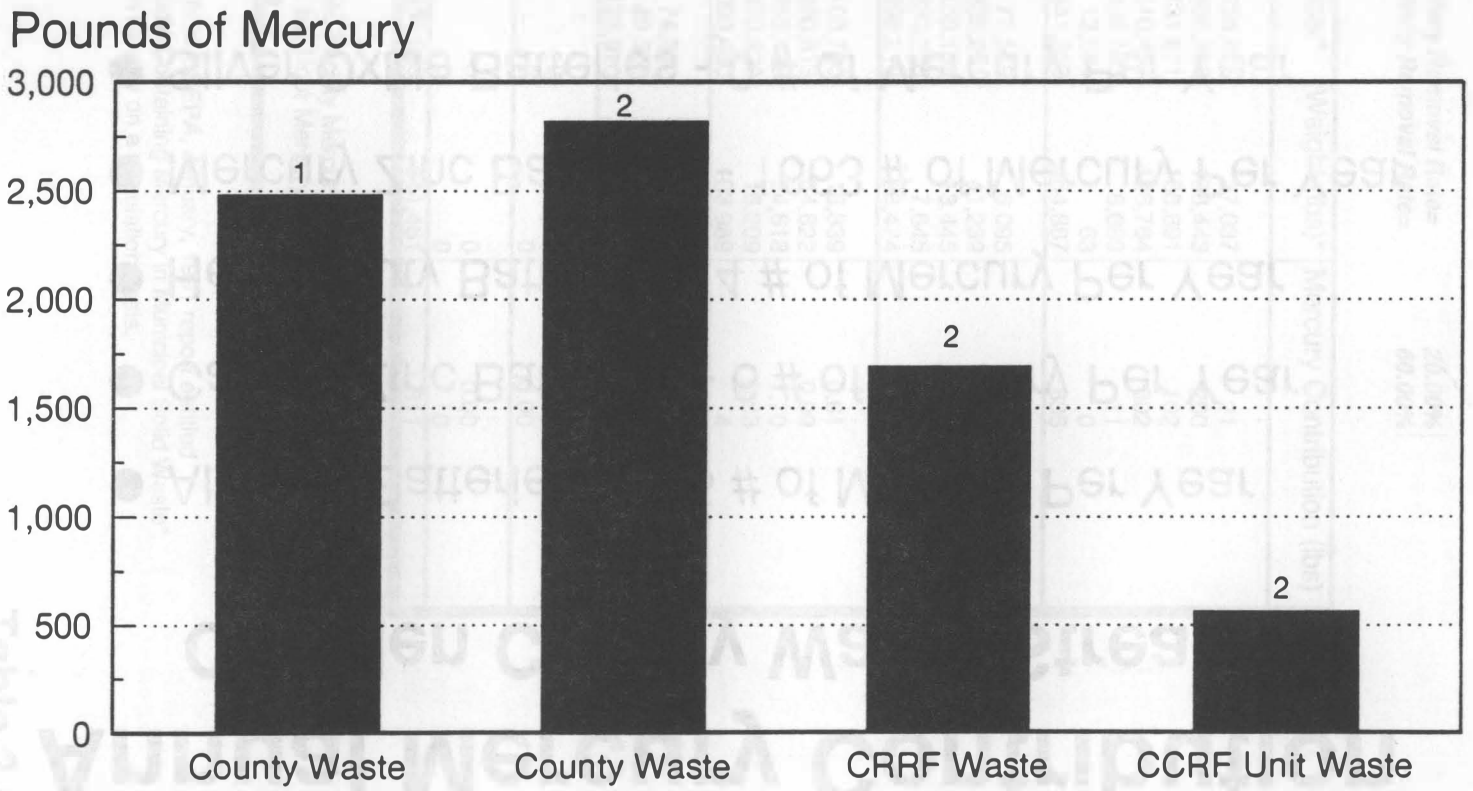
Camden County Waste Stream

- Alkaline Batteries - 795 # of Mercury Per Year
- Carbon Zinc Batteries - 6 # of Mercury Per Year
- Heavy Duty Batteries - 4 # of Mercury Per Year
- Mercury Zinc Batteries - 1663 # of Mercury Per Year
- Silver Oxide Batteries - 0 # of Mercury Per Year
- Zinc Air Batteries - 13 # of Mercury Per Year
- Total - 2481 # of Mercury Per Year

Table 3

Annual Weight of Mercury

County Waste Stream, CRRF Total Waste Stream, CRRF Unit Waste Stream



1. Mercury From Batteries
2. Mercury From All Waste Sources

Table 4

Stack Mercury Emissions

Estimated vs. Stack Test Results

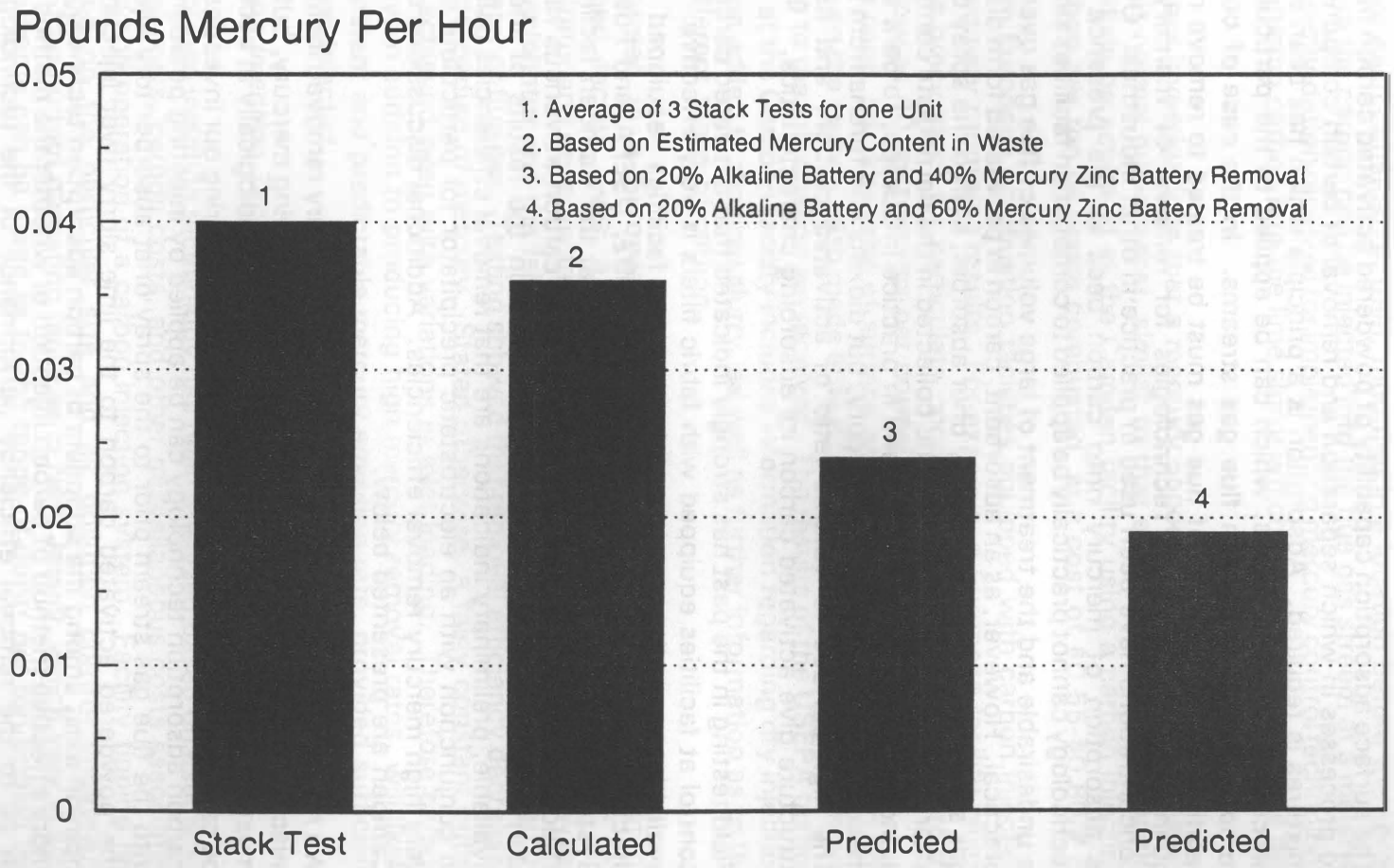


Table 5

approximately 50% remains as vapor. Additions of activated carbon have been shown to effectively reduce the amount of mercury remaining in the flue gas.

The surface adsorption capability of powdered activated carbon has long been applied to processes in which separation and removal of certain components in gas or liquid mixtures is required. Adsorption is a principle which has been employed in various processes for many years, which can be applied to the particular case of mercury removal from combustion flue gas streams. In the case of combustion flue gas, relatively large volumes of flue gas must be treated to remove relatively very small quantities of mercury. Technologies for removal of mercury in relatively high concentrations have been used in practice in other industries. One such technology is *absorption* of mercury onto carbon beds in the presence of chlorine. This technology cannot practically be applied to combustion facilities since chlorine addition is undesirable and the treatment of large volumes of flue gas over carbon beds is not practical. However, as an adsorbent, carbon in powdered form dispersed into the flue gas stream i) ahead of the spray drier absorber, ii) into the spray drier absorber, or iii) after the spray drier absorber, and collected in the particulate control device, has been demonstrated experimentally, and in practice in Europe, to be a simple and effective means of reducing not only mercury, but dioxins and furans from the flue gas stream. The high surface to volume ratio of activated carbon, and its microscopic pore structure give activated carbon its adsorbing characteristics.

Field testing in the past has strongly indicated that activated carbon used for mercury control at facilities equipped with fabric filters is very effective. Less information is available regarding carbon injection at facilities equipped with electrostatic precipitators. During May and June of 1992, USEPA and Foster Wheeler Power Systems, Inc. performed extensive testing at the Camden facility to determine the effectiveness of injecting different types of carbon at various rates in both dry and slurry form. Although the official report on the results of the testing is not yet available, preliminary indications are that removal efficiencies using activated carbon in conjunction with an electrostatic precipitator for particulate collection, produces very high mercury removal efficiencies. Additional discussions of USEPA testing at Camden are presented below.

We reviewed a number of technologies for mercury removal, including sodium sulfide injection and wet scrubbing as a means of removing mercury, but concluded that the most effective means of removing mercury technologically at acceptable costs would be carbon injection for adsorption of mercury. During our investigations we found that carbon adsorption technology can be applied by injecting powdered activated carbon into the flue gas stream prior to the spray drier absorber (dry injection) or by adding the powdered activated carbon to the lime slurry (wet injection). Differences of opinion exist among the suppliers of carbon adsorption technology as to which is the more effective method of carbon injection or whether the method of injection matters at all to the removal efficiency performance of the technology. In any case, a common opinion exists among suppliers of this technology that electrostatic precipitators would likely result in higher carbon consumption than would be required

with a fabric filter equipped similar facility.

One recommended method of injection was the use of one "supersac" or large bag filled with carbon for each combustion train, mounted in a location before the spray drier absorber, where the carbon can be injected into the flue gas stream at a metered rate. A second recommendation received for implementing mercury control technology was based on introducing carbon into the lime slurry which is mixed with the flue gas in combined form.

We learned during our investigations that a mercury concentration of approximately 100 micrograms per normal cubic meter, similar to that experienced at a European installation, could likely be achieved at the Camden facility using a carbon injection rate of 0.5# of carbon per ton of waste combusted, at a cost of $0.55-$0.80/# of carbon.
Operating data from European combustion facilities equipped with carbon injection systems have shown very promising results. For example, a European facility which has an electrostatic precipitator for particulate control has reported outlet mercury concentrations as low as 40 micrograms per normal cubic meter.
The type of carbon used, i.e., the ratio of surface area to volume of the carbon and the surface coating on the carbon, also made little difference on the resulting removal efficiency according to the information we received. The results of the USEPA testing recently performed at the Camden facility includes information regarding dry injection of carbon and carbon added to the lime slurry, as well as further information as to the effectiveness of different types of carbon.

Testing was performed in a European, spray drier absorber and electrostatic precipitator equipped facility, with a fabric filter installed downstream of the electrostatic precipitator and dry activated carbon injected into the ductwork between the electrostatic precipitator and the fabric filter at a rate of 40 milligrams of carbon per normal cubic meter of flue gas. Testing showed that removal efficiency decreased with decreasing inlet loading of mercury. Stated otherwise, a fairly constant outlet mercury loading is achieved even with variations in inlet loading. Therefore carbon injection technology, in addition to producing high mercury removal rates, will likely result in a fairly constant and predictable mercury emission rate, provided sufficient carbon quantities are injected.

Economics of Carbon Injection Technology

The economics of carbon injection technology has been analyzed based on estimated licensing and capital costs, carbon costs, and other miscellaneous costs associated with the installation and operation of a carbon injection system. Facility tipping fee impacts were based on the particular size and air pollution control equipment arrangement of the four current operating facilities in New Jersey, which vary in size and capacity. A estimate can be made as to the range of dollar per ton tipping fee impacts which may be expected, keeping in mind that facility size, arrangement and air pollution control equipment in use, all have a bearing on the capital and operating

costs of carbon injection technology. For example it appears that fabric filter equipped facilities will consume less carbon to produce the same mercury removal results as a similar sized facility equipped with an electrostatic precipitator and this may have a significant impact on the operating cost. The cost of carbon will be a major part of the annual operating costs of such a system. It is estimated that the tipping fee impact of carbon injection technology may range from approximately $1.00 to $4.00 per ton depending on the final standard for mercury removal or concentration which must be adhered to and the design and operating aspects of the particular facility in question.

USEPA Carbon Injection Testing at Camden Resource Recovery Facility

The Camden facility had been in commercial operation for less than a year when testing began. The facility has a nominal rating of 1050 tons per day and air pollution control equipment consisting of individual spray drier absorbers and five field electrostatic precipitators on each of its three combustion trains.

The final issue of the USEPA test report is not yet available. The preliminary test results form the basis of all information and analyses presented herein. The results and analyses presented are therefore subject to modification, should the final test results deviate from the initial test results as reported by USEPA.

The testing variables included location of the injection point, the method of injection, the ESP inlet temperature, the carbon feed rate, and number of ESP fields in operation. The parameters regarding the sorbent material included mercury speciation and flue gas composition, particle size and mixing, particle size and surface pore structure, temperature and residence time, mixing and particle collection. Flue gas measurements included inlet metals, particulate matter, flyash carbon content, oxygen, carbon monoxide, carbon dioxide, sulfur dioxide, hydrogen chloride, outlet metals, and PCDD/PCDF. USEPA Test Method 5/Multimetals was used for determining metals concentration including mercury within the flue gas.

The field testing was conducted in two phases. The first phase of testing was a characterization test to determine the best type of carbon to use and the carbon feed rates necessary to achieve satisfactory mercury capture during the second phase of testing. Phase II of testing included short term emission performance testing and long term ability to maintain mercury capture without degradation in ESP performance over extended periods of elevated levels of carbon content in the products of combustion.

The objective of Phase II of the performance tests was to define mercury control levels that can be achieved with a spray drier absorber and electrostatic precipitator equipped facility. Additional objectives included determining the effect of operating variables on mercury control levels; examining the impact of carbon injection on organic emissions; examining the impact of carbon feeding over an extended period on electrostatic precipitator performance; and examining the importance of particulate matter control efficiency on the level of mercury control using carbon injection.

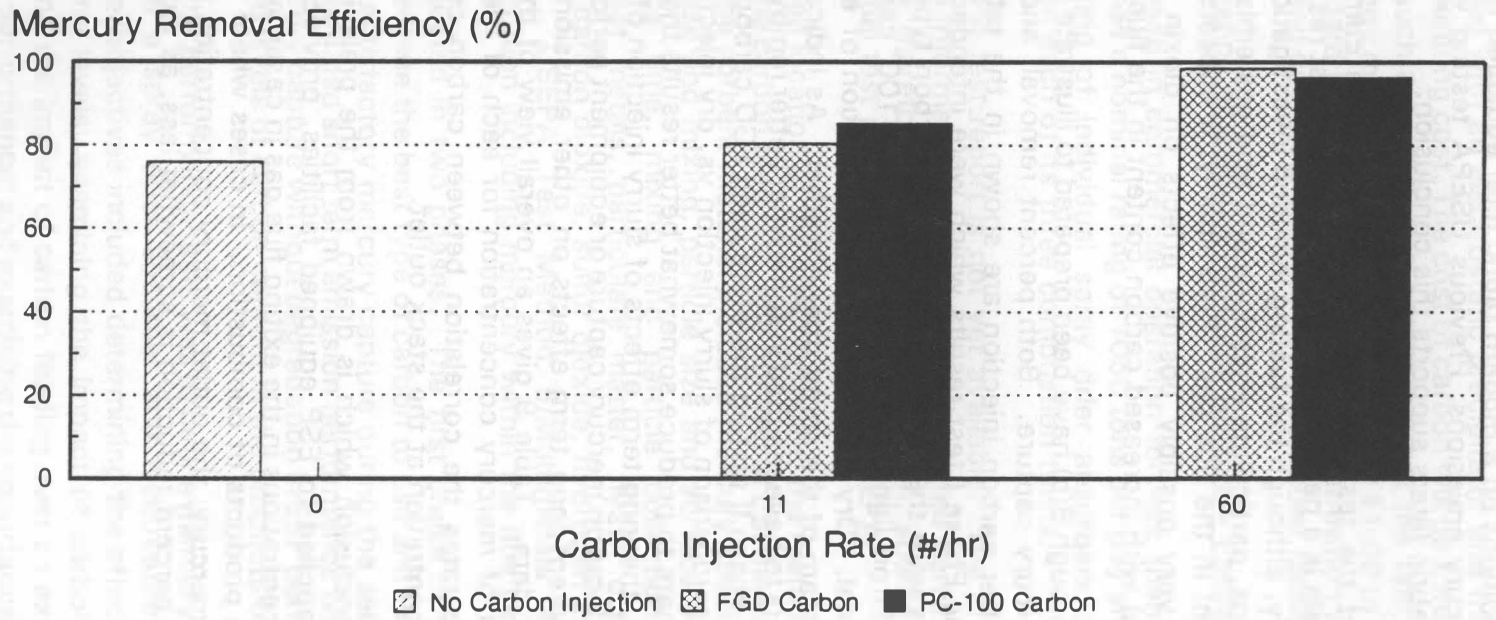
Although the testing performed at Camden was specific to an ESP equipped facility, it is generally accepted that the performance of a carbon injection system under similar operating conditions on a modern fabric filter equipped facility would produce lower levels of mercury emissions. Previous USEPA testing with activated carbon on a facility with fabric filters supports this conclusion.

The details of the test plan will be included in a comprehensive USEPA report. Reported herein is a generalized summary of the test results with regard to mercury emissions only, although the testing included investigations of effects on dioxin and furan emissions, particulate emissions and acid gas emissions from the elevation of carbon content in the flue gas. Preliminarily, it appears that there are no adverse effects, and very possibly positive effects on dioxin emissions (reduced dioxin concentration) with increased carbon content in the flue gas.

Tables 6(a) through 8(b) have been prepared to illustrate the general test results with regard to mercury capture. Both percent removal, and concentration of mercury before and after carbon injection are shown in the tables. Tables 6(a) and 8(b) summarize the Phase I test results which were intended to analyze various carbon injection rates with the use of two different carbon types. "FGD" carbon, which is manufactured from lignite, was compared to "PC-100" carbon, which is prepared from bituminous coal. Dry powdered activated carbon of each type in this case was injected upstream of the spray drier absorber. As indicated in the figures, the FGD carbon appears to have resulted in somewhat better removal performance than the PC-100 carbon. Phase II testing therefore used FGD carbon only. Tables 7(a) and 7(b) illustrate the comparison of slurry injection vs. dry injection of the FGD carbon. Dry injection appears to produce somewhat better results than slurry injection. In Tables 8(a) and 8(b), the long term effects of slurry injection of carbon appears to result in no adverse effects on mercury capture or equipment performance. Additionally, there were no apparent long term effects on other emissions based on a review of all available test data. Table 9 gives an overall view of the test results regarding the measurement of mercury concentration for each of the variables tested. Table 9 generally illustrates the correlation between carbon content in the flue gas and mercury concentration at the stack outlet.

A general conclusion which is drawn from the preliminary testing is that carbon injection as applied to ESP equipped facilities, provides a significant reduction in mercury concentrations in the exiting flue gas in cases where mercury concentration is high in the products of combustion. In cases where the products of combustion contain less mercury, the outlet mercury concentration is maintained at a low level, although the percent reduction is somewhat less, as would be expected.

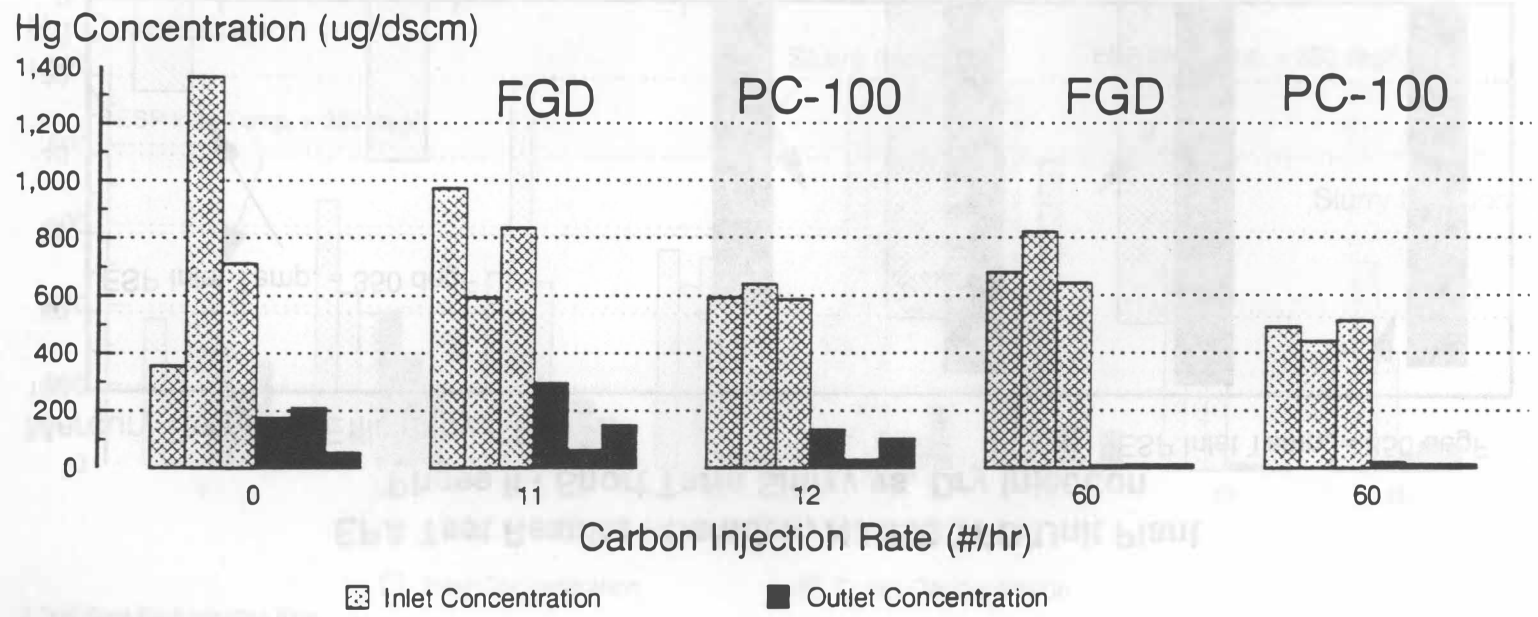
EPA Test Results - Camden, NJ 350 TPD/Unit Plant
Phase I - Determination of Best Carbon Type



Removal Efficiency is Average of 3 Test Runs

Table 6(a)

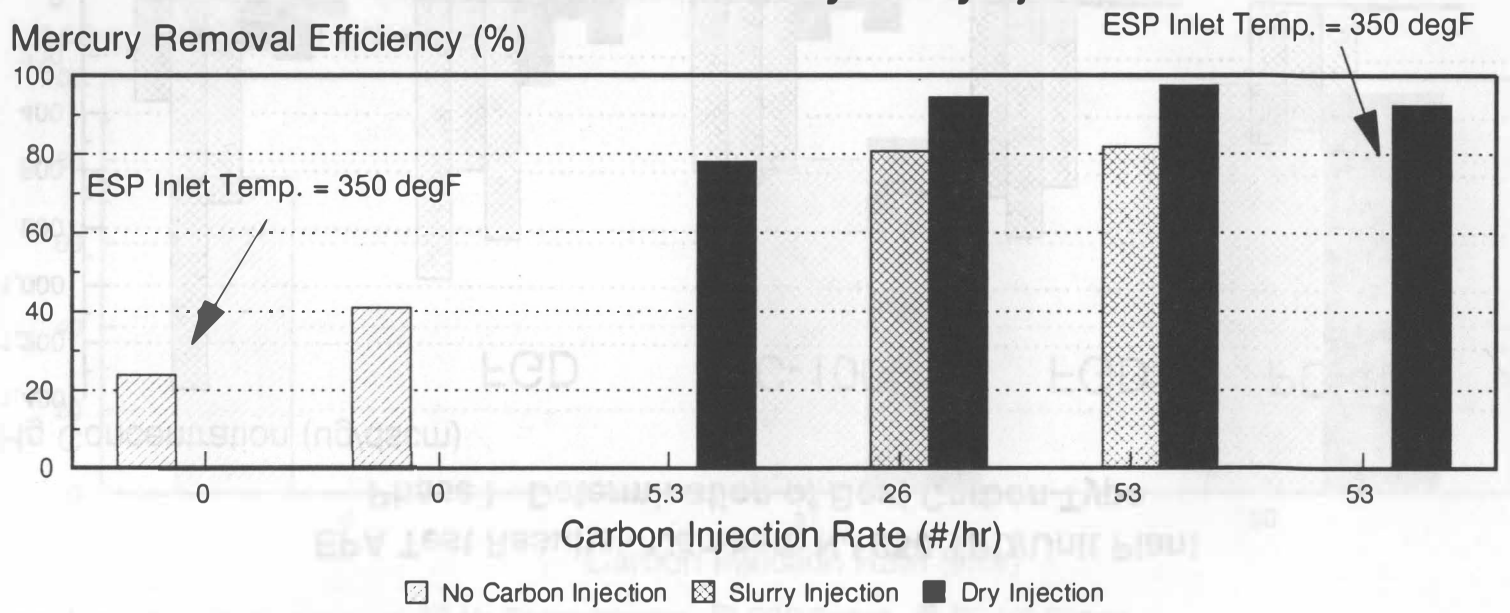
EPA Test Results - Camden, NJ 350 TPD/Unit Plant
Phase I - Determination of Best Carbon Type



3 Test Run Results Shown for Each Injection Rate

Table 6(b)

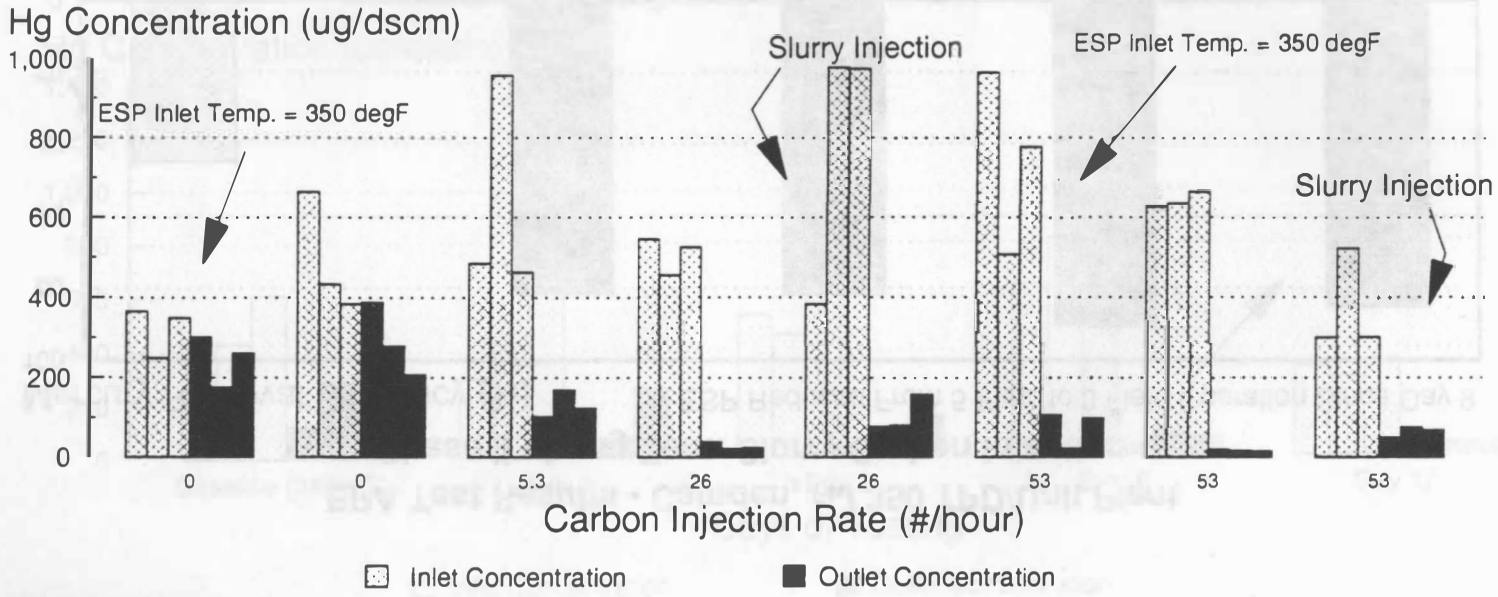
EPA Test Results - Camden, NJ 350 TPD/Unit Plant
Phase II - Short Term Slurry vs. Dry Injection



Removal Efficiency is Average of 3 Test Runs
ESP Inlet Temp. = 270 F Unless Otherwise Shown

Table 7(a)

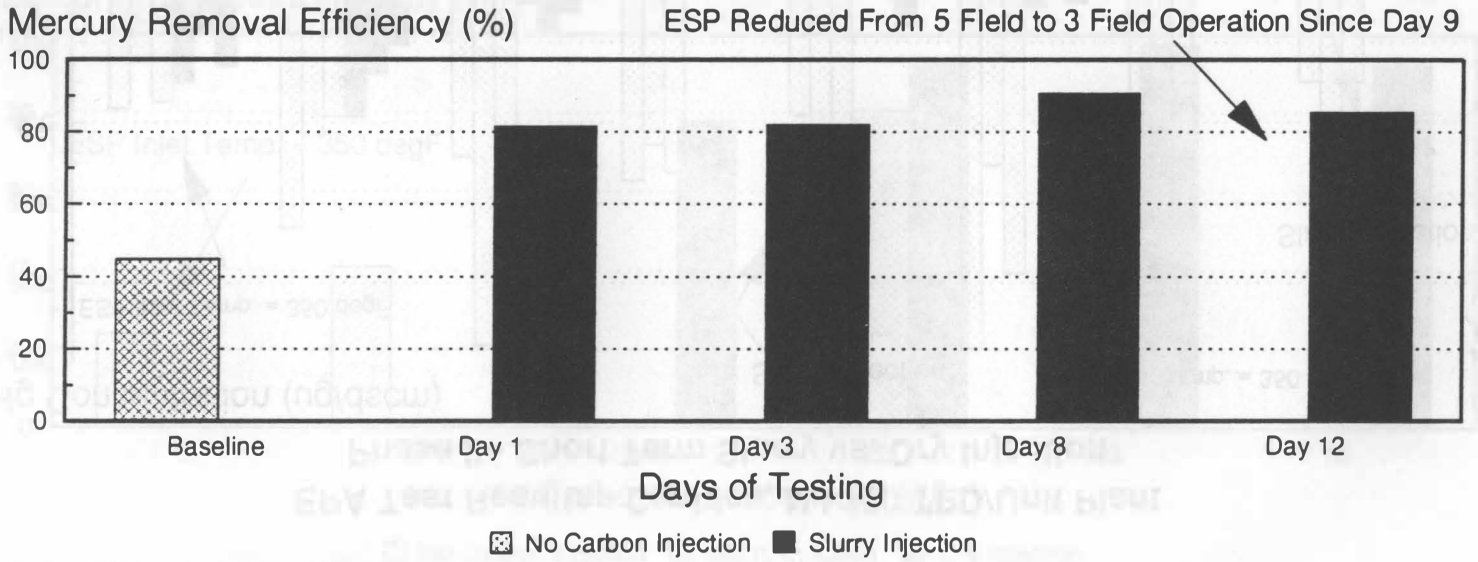
EPA Test Results - Camden, NJ 350 TPD/Unit Plant
Phase II - Short Term Slurry vs. Dry Injection



3 Test Runs Each Injection Rate

Table 7(b)

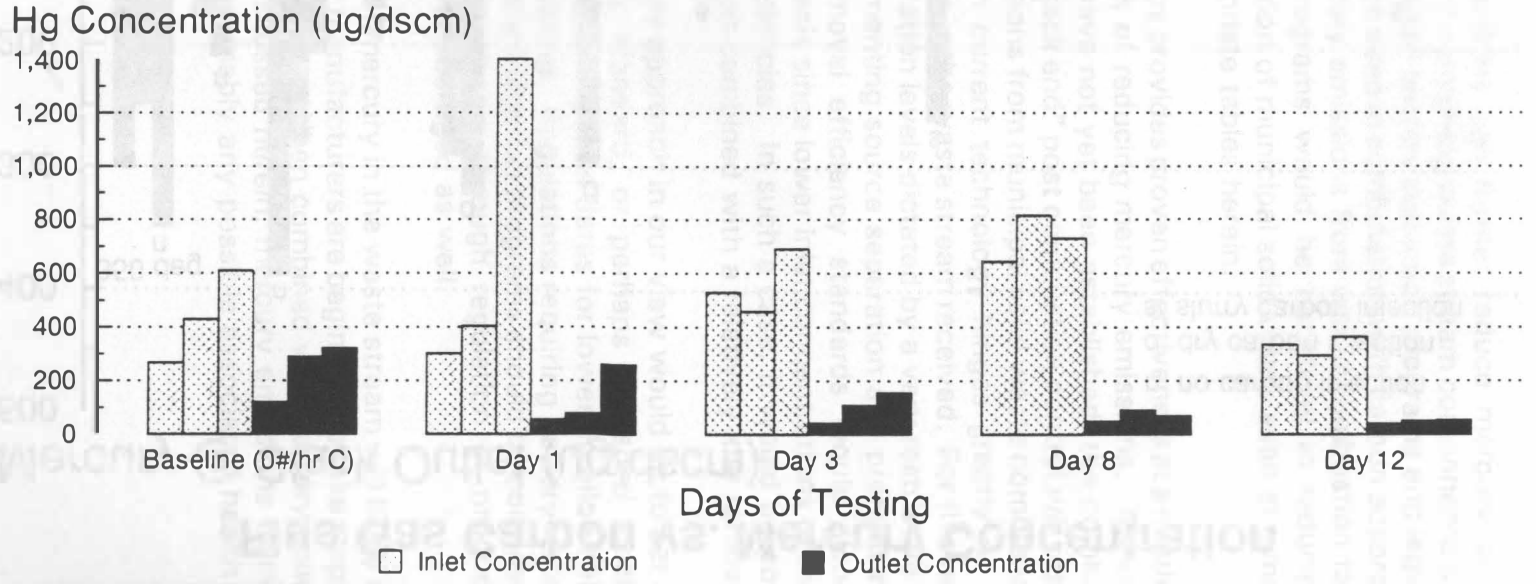
EPA Test Results - Camden, NJ 350 TPD/Unit Plant
Phase II - Long Term Slurry Carbon Injection



Removal Efficiency is Average of 3 Test Runs
ESP Inlet Temp. = 270 F Unless Otherwise Shown
Carbon Injection Rate = 45 to 55 #/hour

Table 8(a)

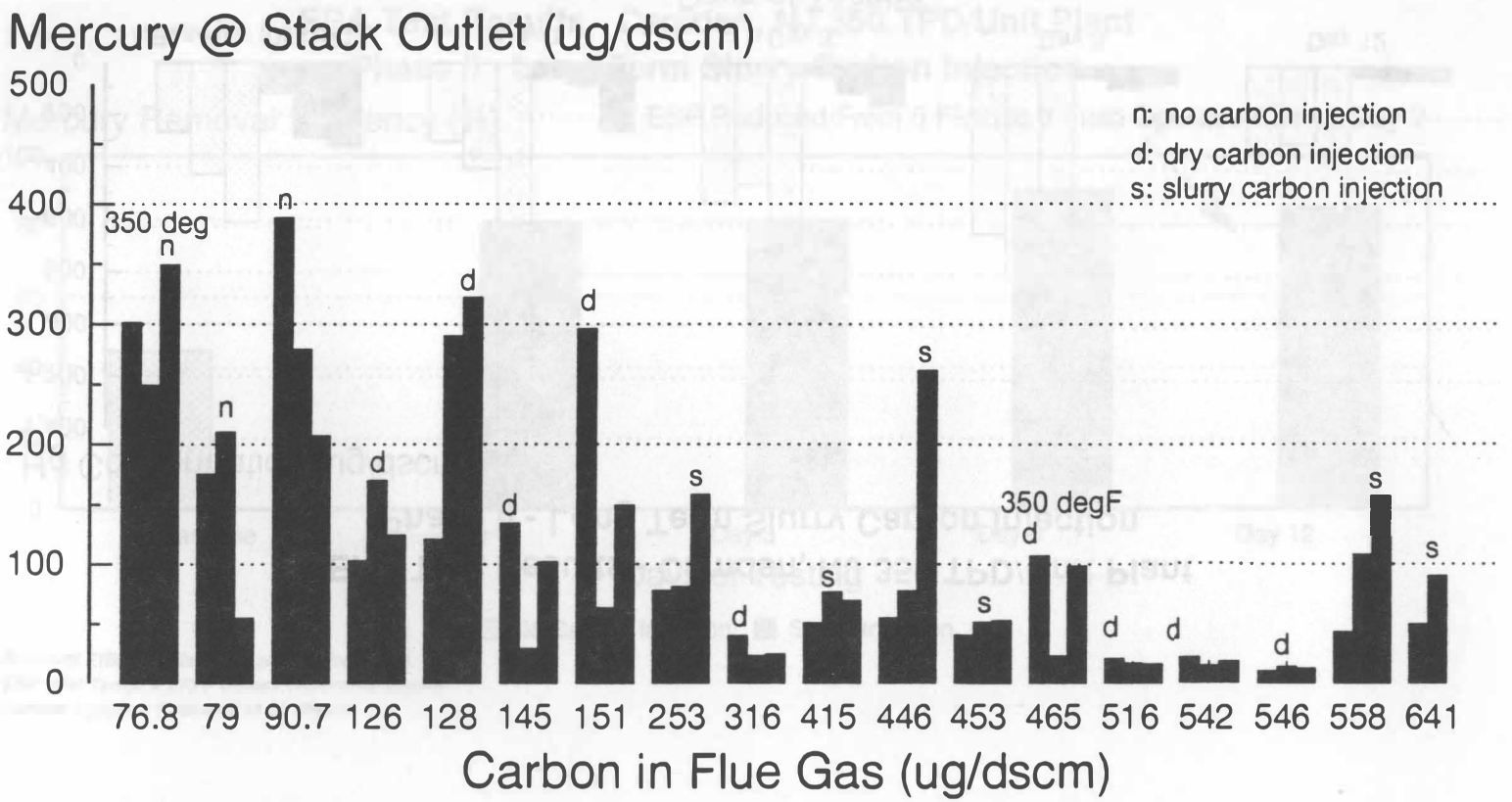
EPA Test Results - Camden, NJ 350 TPD/Unit Plant
Phase II - Long Term Slurry Carbon Injection



3 test Run Results for Each Day
ESP Inlet Temp. = 270 F Unless Otherwise Shown
Carbon Injection Rate = 45 to 55 #/hour

Table 8(b)

USEPA Test Results-Camden, NJ 350 TPD/Unit Plant
Flue Gas Carbon vs. Mercury Concentration



3 Test Runs @ Each Carbon Rate
270 degF ESP Temperature Unless Otherwise Shown

Table 9

Conclusion

Solid waste combustion facilities can further reduce mercury emissions through increased removal of mercury containing waste stream components such as batteries. State, county, and local initiated battery collection programs and legislation designed to encourage recycling can be used in combination with carbon adsorption technology to significantly reduce mercury emissions from waste combustion facilities. Battery collection and recycling programs would be beneficial in reducing the mercury emissions from the combustion of municipal solid waste even at a moderate success rate as shown in the appropriate tables herein.

Carbon adsorption technology provides proven effectiveness at a relatively inexpensive cost and is a reliable means of reducing mercury emissions. Although federal and state numerical standards have not yet been established, the combination of "front end" battery removal and "back end" post combustion control will result in significant reductions in mercury emissions from municipal solid waste combustors. The amount of mercury removable with current technology hinges greatly on the quantity of mercury containing products in the waste stream received. For this reason, the ability to meet consistent concentration levels dictated by a very restrictive standard will be difficult without also implementing source separation and product mercury content standards. Restrictive removal efficiency standards would also be difficult to accomplish on a constant basis since lower inlet concentrations of mercury will likely produce lower removal efficiencies. In such a case, it would be possible to have a very low outlet concentration combined with a relatively low removal efficiency.

The most effective regulatory approach in our view would be to set a *recommended* mercury removal efficiency standard, or perhaps a *staged* stack concentration standard with scheduled implementation dates for lowering allowable concentration levels, subject to periodic testing. Regulations requiring battery collection programs or household hazardous waste collection programs should be considered and removal of mercury from the waste stream through regulation or product manufacturer voluntary efforts should be encouraged as well.

Very significant reductions of mercury in the waste stream will likely occur during the next few years since battery manufacturers are beginning to take steps in reducing the use of mercury in their products. When combined with battery collection programs and the control methods discussed herein, mercury emissions from municipal solid waste combustors, and presumably any possible associated health risks, would be reduced significantly.