IT3 Conference, May 9-13, 2005, Galveston, Texas

Demonstration of Mercury Capture Efficiency during Medical Waste Processing in a PEM™

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ABSTRACT

Medical waste has historically contained mercury which escaped to the environment during incineration. In 1997, EPA enacted strict regulations on mercury and other emissions which resulted in closure of about 90% of the medical waste incinerators. As an alternative to incineration, IET has developed a plasma based gasification system for medical waste processing. One of the design criteria was to eliminate or at least minimize mercury release from the system. This paper presents the results of a series of three tests on mercury emissions where the release was shown to be well below EPA regulatory criteria. Two of the three tests on the system offgas were below the EPA Method 29 detection limit.

INTRODUCTION

During the past several years, public concern over the safe handling and disposal of medical waste has greatly increased. The increased concern is, in part, due to the potential risk of the transmission of infectious agents, such as human immunodeficiency virus (HIV), hepatitis B virus (HIB), SARS and others. This concern has occurred at the same time as the public fears have increased over hazards from the offgas emissions from medical waste incinerators, especially mercury and dioxins. According to the EPA, in 1997, the mercury concentration in medical waste was about 20 ppm. Regulations enacted at that time required a substantial reduction in mercury emissions (85%) or an offgas concentration less than 550 ug/dscm.[1]

Medical waste generators have reduced the use of mercury in medical equipment as a means to reduce mercury contamination in their wastes, however, it still persists. Phase out of equipment containing mercury (such as mercury thermometers) combined with a general worker awareness of mercury hazards have reduced the mercury entering the medical waste stream.[a] In addition, as a result of the concerns over emissions from incineration and the costly upgrades to existing incinerators needed to meet regulatory requirements, a large segment of the medical waste treatment technology in the country has switched to the use of autoclaves and other non-thermal technologies for waste treatment. While using autoclaves and other non-thermal technologies may reduce atmospheric emissions of mercury, nothing is done to assure that the mercury is not released elsewhere in the autoclave processing cycle. Recently, fugitive mercury emissions have been reported from autoclaves.[2] This paper demonstrates that a high temperature thermal destruction process can be operated without the high mercury emissions historically associated with medical waste incinerators.

TEST OBJECTIVE AND RESULTS SUMMARY

The test objective was to demonstrate the mercury capture effectiveness of the Plasma Enhanced Melter™ (PEM™) system. This paper presents test results which showed that mercury was safely contained by the PEM™ system when processing medical waste with very high mercury concentrations (200 ppm versus 20 ppm in pre-1997 waste).[b] Testing proved that the PEM™ offgas treatment system

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[a] IET's Mercury Capture System serves as an "insurance policy" to back up administrative controls prohibiting the disposal of mercury in the medical waste stream.

[b] EPA Method 29 testing procedure with a detection limit of approximately 0.4 ug/dscm.

was very effective at controlling mercury emissions. The special mercury carbon filters performed as expected, capturing **essentially 100%** of the mercury in the offgas.[c]

TECHNOLOGY DESCRIPTION

The PEM™, developed by Integrated Environmental Technologies, LLC (IET), is a high temperature technology that minimizes dioxin generation and mercury emission while substantially reducing the volume of waste. Following treatment, the only solid residual is a glass that can be recycled into construction products or metal that can also be recycled. So, no waste is sent to a landfill. The PEM™ technology operates at temperatures in excess of 1100°C and provides complete destruction of the infectious agents while protecting the environment from toxic emissions.[3, 4, 5] A simplified process flow

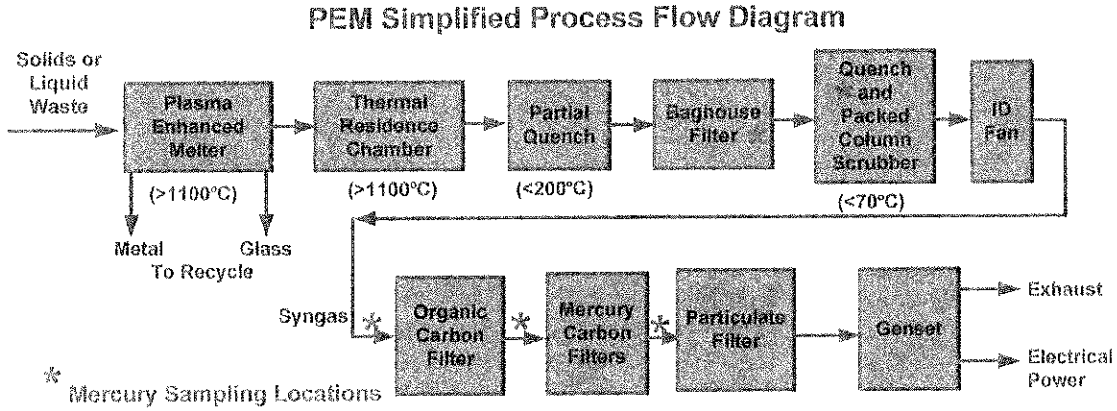

Figure 1. Simplified Process Flow Diagram for IET Medical Waste Processing System and for PEM™ System Used in the Mercury Capture Test. Mercury Sampling Locations are Indicated by Red Asterisk.

diagram for the PEM™ system is shown in Figure 1.

The PEM™ system uses steam reforming gasification to convert waste into a hydrogen rich syngas (fuel gas) to recycle the chemical energy in the waste for the production of electricity. Prior to use as a fuel gas, the syngas is cleaned to remove chlorine, metals, and other trace contaminants. Mercury is vaporized during waste gasification and is captured in the offgas cleaning system. This document describes testing that was conducted to verify the performance of special mercury filters that are part of the PEM™ offgas cleaning system to ensure the capture of mercury that may be present in medical waste.

MEDICAL WASTE FEED CHARACTERISTICS

Medical waste for the testing was obtained from a local hospital. The waste contained a high concentration of plastic and rubber. The rubber consisted of latex and nitrile gloves. The waste also contained drapes, surgical tubing, small pieces of hard plastic, and other un-identifiable items.

Since the waste was collected from the steam sterilization process, the as-received waste was very wet.[d] The waste was subsequently air dried to evaporate excess moisture. The density after drying was approximately 11 lb/ft^3 (84 lbs per 55-gallon drum). The mercury content of the waste was not measured but was assumed to be very low due to the hospitals mercury management program.

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[c] The carbon filters used Mersorb, a special formulation of sulfur impregnated granular activated carbon for mercury capture from Nucon International.

[d] The hospital that supplied the waste for the test required that the waste be shredded and steam sterilized to destroy the pathogens before the waste left their facility.

The medical waste was fed to the PEM™ (Figure 2) using a containerized feeding process. The waste was hand packed into small cardboard tubes with plastic end caps as shown in Figure 3. Mercury was added to the waste by inserting a glass vial containing mercury into every sixth container. The glass vials are also shown in Figure 3. The cardboard tubes used to hold the medical waste had the following properties:

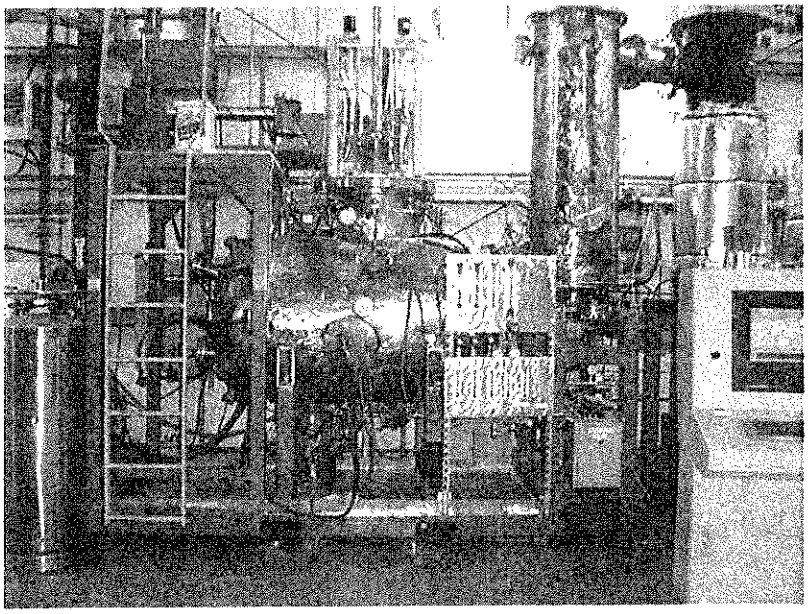

Figure 2. PEM™ Test Facility Used in Mercury Capture Demonstration Tests

- Tube inner dimensions - 2 inches ID x 6 inches inside length
- Tube overall length - 7 inches.
- Tube wall thickness -0.060 inches.
- Empty cardboard tube weight - 41.5 grams
- Weight of 2 plastic end caps - 8.5 grams
- Average gross weight of tube with medical waste and end caps 135 grams

PROCESSING CONDITIONS

The desired processing rate for this system was about 10 lbs/hr. Using an average container weight of 135 grams, a container feed rate of 10.7 lb/h is achieved feeding 36 containers per hour (approximately 1 container every 100 seconds).

The IET mass and energy balance (MEB) model was used to estimate appropriate values for the oxygen and steam flow rates for this feedrate. The remaining operating parameters were determined from past experience and are shown in Table 1.

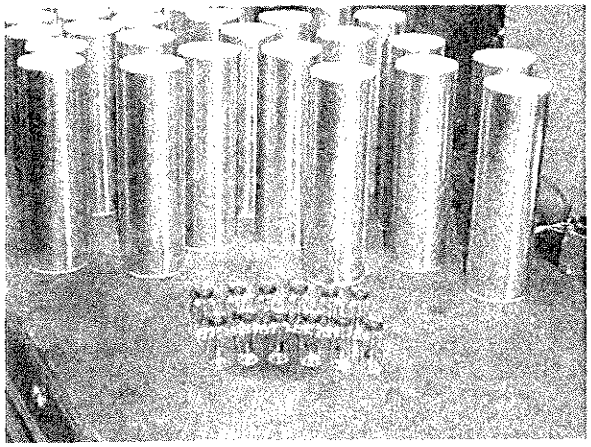

Figure 3. Cardboard Waste Containers for Feeding Medical Waste are shown in the Background. Shown in the Foreground are the Glass Vials Containing Mercury.

MERCURY SAMPLE SIZE AND PREPARATION

In order to determine the effectiveness of the PEM™ **Mercury Capture System,** the medical waste was spiked with a known quantity of elemental mercury. The as-received medical waste was assumed to have

very small or zero mercury content.[c] The planning quantity was selected to provide concentrations in the offgas that would be considerably above regulatory limits without an effective capture system.

Table 1. Operating Parameters for Mercury Capture Demonstration Test		
Parameter	Setting	Comments
Oxygen to PEM™	1.1 scfm	Oxygen required for a CO to (CO + CO2) ratio of 0.7.
Oxygen to TRC	0.25 scfm	Oxygen required to maintain TRC temperature.
Steam to PEM™	3.0 lb/hr	Steam required for gasification reactions.
PEM™ Temperature	1200 °C	Operate PEM with a target of exceeding 1200 °C.
TRC Outlet Temperature	850 – 900 °C	The model predicts that a 900 °C outlet temperature implies that the internal temperatures exceed 1200 °C for at least 2 seconds.
Quench flow – N_2	70 cfh @ 10 psig	Minimize nitrogen.
Quench flow - water	0	Only use if needed.
Baghouse	N/A	Pulse as needed.
Chilled water	51 °F (11 °C)	As cold as practical.
Offgas blower	60 Hz	Set at constant value during processing.
Offgas blower outlet temperature	40 to 50 °C	Temperature expected based on operating experience.
Preheat carbon beds	50 °C	Preheat carbon beds prior to start of test to prevent condensation of water vapor in the syngas. Heaters turned off during testing.
Genset operation	Load bank on full.	Process all synthesis gas through the genset.

A pre-test mass and energy balance predicted an offgas flow rate of 15 dry standard cubic meters per hour (dscm/hr). The desired mercury concentration at inlet to carbon bed was 1500 ug/dscm. This corresponds to a value that is almost three times the regulatory limit for uncontrolled emissions (550 ug/dscm at 7% O_2) and corresponds to a value that is five times the value observed during previous medical waste processing.[6]

For the PEM™ system, it is probable that a significant fraction of the mercury will be retained in several parts of the offgas system, e.g., baghouse and wet scrubber. In order to determine the appropriate level of mercury to add to the waste, it was assumed that only 10% of the mercury added to the PEM™ would actually reach the carbon filters shown in Figure 1.

After this planning effort determined that adding the small amount of mercury to the vials reliably would be difficult, the quantity was tripled to an average of about 0.113 g/vial. The glass vials were then prepared and are shown in Figure 3. At the estimate flow rate and this mercury addition, the unattenuated mercury concentration entering the offgas system would then be about 40 to 50 mg/dscm.

SAMPLING AND ANALYSIS

The mercury sampling locations are shown in Figure 1. Three sampling locations were for syngas collection, one for the baghouse dust sampling, and the other sampling location is for the scrubber water.

[c] If this assumption is not valid, then the total mercury content is greater than reported herein. Thus, the mercury removal efficiency is even higher than reported. Thus, this is a conservative assumption relative to the reported mercury capture results.

The continuous offgas sampling was performed by AmTest Air Quality, an independent analytical laboratory that performs sampling and analysis according to USEPA protocols. The sampling protocol used was EPA Method 29. IET took post-test samples of the baghouse dust and scrubber water and shipped them to an independent laboratory for analysis.

REGULATORY REQUIREMENTS

EPA regulations for mercury emissions for medical waste incinerators are contained in 40CFR Part 60, Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Hospital / Medical / Infectious Waste Incinerators, September 15, 1997.[f] Table 7 of this reference limits mercury to 0.55 mg/dscm (550 ug/dscm) at 7%O_2 or 85% reduction from the incoming feed. While the PEM™ used in a medical waste application is not governed by the MACT regulations, its performance compared to the MACT regulations is of interest.[7] The MACT regulations typically governing much large incinerators are much more stringent than the HMIWI regulations with a mercury emission limit of 45 ug/dscm at 7% O_2.

TEST RESULTS

Syngas Samples

Three test runs were conducted on March 30, 2004. Key data are presented in Table 2 along with calculated removal efficiency parameters. The overall mercury total system capture efficiency of the PEM™ is shown to be essentially 100% effective after the first test. The results also show that the average capture efficiency of the PEM™ offgas system upstream of the carbon beds is over 90%. This performance even without the downstream carbon filters would meet the EPA requirements of 85% removal.

Table 2. Test Results and Analysis of System Capture Efficiency

Test Parameters	Run 1	Run 2	Run 3	Average
Run Duration (minutes) **AmTest Data**	112	120	120	117
Mercury Added to PEM™ System (g)	1.20	1.31	1.60	1.37
System Flowrate (dscm/h) **AmTest Data**	32.1	32.0	32.0	32.0
Mercury Capture Efficiency of System Upstream of Carbon Filters (%)	97.2%	91.0%	93.1%	93.8%
Concentration into First Carbon Bed (ug/dscm) **AmTest Data**	550	1841	1737	1376
Concentration out of First Carbon Bed (ug/dscm) **AmTest Data**	3.96	1.35	0.482	1.93
Efficiency of First Carbon Filter (%)	99.28%	99.93%	99.97%	99.73%
Concentration out of Second Carbon Filter (ug/dscm) **AmTest Data**	0.797[1]	BDL[2]	BDL[2]	0.266
Total System Mercury Capture Efficiency (%)	99.996%	100.00%	100.00%	100.00%

Note 1. Small quantity of mercury passing through system on the first test may be associated with new carbon bed performance which apparently stabilizes within a couple of hours as evidenced by increasing efficiency out of carbon bed 1 during the three tests and the BDL levels in the second and third tests out of carbon bed two.
Note 2. BDL is below detection limit which was reported by AmTest to be 0.408, 0.402, and 0.417 for the three runs respectively.

Baghouse Dust

The baghouse dust was sampled at the

[f] No unique EPA requirements govern steam reforming gasification systems so it is assumed that the emissions requirements would be the same as for incinerator systems.

end of the three test runs and analyzed for mercury by Wyoming Analytical Laboratories. The dust was found to contain 144 mg-Hg/kg of dust. The dust was about 63% carbon with the balance being ash. Consequently, the carbon carryover from these tests serves to capture a significant fraction of the mercury. In the recommended operating mode, this material is returned to the PEM™ and any mercury would be retained within the process. However, it is important to note that the dust, when subjected to TCLP testing showed a non-detect for mercury and is then non-hazardous by RCRA Criteria (40CRF261.24) as the mercury is tightly bound and is not leachable. In general, the baghouse ash will be recycled to the PEM™ system so that from this source, there would be no mercury release to the environment.

Scrubber Water

The raw scrubber water was sampled and analyzed for mercury at the end of the three test runs. The initial sample indicated the presence of mercury at the end of the three test runs (0.3 mg-Hg/l) while a later sample was below the detection limit of 0.0005 mg/l. The raw scrubber water is circulated continuously and passes though a particulate filter. It is probable that the initial sample contained suspended particulate with adsorbed mercury that was later removed by the filter.

Table 3. Comparison of Mercury Capture Efficiency between IET PEM™ Tests and a Similar INEEL Test Configuration

Test Series	Baghouse and Wet Scrubber	Carbon Beds	Total System
PEM™ System (1st Test Run)	92.2%	99.85%	99.99%
PEM™ System (After 1st Run)	74.6%	100% (2 beds)	100%
INEEL Tests (Average of 2 Test Runs)	78.1%	99.99% (3 beds)	99.97%

DISCUSSION OF RESULTS

Syngas

These test results demonstrate that the mercury capture performance of the PEM™ is excellent. After the first 2.8 hour test, the subsequent tests with higher levels of mercury showed that the **mercury emission was below the detection limit of 0.41 ug/dscm.**

These results compare well to other tests using a wet scrubber and the same type of carbon filter material for mercury removal from an Idaho National Engineering and Environmental Laboratory (INEEL) simulated offgas stream as shown in Table 3.[8] The INEEL tests were also focused on measuring the effectiveness of the carbon filters. The major difference in the gas streams were related to the gas composition which was oxidizing in the INEEL test offgas versus reducing conditions of the PEM™ offgas and the mercury input to the carbon filters. For the INEEL tests, the mercury concentration was about 16,000 ug/m^3 or nearly 10 times the IET test concentration. The INEEL output concentration was reported at 0.7 ug/dscm. Clearly, in the IET and the INEEL test series, mercury removal and capture using Mersorb sulfur impregnated carbon far exceeds regulatory requirements of 45 ug/dscm under MACT.[g]

As part of the same program at the INEEL, additional tests were conducted to establish the effectiveness of the Mersorb carbon for mercury removal at longer exposure times. The tests showed that there was "no significant change" in mercury removal efficiency over a 1000 hour test period with samples taken at 24, 200, 762, and 1000 hours.[9] These INEEL tests were conducted at temperatures from 100°C to 150°C – conditions more challenging for mercury removal than for the PEM™ offgas system which operates at about 50°C. The input mercury concentration for these INEEL tests were of the same magnitude (2460 to 5240 ug/dscm) as for the PEM™ system tests (550 to 1840 ug/dscm). Based on the similarity of the IET PEM™ tests and the INEEL tests, long carbon filter lifetimes at high removal efficiency can be assured.

[g] The INEEL test objective is to meet the MACT requirement.

Based on the manufacturer's design recommendations, the IET mercury capture carbon filters will have a lifetime exceeding one year even if the input of mercury were continuous at the concentration used in this test program. At expected low mercury concentrations, the filters can be expected to operate efficiently for even longer times.

Baghouse Dust
Mercury retention in the baghouse is expected, especially with carbon particles from the PEM™ present in the offgas. The mercury is captured by the carbon and becomes a RCRA compliant, non-hazardous material suitable for disposal as a non-hazardous material. However, as it is planned to recycle the baghouse dust, this mercury will not reach the environment. Alternatively, the baghouse dust can also be disposed in a licensed hazardous waste facility.

Scrubber Water
One sample of raw scrubber water indicated the presence of a small amount of mercury while a later sample was below the detection limit. IET's recommended practice is to pass raw scrubber water through a carbon filter prior to disposal.[h] Data from the carbon material manufacturer indicate that these carbon beds are highly effective in removing mercury from water and eliminate any potential for release through this pathway. Consequently, with this process treatment, no significant mercury will be released to the environment from the scrubber water discharge.

FATE OF MERCURY IN MEDICAL WASTE TREATMENT

Historically, other medical waste treatment processes such as microwaves and autoclaves have not had to establish mercury release data.[i] When mercury is present in medical waste, treatment using autoclaves and microwaves does nothing to remove the mercury in a controlled manner. Mercury ends up as either fugitive emissions to the building air, as a contaminant in autoclave effluent water with subsequent transfer to the local sewer system, or is transferred to a landfill when the treated waste is disposed.

In marked contrast, the environmental fate of mercury contained in medical waste fed to the PEM™ system is controlled since essentially all mercury is captured within the offgas system and can be safely managed and disposed as hazardous waste.

CONCLUSIONS

Clearly, the best way to avoid any mercury release to the environment is to keep mercury out of the medical waste stream. This is the direction the medical waste generators are heading. However, if mercury is present in the waste stream, the PEM™ offgas system design assures that essentially all of it will be safely captured within the system and uncontrolled releases to the air, water or landfills are avoided. The results of this test show very efficient mercury capture.

Furthermore, the INEEL tests using the same carbon materials further demonstrate that the excellent performance can be expected even with higher mercury concentrations and for sustained time periods. Consequently, mercury release to the environment will be well below any regulatory standards and, as shown in this test, even below laboratory detection limits. The captured mercury will then be managed and disposed of as a solid hazardous waste under the provisions required by the EPA under RCRA (40CRF261.24).

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[h] Nucon International also reports excellent mercury capture from aqueous streams based on work performed for the DOE at the Oak Ridge National Laboratory

[i] No current regulatory requirements for emissions from autoclaves are known to the authors. However, as a result of recent fugitive release to the air from an autoclave in Michigan and aqueous contaminants released from an autoclave in California, future regulation governing autoclaves are likely.

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