

# Combined PCDD/F Destruction and Particulate Control in the Baghouse



Experience with a  
Catalytic Filter  
System at a  
Medical Waste  
Incineration Plant

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## Abstract

Phoenix Services, Inc., owns and operates the Baltimore Regional Medical Waste Incinerator in Baltimore, Maryland, USA. New regulations for dioxins and furans imposed a limit that was considerably below historical emission levels. In order to determine a method to comply with the new dioxin/furan regulations, Phoenix Services performed trials with powdered activated carbon. Although the results with carbon were acceptable, Phoenix Services decided to replace their woven fiberglass filter bags with catalytic filters that simultaneously destroy dioxins and furans and collect particulate matter. The catalytic filter system offered several advantages to Phoenix Services, including destruction of dioxins and furans instead of adsorption on carbon. The catalytic filters also offered a passive solution that did not require new carbon injection equipment.

In January 2000, a campaign to measure dioxins/furans and particulate matter was undertaken. The measurements allowed the catalytic filter system to be evaluated. Some of the key findings of this investigation are:

- The dioxin/furan emission was below  $0.1 \text{ ng TEQ/Nm}^3$  @ 11%  $\text{O}_2$ . This concentration is approximately two orders of magnitude below historical averages, and it is well below the new regulatory limits for both existing and new sources of this type.
- The amount of dioxin/furans destroyed by the catalytic filters was approximately  $1.73 \text{ ng TEQ/Nm}^3$  @ 11%  $\text{O}_2$ .
- The particulate emission was 12-17 times lower than the regulatory limit.

## Introduction

### Plant Description

The Baltimore Regional Medical Waste Incinerator processes regulated medical waste and general waste from hospitals and clinics in Baltimore, Maryland, and regulated medical waste from health care institutions throughout the mid-Atlantic area of the United States. The service area of the facility is constrained by local ordinance to a radius of approximately 400 kilometers from Baltimore. The plant, which began commercial operation in January of 1991, is the largest dedicated medical waste incinerator in the world, and is now owned and operated by Phoenix Services, Inc.

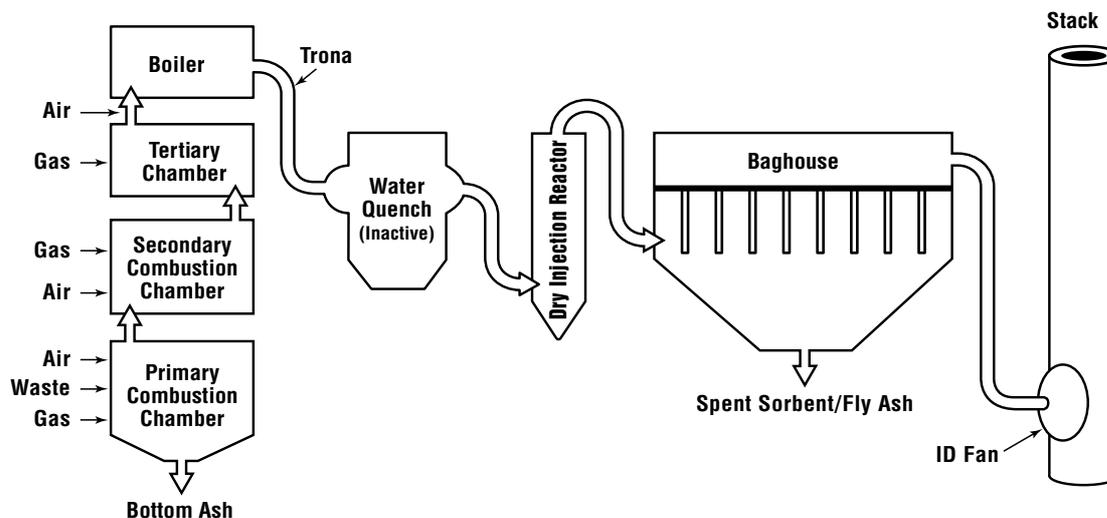
The process consists of two identical controlled air-type incineration lines, each with a nominal-processing rate of 77 metric tons of waste per day. The entire facility is permitted to process up to 136.4 metric tons per day. Each incineration line comprises primary, secondary, and tertiary combustion chambers, a heat recovery steam generator, and a dry-injection/fabric filter air pollution control system. Waste is fed into the primary chamber of the incinerator by a hydraulic pusher.

The primary chamber consists of a series of stepped hearths, each equipped with a hydraulic pusher. A sub-stoichiometric amount of combustion air is delivered continuously through pipes in each hearth, maintaining the temperature in the primary chamber at approximately  $900^\circ\text{C}$ . Over a period of about 8 hours, the solids are tumbled down the hearths and reduced to a char. Combustible gases driven off from the pyrolyzed solids are burned with excess air in the secondary chamber, which is maintained at a temperature of approximately  $1000^\circ\text{C}$ . Combustion gases are then maintained above  $1000^\circ\text{C}$  for an additional one second of retention time in the tertiary chamber. After the tertiary chamber, additional tempering air is added to reduce the gas temperature to approximately  $427^\circ\text{C}$  and the combustion gases then pass into the fire-tube boiler. The tempering air is designed to reduce the combustion gases below the fusion temperature of alkali metal salts that are characteristic in solid waste combustion gases, and that can foul heat transfer surfaces.

Energy recovered as steam in the boiler is delivered to turbine drivers on the induced draft fans, and used to heat the building and water for disinfecting reusable waste shipping containers. Flue gases pass out of the boiler at approximately  $275^\circ\text{C}$  and flow into a crossover manifold which enables operating either incinerator with either air pollution control system.

Gas leaving the crossover manifold then passes through transition ducts into the dry scrubber. The plant was originally designed to use dry hydrated lime ( $\text{Ca}(\text{OH})_2$ ) for acid gas ( $\text{HCl}$  and  $\text{SO}_2$ ) scrubbing. The target reaction temperature range for this material is between  $120^\circ\text{C}$  and  $150^\circ\text{C}$ . A vertical plain water quench tower was originally installed to provide the additional gas cooling required after the boiler. Hydrated lime was gravity fed downstream of the cooling in a proprietary reactor vessel designed to internally re-circulate solids to minimize sorbent usage.

Due to operational problems, hydrated lime was replaced with sodium bicarbonate ( $\text{NaHCO}_3$ ) in 1994. At that time the plain water quench was taken out of service since the reaction between the sodium alkaline sorbent and the acid gases can occur at a higher temperature. With radiant cooling and air inleakage, the baghouse inlet temperature could still be kept below the limit of  $260^\circ\text{C}$ .



**Figure 1.** Plant Configuration for Phoenix Services Medical Waste Incinerator Facility (natural gas inputs are used only for startup and shutdown).

In 1996 sodium bicarbonate was replaced with sodium sesquicarbonate ( $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$ ) or trona, a less costly sodium sorbent, which is currently in use at the facility. After passing through the dry scrubber system, the dust-laden flue gas enters a four-compartment pulse jet baghouse. Combustion gases are drawn through the baghouse by an induced draft fan, after which they pass up a single stack, common to both incineration trains. Figure 1 shows a diagram depicting the process flow for one incineration train.

### Emissions Standards

Because of its uniquely large scale and public visibility, the State of Maryland imposed stringent emissions standards on the facility, for both criteria and hazardous air pollutants (HAPs), from the project's inception. In September 1997, under requirements of Sections 111 and 129 of the Clean Air Act as amended in 1990, the US EPA promulgated new source performance standards and emission guidelines, for new and existing Hospital/Medical/Infectious Waste Incinerators. The most stringent requirements were for those units capable of processing more than 5.5 metric tons of waste per day.

The new emissions limits for particulate matter (PM), carbon monoxide (CO), nitrogen oxides ( $\text{NO}_x$ ), and acid gases (HCl and  $\text{SO}_2$ ) are essentially the same as those imposed on the facility by the original operating permit. However, for certain HAPs (lead [Pb], cadmium [Cd], mercury [Hg], and dioxins/furans [PCDD/F]), the new

regulations impose concentration-based limits. Previously, HAP emissions compliance had been risk-based, using dispersion modeling to demonstrate an acceptable ambient impact from emissions. The concentration-based limits in the new regulations are significantly more stringent than the risk-based limits. Although results from previous compliance testing indicated that the new metals limits could be met, the new PCDD/F limit of 2.3 ng TEQ/dscm @ 7%  $\text{O}_2$  (1.76 ng TEQ/ $\text{Nm}^3$  @ 11%  $\text{O}_2$ ) is considerably below historical levels of PCDD/F measured during compliance testing at the facility.

### Alternatives Considered

Anticipating the eventual requirement to reduce PCDD/F emissions from the plant, Phoenix had performed trials in late 1995 with both standard powdered activated carbon (PAC) and a proprietary activated carbon product injected into the flue gas. The results were acceptable for both materials and enabled a target injection rate to be established for future reference.

The trials were performed during the compliance test runs that year and examination of the dioxin/furan results revealed a PCDD/F congener distribution indicative of de Novo synthesis. Along with fly ash, ferric chloride ( $\text{FeCl}_3$ ) is also believed to catalyze de Novo synthesis of PCDD/F. Ferric chloride is present on mild steel surfaces that have been corroded by hydrogen chloride.

Such surfaces exist in the boiler tubes, the inactive water quench vessels, and the interconnecting ducts. The possibility that injecting the alkaline sorbent further upstream could reduce the ferric chloride available to catalyze PCDD/F synthesis prompted another trial in late 1996. At this time trona was pneumatically injected into the flue gas, just downstream of the boiler, during an additional dioxin/furan compliance run. Although this provided only a single data point, the results were encouraging since the PCDD/F on a TEQ basis were reduced to approximately 50 percent of historic average levels.

An additional incentive for moving the sorbent injection as far upstream as possible was to reduce sorbent consumption. Dry scrubbers using hydrated lime are often installed with recycle systems to reinject baghouse dust containing unconverted calcium as a means of reducing overall sorbent usage. A dilute-phase pneumatic recycle system had been retrofitted on the facility's dry scrubber in 1994 and was still in use with the sodium sorbent. Although the recycle had a measurable positive effect on sodium sorbent usage, it created the disadvantage of increasing the baghouse inlet dust loading by a factor of 2 to 3. Since most of this solid material has already been converted to salts, it is largely inert and simply creates baghouse pressure drop, which increases bag cleaning cycles and reduces bag mechanical life.

Trona reacts quickly with acid gases when suspended in the flue gas stream and its overall usage rate can be decreased significantly simply by increasing the residence time in suspension before it reaches the filter bags. In addition, unlike hydrated lime, trona is effective at much higher gas temperatures, enabling it to take advantage of reaction rate temperature dependence. In 1999, permanent systems were installed for dilute-phase pneumatic transport and injection of trona into the flue gas, immediately downstream of the boilers. This change enabled shutdown of the sorbent recycle system, improvements in baghouse operations, and reduction in sorbent consumption. However, although subsequent testing revealed that the change also had a favorable effect on PCDD/F concentrations, the improvement by itself was insufficient to reduce PCDD/F emissions below the new standard. Consequently, an additional increment of dioxin/furan removal was required.

In late 1997, W. L. Gore & Associates, Inc., introduced a new filtration media concept to Phoenix Services, Inc. The concept combined a filter media with catalytic destruction of dioxins and furans. When compared to conventional PAC injection, the new technology offered the following advantages to Phoenix:

- 1) Gas phase PCDD/Fs are destroyed, rather than simply being adsorbed on a solid.
- 2) The system is a passive solution, without the need for a new chemical feed system.
- 3) Conversion to the new technology is simply a matter of rebagging the baghouses.
- 4) Potential future liabilities associated with PCDD/F contaminated solid residues are reduced.
- 5) The system provides the particulate capture, filter pressure drop, and mechanical life advantages of an ePTFE membrane filter media.

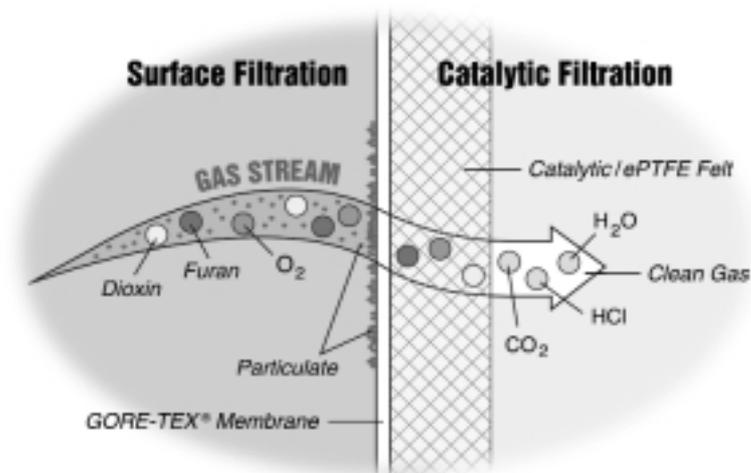
In early 1998, test filters were installed in one of the baghouses at the facility. After 10 months it was determined that the catalytic activity of the filters did not degrade and Phoenix Services made the decision to replace its woven fiberglass filter bags with the catalytic filters. Beginning in May 1999, both baghouses were completely refitted with the catalytic filter system, to simultaneously control PCDD/F and particulate matter.

## **Description of Catalytic Filter System**

The catalytic filter system employed by Phoenix Services is the REMEDIA™ D/F Catalytic Filter System (1, 2). This system is an evolution of two proven technologies: catalysis and surface filtration. The system consists of an ePTFE membrane and a catalytic felt substrate. This substrate is a needlepunched felt made from ePTFE fibers containing a proven dioxin-destroying catalyst. The catalytic felt destroys gaseous PCDD/F at low temperatures (180°C – 260°C) by means of a catalytic reaction. PCDD/F molecules diffuse on the catalyst surface and react to form insignificant amounts of CO<sub>2</sub>, H<sub>2</sub>O, and HCl.

The filters also employ a microporous, ePTFE membrane for particulate control, which is laminated to the catalytic felt substrate. The membrane, which is a GORE-TEX® membrane, captures submicron particulate without allowing particles to penetrate or pass through the catalytic

felt substrate. Thus the membrane provides a means for capturing particulate containing adsorbed PCDD/F. Gaseous PCDD/Fs, however, pass through the membrane and into the catalytic felt. The catalysis and surface filtration principles are illustrated in Figure 2.



**Figure 2.** Cross section of the catalytic filter. The membrane removes particulate while the catalytic felt destroys gaseous PCDD/F.

## PCDD/F and Particulate Measurements

### Description

In January 2000, PCDD/F measurements were performed to evaluate the performance of the catalytic filters in baghouse #2. Two sampling locations were chosen: baghouse inlet duct (raw gas) and stack (clean gas). The two locations were sampled simultaneously. For each location two sampling runs were performed. Each run was performed on a separate day. The sampling methods employed were per EPA Method 23.

In addition, two particulate sampling runs were performed at the same two locations. The particulate sampling occurred prior to the start of a PCDD/F run. Analysis to determine total PCDD/F was performed using high resolution GC/MS. Particulate concentrations were determined according to EPA Method 5. Plant operating conditions at the time of the measurements were averaged and are summarized in Table 1. During all the measurements, all waste was fed to incinerator #1, and all the flue gas was pulled through baghouse #2.

	<b>RUN 1</b>	<b>RUN 2</b>
Total Waste Feed (kg/h)	3138	3157
Boiler #1 Inlet Temperature (°C)	955	947
Boiler #1 Steam Flow (kg/h)	10639	9891
Baghouse #2 Inlet Temperature (°C)	202	194
ID Fan #2 Inlet (Baghouse #2 Outlet) Temperature (°C)	177	167
Filter Pressure Drop (mm H <sub>2</sub> O)	140-150	140-150

**Table 1.** Average plant operating conditions during measurement campaign (by sampling run).

## Results

Figure 3 presents total PCDD/F concentrations (solid + gas phase) in the raw gas and clean gas. The data are presented as I-TEQ values. The PCDD/F results for Run #2 in the raw gas are unreliable due to a leak in the sampling train; therefore, the results are not shown in Figure 3. From Run #1 data, the PCDD/F removal efficiency is 98.4%.

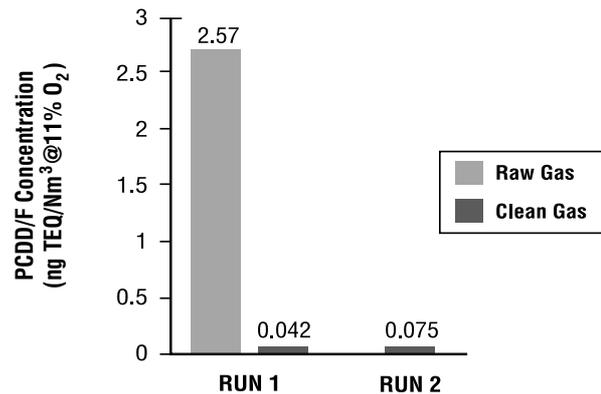


Figure 3. Total PCDD/F Concentrations in the Raw and Clean Gas (by sampling run).

Figure 4 presents the total particulate matter (PM) concentrations in the raw gas and clean gas for both runs. Over the two runs, the average PM removal efficiency is 99.95%. The PM concentrations in the clean gas are 12-17 times lower than the emission guideline of 26 mg/Nm³ @ 11% O₂.

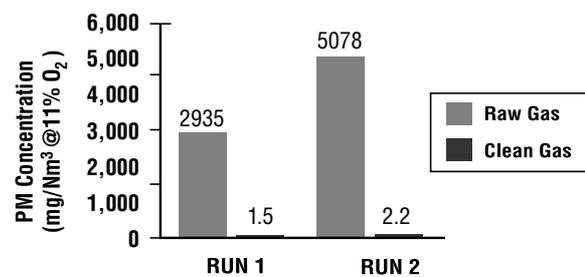


Figure 4. PM Concentrations in the Raw and Clean Gas (by sampling run).

## Comparison with Regulatory Requirements and Historical Values

Figure 5 presents the total PCDD/F emissions in the stack for the current study where the baghouse is equipped with the catalytic filter system. This is the solid + gas phase PCDD/F (as I-TEQ) averaged over both runs. This value is compared with the new EPA emission guideline for existing medical waste incinerators and the average historical value measured in 1998, which was the last measurement performed prior to the installation of the catalytic filter system. The PCDD/F emission with the catalytic filters is more than one order of magnitude lower than both the new EPA limit and the historical average. The emission is also lower than the more stringent European standard of 0.1 ng TEQ/Nm³ @ 11% O₂.

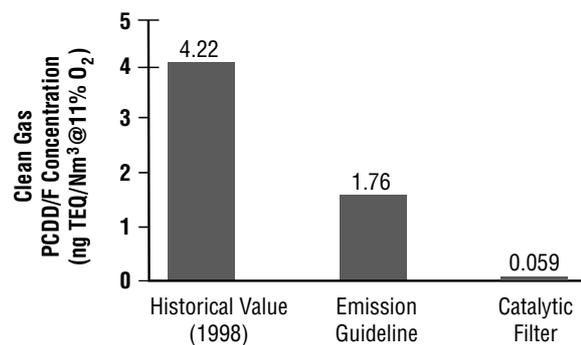


Figure 5. Comparison of Average Total PCDD/F Concentration with Emission Guideline and Historical Value.

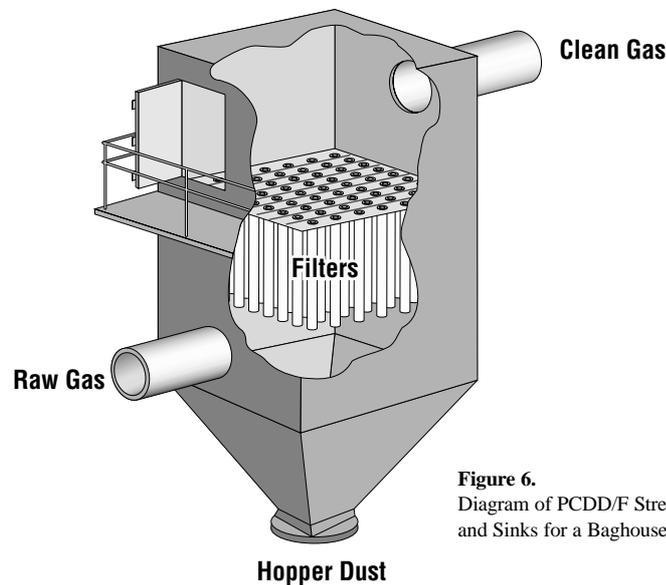
## Results

In order to perform a PCDD/F mass balance on the baghouse, it is important to understand the gas-solid phase partitioning of PCDD/F in the raw and clean gas. The total PCDD/F concentrations in the raw and clean gas were originally reported as three fractions: 1) solid phase collected on the filter of the sampling train, 2) gas phase adsorbed on the XAD trap, and 3) solid + gas phase contained in the sampling train rinse. This rinse was done for the entire sampling train according to EPA Method 23. The rinse for the nozzle, probe, and probe-filter connector (containing solid phase PCDD/F), was mixed with the rinse for the filter-condenser connector and condenser (containing gas phase PCDD/F). The gas phase PCDD/F consists of the XAD fraction plus that portion of the rinse that is gas phase. The solid phase PCDD/F consists of the filter fraction plus that portion of the rinse that is solid phase. The portions of the rinse that are gas vs. solid phase are not known exactly because the two portions were irreversibly mixed. However, reasonable estimates of the gas-solid phase partitioning can be made based on the premise that the concentration of PCDD/F in the hopper dust is very close to the PCDD/F concentration on particulate in the raw and clean gas.

## Raw Gas – Run #1

As shown in Figure 3, the total PCDD/F concentration in the raw gas for Run #1 is 2.57 ng TEQ/Nm<sup>3</sup> @ 11% O<sub>2</sub>. The fractions are as follows: Filter = 0.47 ng TEQ/Nm<sup>3</sup>, XAD = 0.50 ng TEQ/Nm<sup>3</sup>, and Rinse = 1.60 ng TEQ/Nm<sup>3</sup>.

The PCDD/F concentration in the hopper dust ranged from 84-157 ng TEQ/kg over the two-day measurement campaign. From Figure 4, the raw gas particulate concentration ranged from 2935-5078 mg/Nm<sup>3</sup> @ 11% O<sub>2</sub>. Taking the average hopper dust concentration (120.5 ng TEQ/kg) and multiplying by the average particulate loading (4007 mg/Nm<sup>3</sup>) gives a result of 0.48 ng TEQ/Nm<sup>3</sup> @ 11% O<sub>2</sub>. In the case of the raw gas, this result matches the PCDD/F filter fraction for Run #1 (0.47 ng TEQ/Nm<sup>3</sup>), and would suggest that all solid phase PCDD/F is contained on the sampling train filter. However, visible observation of the rinse from the raw gas sampling train made it apparent that some particulate was contained in the rinse. Therefore, a more reasonable estimate is to take the maximum PCDD/F concentration in the hopper dust (157 ng TEQ/kg) and multiply it by the maximum particulate loading (5078 mg/Nm<sup>3</sup>).



**Figure 6.**  
Diagram of PCDD/F Streams  
and Sinks for a Baghouse.

This gives a result of 0.80 ng TEQ/Nm<sup>3</sup> @ 11% O<sub>2</sub>. This is the estimated solid phase PCDD/F in the raw gas for Run #1. The estimated gas phase PCDD/F in the raw gas is 1.77 ng TEQ/Nm<sup>3</sup>, which is obtained by subtracting the solid phase PCDD/F from the total (2.57-0.80).

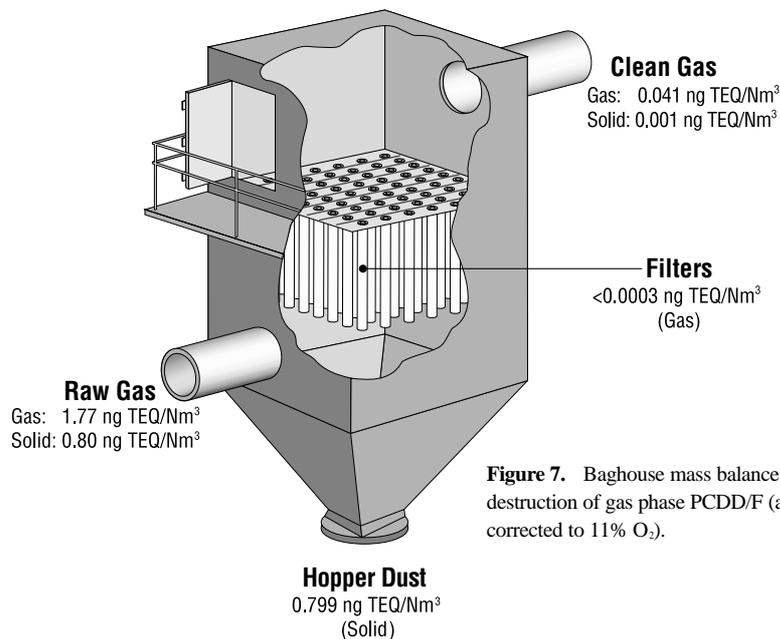
### Clean Gas – Run #1

As shown in Figure 3, the total PCDD/F concentration in the clean gas for Run #1 is 0.042 ng TEQ/Nm<sup>3</sup> @ 11% O<sub>2</sub>. The fractions are as follows: Filter = 0.001 ng TEQ/Nm<sup>3</sup>, XAD = 0.029 ng TEQ/Nm<sup>3</sup>, and Rinse = 0.012 ng TEQ/Nm<sup>3</sup>.

From Figure 4, the clean gas particulate concentration ranged from 1.5 -2.2 mg/Nm<sup>3</sup> @ 11% O<sub>2</sub>. Taking the maximum hopper dust concentration (157 ng TEQ/kg) and multiplying by the maximum particulate concentration (2.2 mg/Nm<sup>3</sup>) gives a result of 0.0003 ng TEQ/Nm<sup>3</sup> @ 11% O<sub>2</sub>. In the case of the clean gas, this result is in general agreement with the PCDD/F filter fraction for Run #1 (0.001 ng TEQ/Nm<sup>3</sup>).

This suggests that all solid phase PCDD/F is contained on the clean gas sampling train filter. There was no visible sign of particulate in the rinse from the clean gas sampling train. Therefore, it is reasonable to state that there is no solid phase PCDD/F in the clean gas rinse, only gas phase. Thus, the gas phase PCDD/F is the sum of the XAD fraction and the rinse, or 0.041 ng TEQ/Nm<sup>3</sup>.

Figure 7 presents the baghouse schematic from Figure 6 with the results from the PCDD/F balance. The results are given in terms of PCDD/F concentration and phase (gas and solid). The amount of gas phase PCDD/F attributed to adsorption on the catalytic filters was determined to be negligible (< 0.0003 ng TEQ/Nm<sup>3</sup>). The amount of solid phase PCDD/F attributed to the hopper dust is the difference between the raw and clean gas concentrations in the solid phase (0.80-0.001 = 0.799 ng TEQ/Nm<sup>3</sup>). By performing the balance, the amount of gas phase PCDD/F destroyed by the catalytic filters is 1.73 ng TEQ/Nm<sup>3</sup>.



**Figure 7.** Baghouse mass balance showing destruction of gas phase PCDD/F (all data corrected to 11% O<sub>2</sub>).

## Conclusions

The key findings of the PCDD/F and PM measurement campaign are:

- The total PCDD/F removal efficiency is 98.4%.
  - The amount of gas phase PCDD/F destroyed by the catalytic filters is 1.73 ng TEQ/Nm<sup>3</sup> @ 11% O<sub>2</sub> or 97.7%.
  - 99.9% of solid phase PCDD/F is removed by the catalytic filters.
- The clean gas PCDD/F concentrations are < 0.1 ng TEQ/Nm<sup>3</sup> @ 11% O<sub>2</sub> and are more than one order of magnitude lower than the emission guideline and historical values.
- The PM removal efficiency is 99.95% and clean gas PM concentrations are 12-17 times lower than the emission guideline.

The expected life of the catalytic filter system at Phoenix Services is five operating years. As a way of testing the activity of the catalytic filters over time, individual filters were removed at various times since the original installation in May 1999. Each filter was then tested in the laboratory and catalyst activity was measured. To date, the activity of the catalytic filters is 100% of the original activity. The retained mechanical strength of the filters to date is 100%. The pressure drop across the filters has remained stable at approximately 150 mm H<sub>2</sub>O, at an average baghouse cleaning frequency of 28 cycles per 24 operating hours.

## Acknowledgments

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## Key to Abbreviations

dscm	dry standard cubic meter
ePTFE	expanded polytetrafluoroethylene
GC/MS	gas chromatography/mass spectroscopy
HAP	hazardous air pollutant
ID	induced draft
I-TEQ	amount of 2,3,7,8 tetrachlorodibenzo-p-dioxin equal to the total PCDD/F calculated using International Toxicity Equivalency Factors
ng	nanogram
PAC	powdered activated carbon
PCDD/F	polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans
PM	particulate matter
TEQ	Toxicity Equivalents
XAD	adsorbent resin used in PCDD/F sampling train

## Footnotes

\*John Kumm held the position of Operations Manager at Phoenix Services, Inc., from June 1996 until October 1999.

## References

- 1) J. L. BONTE et al., "Dioxin/Furan Destruction in the Baghouse," (Dioxin '99) Venice, Italy, September 1999.
- 2) M. PLINKE et al., "Catalytic Filtration – Dioxin Destruction in a Filter Bag," (AIChE 2000 Spring) Atlanta, Georgia, USA, March 2000.



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