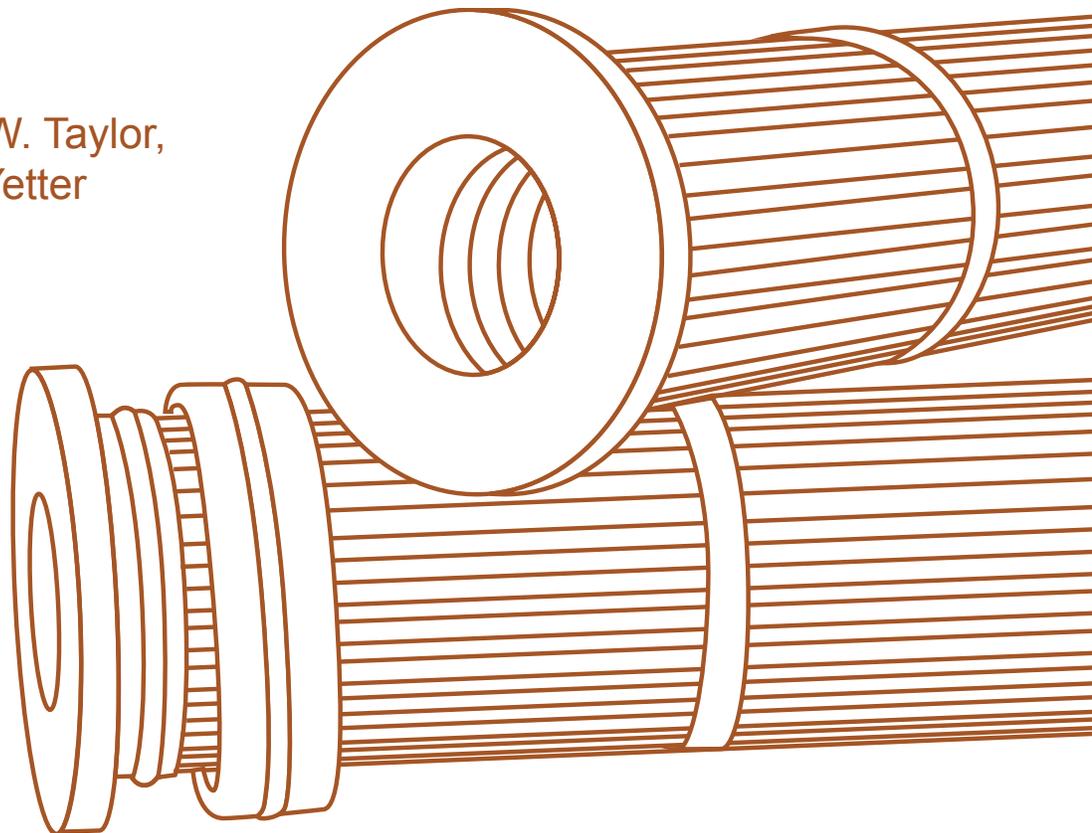


# Enhanced Capture of Mercury in Baghouse

by using Novel Filtration Media and Filter Design

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# Abstract

Study was conducted at a 5-MW equivalent slipstream facility of Gulf Power's Plant Crist Unit 5 located in Pensacola, FL. The facility is also commonly referred to as Mercury Research Center (MRC). During the trials lasting 10 days, the effect of a range of process variables was studied. The variables included flue gas temperature, air-to-cloth ratios, interval between cleaning, and the effect of removing some of the fly ash by an ESP upstream of baghouse, etc. CLARCOR Industrial Air tested a novel membrane-based filtration media formed as pleated elements.

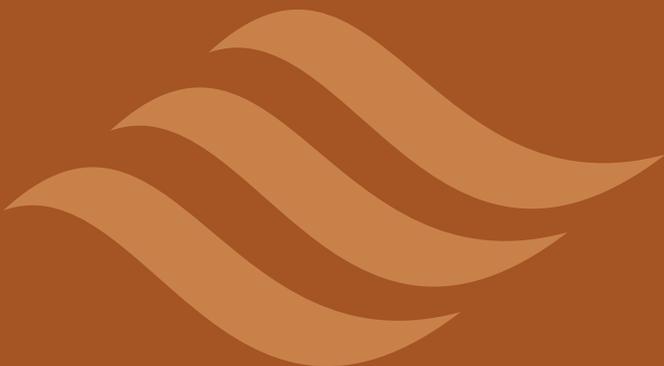
Data will be presented that shows that by using the CLARCOR Industrial Air novel filtration elements, Mercury capture as high as 98% can be achieved by inherent fly ash alone (without needing to inject powdered activated carbon).

This was true in spite of majority (about 80%) of Mercury being in elemental form in the flue gas. Traditional round filter bags are typically known to capture significantly lower percentage of Mercury in the flue gas by inherent fly ash.

Data was also collected with injection of activated carbon upstream of baghouse. It was found that by using these novel filtration elements, if a plant is already using powdered activated carbon the consumption of activated carbon can be reduced by as much as 85%.

Data will be reviewed along with the proposal of mechanisms about how this novel filtration

element works in achieving such high Mercury captures, as compared to traditional round bags.



# Introduction

Control of mercury emissions from coal-fired boilers is imminent. Several states have instituted mercury emission limits in lieu of a national standard. The USEPA is instituting mercury emission limits for Industrial and utility coal fired boilers. Many of the mercury emission standards imply a reduction efficiency of about 80% to 90% will be required. As a result, an economical means of achieving the proposed mercury emission limits is required.

CLARCOR Industrial Air manufactures pleated filter elements for flue gas filtration from coal-fired boilers. These filter elements (BHA® ThermoPleat®) are constructed from a patent-pending high density unsupported needle felt media that is stiffened by a state of the art thermal bonding process (a version of these made from Aramid fibers is available as well). These elements are a direct replacement for standard filter bags and cages. Their shorter length keeps the filter element out of the inlet gas stream, reducing abrasion problems and providing for a larger drop-out area.

Table 1 shows a typical comparison of filtration surface area provided by BHA ThermoPleat pleated elements as compared to traditional filter bags and cages. Figure 1 shows a picture of CLARCOR Industrial Air BHA ThermoPleat element, as an example.

## BHA ThermoPleat® vs. Conventional Felt Bags

	BHA ThermoPleat	Conventional Felt Bag
Diameter (inches)	6.25	6.25
Length (inches)	81	169.50
Ft <sup>2</sup> of Filtration Area	44.3	23.1

Table 1. Typical Comparison of Filtration Area

### Rationale for the Study

It is generally known in the coal-fired power industry that the fly ash in flue gas contributes to some capture of Mercury. The Mercury capture is not dependent on unburned coal in the fly ash (LOI of fly ash). That is one factor. Oxidized Hg will adsorb on flyash without carbon present. Our finding is that the pleated element oxidized the Mercury making it easier to adsorb on any particles including unburned carbon. The phenomenon is also sometimes referred to as native capture of Mercury by fly ash. This fly ash with Mercury is then collected by traditional air pollution control equipment used by the plant (Fabric Filter baghouse or Electrostatic Precipitator). In general, this native capture of Mercury is found to be larger by Fabric Filter baghouses (as compared to ESP).

Pleated filter elements (like BHA's ThermoPleat) provide significantly higher filtration surface area as compared to conventional round felt bags. As a result, we hypothesized a greater native capture of Mercury by a baghouse using these elements. This hypothesis was also built upon some anecdotal data CLARCOR Industrial Air had collected from customers. To prove this hypothesis, CLARCOR Industrial Air conducted a scientific study at Southern Company's Mercury Research Center (MRC).

### Study

PCT, Inc. conducted the testing for CLARCOR Industrial Air in the baghouse located in the MRC at Plant Crist Unit 5 in Pensacola, Florida. The MRC is a fully-functional, pollution control research facility located on a 5-MW sidestream of Unit 5.

PCT, Inc. provided flue gas mercury measurements at the MRC inlet, the baghouse inlet and at the baghouse outlet. The primary measurements were made using Thermo Fisher Scientific mercury CEM analyzers with quality control measurements made using sorbent traps. Coal and fly ash samples were obtained throughout the program for off-site LOI and/or mercury analysis. Velocity traverses utilizing a standard pitot were made daily to confirm flow rates. The sorbent injection system was comprised of a Porta-PAC™ injection skid.

The coals combusted during the test program were typically a blend of Drummond and Galatia coal. The Drummond is a low sulfur sub bituminous of Columbian origin and the Galatia is a bituminous coal from the Central Illinois Basin. The blend is a low sulfur (0.75%) sub bituminous analog.

Testing was conducted over the period of ten days, between September 7 and 16, 2010. A short period of break-in or "seasoning" of the bags took place from September 7 through September 12, followed by the four days of testing during which parametric variables such as cleaning times, flue gas temperature, and flow rate were changed.



Figure 1. An Example of CLARCOR Industrial Air BHA ThermoPleat Filter Element

# Test Facility

Figure 2 shows a simplified schematic of the layout of the MRC facility in relation to Plant Crist.

The MRC facility can be operated in a baghouse-only mode, ESP-only mode, or use ESP and baghouse in series. As an example, Figure 3 shows the arrangement of MRC in a baghouse-only mode. Most of the CLARCOR Industrial Air testing was conducted in baghouse-only mode. The SCR was bypassed during the entire duration of testing.

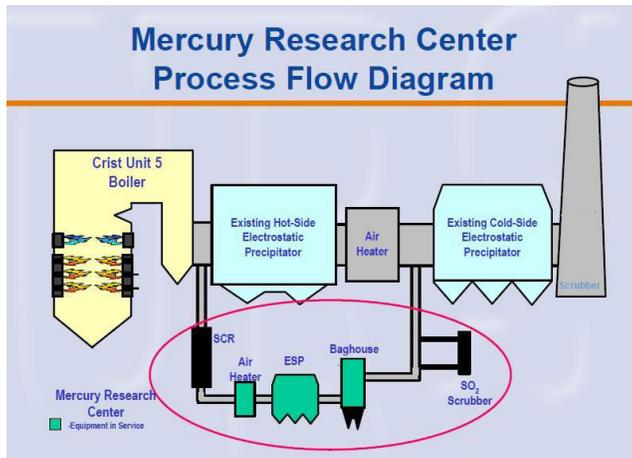


Figure 2. Mercury Research Center Process Flow Diagram

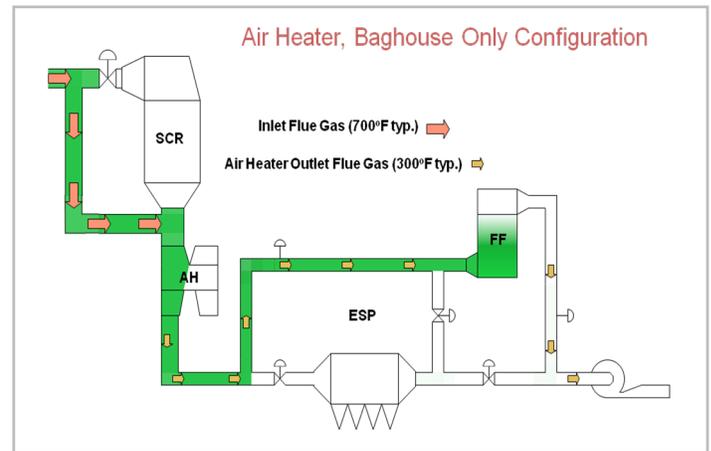


Figure 3. MRC in Baghouse-only Mode

## Baghouse

The pulse jet baghouse had 82 filter elements arranged in 9 rows. The system was equipped to conduct cleaning based on pressure set points, or based on time. The pulse cleaning parameters were as follows – cleaning pressure of 55 psig, pulse time of 0.15 seconds, and time between pulses of 6 seconds.

The baghouse was designed for 27' long standard round PPS bags supported by wire cages. These bags and cages were removed, and the baghouse was fitted with CLARCOR Industrial Air 81" long BHA ThermoPleat elements. The 81" long BHA ThermoPleat elements provided the same filtration area as 27' long conventional round bags.

## Filter Elements Tested

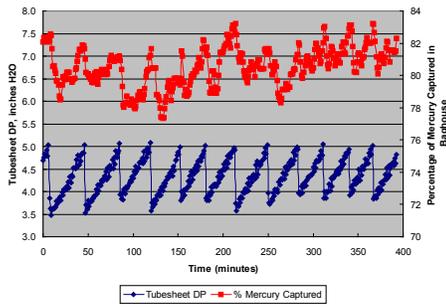
The BHA ThermoPleat elements were 81" long with a diameter of 6.25". The filtration media in these elements was CLARCOR Industrial Air proprietary laminate QR811. The media uses a stiffened felt that is a blend of PPS and P84 fibers, and is laminated to a microporous expanded PTFE membrane, as the filtration surface.

During the rest of this paper, these elements will be referred to as QR811 elements.

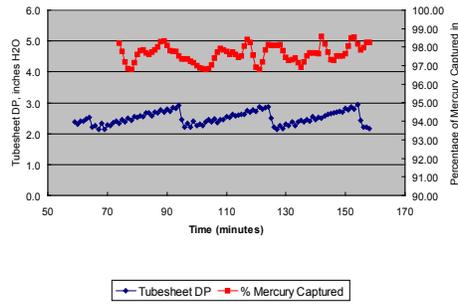
## Variables Studied

The study was designed to evaluate the effect of the following variables:

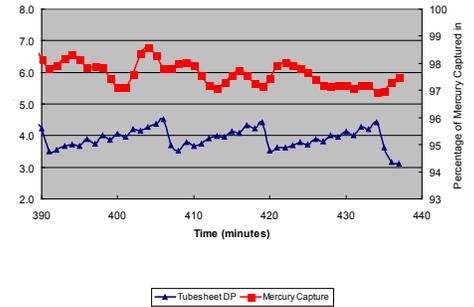
- Flue gas flowrate – 14,000 acfm vs. 19,000 acfm. Corresponds to an air-to-cloth ratio of 3.7 and 5.15.
- Flue gas temperature – 280°F and 343°F
- Different cleaning intervals and modes (Pressure settings vs. time settings)
- Effect of Powdered Activated Carbon Injection (to further increase Mercury capture beyond what can be accomplished by fly ash alone)



**Figure 4.** Mercury Capture Data at Flue gas flow rate of 14,000 acfm (air:cloth ratio of 3.7); Temperature 343°F; Cleaning in pressure mode with set points of 4" and 5" for clean and dirty conditions



**Figure 5.** Mercury Capture for Flue gas flow rate of 14,000 acfm (air:cloth ratio of 3.7); Temperature 280°F; Cleaning in Time Mode every 30 minutes – Snapshot of data through 3 cleaning cycles



**Figure 6.** Mercury Capture for Flue gas flow rate of 19,000 acfm (air:cloth ratio of 5.15); Temperature 280°F; Cleaning in Time Mode every 15 minutes – Snapshot of data through 3 cleaning cycles

## Results and Discussion

Figures 4, 5, and 6 shows some of the results at various conditions of gas flow rate, cleaning modes, and flue gas temperatures. The average level of Mercury in the flue gas stream incoming to the baghouse was  $10.3 \mu\text{g}/\text{m}^3$ . The speciation was 80% elemental and 20% oxidized. As noted earlier, the SCR was kept out of service for the entire duration of testing. Without the SCR, this level of Mercury speciation is consistent with historic data from Mercury Research Center (MRC) facility.

Table 2 provides a more comprehensive summary of the capture rates of Mercury under various combinations of variables.

The data shown in Table 2 came as a great surprise to the team. The data showed that by using native fly ash alone, Mercury capture of 98% can be achieved in the baghouse with BHA pleated elements if the flue gas inlet temperature can be reduced to 280°F. This is true in spite of the Mercury being predominantly in the elemental state. For a more conventional flue gas temperature of around 343°F, the capture percentage of between 75%

to 80% can be achieved. These numbers are surprising, as the historic data from MRC shows that with traditional round non-membrane bags, the expected capture percentage is around 30%.

The data also shows that there is some benefit to operating the process in a pressure-based cleaning mode (compare results from Tests 1 and 2). There is some advantage to increasing the time between cleaning (compare the results from Tests 2 and 3).

At higher flue gas temperature (343°F), the data further showed that operating at higher air-to-cloth ratio could actually be better for Mercury capture. This came as another counter-intuitive observation.

Test Number	Air-to-Cloth Ratio, fpm	Flue Gas Temperature (at BH entrance), dg F	Cleaning Mode	Time-average Percentage of Mercury Captured by Fly ash in the baghouse, %
1	3.7	343	Based on differential Pressure Set-points (4" for clean and 5" for dirty)	80.5
2	3.7	343	Time-mode Cleaning, Every 30 minutes	77.0
3	3.7	343	Time-mode Cleaning, Every 60 minutes	78.5
4	5.15	343	Time-mode Cleaning, Every 8 minutes	90.3
5	5.15	343	Time-mode Cleaning, Every 15 minutes	91.0
6	3.7	280	Time-mode Cleaning, Every 30 minutes	98.0
7	3.7	280	Time-mode Cleaning, Every 60 minutes	98.0
8	5.15	280	Time-mode Cleaning, Every 8 minutes	97 – 98%
9	5.15	280	Time-mode Cleaning, Every 15 minutes	97 – 98%

Table 2. Summary of Mercury Capture across baghouse at various conditions of air-to-cloth ratio, flue gas temperatures, and cleaning modes. The average level of Mercury in the flue gas stream incoming to the baghouse was  $10.3 \mu\text{g}/\text{m}^3$ . The speciation in the inlet flue gas was 80% elemental and 20% oxidized.

## Confirmatory Tests on the Validity of Data

Since the observed Mercury capture percentages were significantly higher than traditional round bags, we ran a few confirmatory tests to rule out any equipment error or anything unusual with flue gas chemistry.

In order to confirm that the Mercury analyzers were reading correctly, we ran the following two confirmatory tests.

- The flue gas duct was reconfigured to bypass the baghouse. On bypassing the baghouse, the outlet Mercury analyzer read within 2% of the inlet analyzer.
- During steady state operation with baghouse in service, Mercury samples were also collected with carbon traps. These carbon traps were sent to an outside test lab. The data from these carbon traps matched the inline Thermo data very closely.
  - Average of two traps  $0.90 \mu\text{g}/\text{m}^3$  at 3% O<sub>2</sub> (ran for 111 minutes)
  - Average of Thermo Total Hg over the 111 minutes  $0.88 \mu\text{g}/\text{m}^3$  at 3% O<sub>2</sub>

Based on these two tests, any concerns with Mercury analyzers were ruled out.

The second concern was whether there was some temporary fluctuation in the plant operation that is leading to unusual gas stream chemistry or unusually high affinity of fly ash for Mercury. In order to confirm that this was not the case, we collected Mercury capture data across ESP alone. The rationale was that since amount of Mercury capture by ESP in a typical power plant is very well documented, by collecting the baseline data with ESP, any unusual issues with this particular gas stream chemistry or fly ash composition can be ruled out. The four-field ESP was operated at the standard operating conditions (50KV on each field).

ESP was operated at temperature 340°F. The flue gas flow rate was 14,000 acfm. At these conditions, the percentage of Mercury captured across ESP was around 35%. This level of capture of Mercury across ESP is consistent with documented studies, and historical data from MRC. Hence, anything unusual about this fly ash or gas chemistry can be ruled out.

## Testing with Injection of Powdered Activated Carbon

Since injection of powdered activated carbon is accepted as a well-accepted method for Mercury control, we hypothesized that by using CLARCOR Industrial Air BHA ThermoPleat elements the amount of carbon needed by an Utility can be substantially reduced.

Testing was conducted with Darco® Hg-LH powdered activated carbon supplied by Norit. This is impregnated activated carbon, and is designed for flue gas streams having high percentage of elemental Mercury.

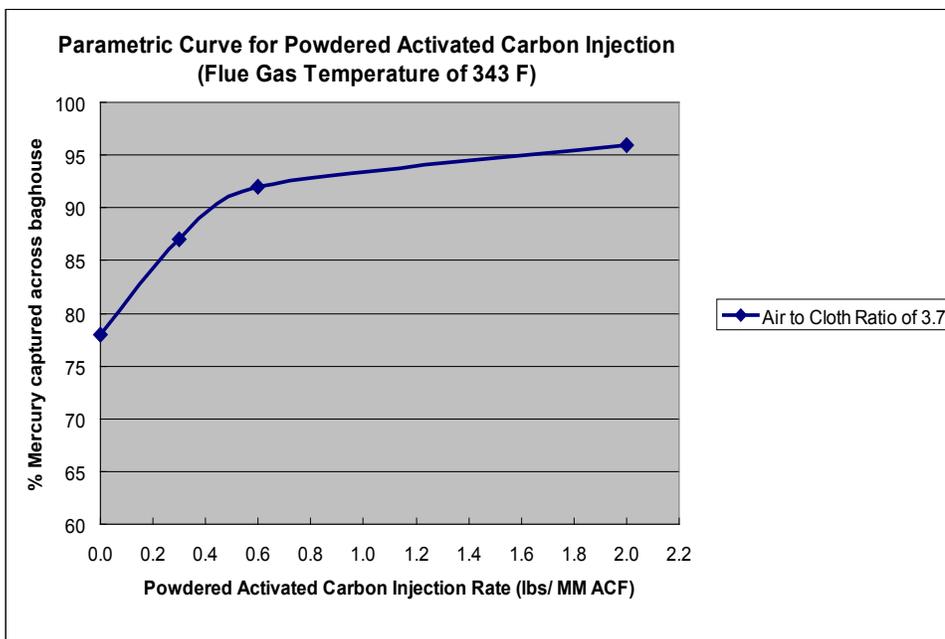


Figure 7. Percentage of Mercury captured with the injection of powdered activated carbon. Flue gas flow rate of 14,000 acfm (air-to-cloth ratio of 3.7)

Figure 7 shows the parametric curve with various levels of activated carbon injection rates.

The activated carbon studies showed that with BHA ThermoPleat element, a capture rate of 92% plus can be achieved by carbon injection rate of 0.6 lbs/MM ACF. This compares to typical injection rate of 4.0 lbs/MM ACF reported in literature for standard non-membrane bags?

## Summary of Key Findings

- Mercury capture of 98% can be achieved in the baghouse with QR811 elements, if the flue gas inlet temperature can be lowered to 280°F. This is true in spite of the Mercury being predominantly in elemental state.
- Mercury capture of 75% to 80% can be achieved in the baghouse with QR 811 pleated elements, if the flue gas temperature is kept at typical set-up of around 345°F.
- Further increase to mercury capture can be achieved at the higher temperature settings (343°F) by activated carbon injection. Capture rate can be increased to 92% plus by carbon injection rate of 0.6 lbs/MM Acf. This compares to typical injection rate of 4.0 lbs/MM Acf reported in literature for standard non-membrane bags.

## Proposed Mechanism

The exact mechanism for these unexpected findings is still being investigated. An initial hypothesis of mechanism is discussed below.

First a recap of the known facts,

- Pleated elements with membrane are leading to very high rate of Mercury capture, compared to literature-reported values with traditional non-membrane round bags.
- Air-to-cloth ratio appear to have weak effect.
- Interval between cleaning does appear to have some effect (lengthening it increases the capture).
- Temperature of flue gas has the strongest effect.
- There appears to be something inherently unique about pleated elements and membrane that is leading to high capture. The mechanism cannot be explained by cleaning interval and air-to-cloth ratio alone.

In order to ascertain that the high rate of Mercury capture across CLARCOR Industrial Air pleated elements is related to fly ash, we conducted an experiment in which the fly ash was removed from the equation. An experiment was conducted in which ESP and baghouse were operated in series. ESP was operated at its standard conditions with all four fields operational. At these conditions, this ESP is believed to remove 99.5%+ of the fly ash, per MRC (no opacity measurement available). Gas flow rate was 14,000 acfm, and temperature was 340°F.

The results are summarized in Table 3.

When operating under these conditions, it was found that the baghouse provided no significant further Mercury capture beyond what was achieved by ESP alone. This leads us to conclude that the key mode of Mercury removal across the pleated elements relies on the fly ash.

However, in the above set-up, what came as a surprise was that while the baghouse provided no additional mercury removal (when operated in series downstream of ESP), it continued to oxidize Mercury (even in absence of fly ash).

Based on this observation, the proposed mechanism for the high amount of Mercury capture by membrane pleated elements is as follows:

- High capture requires membrane **AND** pleats in the filter element.
- High surface area of membrane (nodes and fibril structure on surface) provides collection surface for Hydrochloric acid (HCl) in the gas stream to collect on and to oxidize the elemental Mercury in flue gas to Mercuric Chloride.
- With pleated elements, there is always some fly ash collected in the valleys that captures this Mercuric Chloride. This fly ash does not contribute to filter pressure drop, as it is not actually on the filtration surface, but located in close vicinity of filtration surface.
- In case of round bags, there is very little fly ash that remains in vicinity of filtration surface (the cleaning pulse being directed at 90 degree angle from the bag would push out all the fly ash).

In the proposed model, the membrane facilitates Mercury oxidation, and the pleats facilitate capture of oxidized Mercury. Need to have both to get high total capture.

Upstream of ESP		Downstream of ESP / Upstream of Baghouse		Downstream of Baghouse	
Total Mercury, $\mu\text{g}/\text{m}^3$	Percentage Elemental (%)	Total Mercury, $\mu\text{g}/\text{m}^3$	Percentage Elemental (%)	Total Mercury, $\mu\text{g}/\text{m}^3$	Percentage Elemental (%)
9.49	81	6.36	50	6.07	15

Table 3. Process with ESP and Baghouse operated in series. Total levels of Mercury and speciation at various stages of the process.

## Explanation of Observed Results by Proposed Mechanism

*No additional capture of Mercury by Baghouse when ESP is in service*

- Without fly ash in the flue gas stream, the HCl build-up on the membrane nodes and fibrils would still take place. This would still oxidize the elemental mercury to Chloride form. Experimental data shows that as well.
- However, without any fly ash to capture this Mercuric Chloride, it would simply go through the baghouse as gas (at these concentrations dew point of Mercury in gas is below zero dg C).

*Substantial increased capture of Mercury on reducing the flue gas temperature from 343°F to 280°F.*

At lower temperatures, the surface precipitation of HCl on the membrane surface would be even higher, explaining increased oxidation of Mercury and hence greater capture.

*Somewhat increased capture of Mercury at higher gas flow rate (19,000 acfm vs. 14,000 acfm)*

At higher flue gas flow rates, the cleaning pulse would not be able to push off the cake from the filtration surface that far, and there will be increased collection within the valleys of the filter. This increased collection of ash in the valleys would help with mercury capture.

# Overall Summary

In summary, this demonstration proved that QR811 pleated elements are an effective replacement for standard cloth bags on wire cages and require much less physical space to achieve functionality. Mercury removals of >95% across the baghouse were achieved with relatively low LOI in the fly ash, <4.3%. When supplemented with activated carbon, much higher removals were achieved. Lower temperature operation increased removal as did reducing the cleaning frequency which led to thicker filter cakes on the bags.

In this short-term test it was shown that the pleated bags can achieve very high levels of mercury removal without imposing any detrimental effect on unit operation.

A model for potential mechanisms that result in such high degree of Mercury capture has been proposed. While the exact mechanisms are not known, it is believed that the presence of ePTFE membrane as well as the filter geometry (pleated elements vs. round bags) are critical to achieve the high Mercury capture.

## References

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- 2 McLellan, Debra et al, "Multi-Technology, Mercury Abatement Program Implementation and Performance at Nova Scotia Power", Power Plant Air Pollution Control Mega Symposium, Aug 30- Sep 2, 2010
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## Acknowledgements

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