

**Catalyst Additives to Enhance Mercury Oxidation and Capture**

**Quarterly Report**

Period of Performance:

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## **Abstract**

Bench-scale carbon-catalyst tests were conducted in the first quarter of 2004, to obtain kinetic rates of mercury oxidation and sorption for different forms of carbon. The current quarterly report provides a more extensive quantitative analysis of the data obtained from the CRTF experiments on different carbon types and carbon/calcium mixtures than was presented in the last quarterly report. The procedure and basis for normalizing mercury removals, so that they could be compared on an equal residence time basis, is described. The chemisorption rate of mercury on carbon was found to be first order in mercury concentration and half order in HCl concentration, for the facility configuration investigated. The applicable temperature range of the kinetic rates obtained is from 300 °F to 700 °F, and the applicable chlorine concentration range is from 2 ppmv HCl to 250 ppmv HCl. The gas-sorbent contact time of 0.12 seconds used in this work was shown to be representative of gas-dust cake contact times in full-scale baghouses. All carbon types investigated behaved similarly with respect to Hg sorption, including the effect of temperature and chlorine concentration. Activated carbon was more effective at sorbing mercury than carbon black and unburned carbon (UBC), because the internal surface area of activated carbon is greater. The synergistic relationship between Ca and C is also discussed in the report.

## Table of Contents

Section	Page
<b>Introduction</b> .....	1
<b>Executive Summary</b> .....	1
<b>Experimental</b> .....	2
<b>Results and Discussion</b> .....	4
<u><i>Carbon Catalyst Test Parameters.</i></u> .....	4
<u><i>Normalizing to Comparable Residence Time.</i></u> .....	5
<u><i>Relevance to Full-Scale Residence Times.</i></u> .....	6
<u><i>Carbon Catalyst Kinetics.</i></u> .....	6
<u><i>Examination of Carbon/Calcium Catalytic Synergism.</i></u> .....	11
<b>Conclusions</b> .....	13
<b>Future Work</b> .....	13
<b>References</b> .....	14

## List of Figures

Figure	Page
1 CRTF quartz furnace with catalyst at ~1000 °C (left) and outside of furnace (right) .....	2
2 CRTF furnace, gas-injection system, flue-gas CEMs, and Hg gas-conditioning system .....	3
3 CRTF gas-flow system .....	3
4 Three C-types compared in simulated flue gas with 2 ppmv HCl .....	7
5 Three C-types compared in simulated flue gas with 50 ppmv HCl .....	7
6 Three C-types compared in simulated flue gas with 100 ppmv HCl .....	8
7 Three C-types compared in simulated flue gas with 250 ppmv HCl .....	8
8 Predicted vs measured mercury capture on activated carbon .....	10
9 Predicted vs measured mercury capture on unburned carbon .....	11
10 Activated carbon compared with 10% AC/90% HL processed sorbent mixture .....	12
11 Activated carbon compared with 20% AC/80% HL processed sorbent mixture .....	12
12 From left to right, honeycomb, plate, and hybrid SCR catalysts .....	14

## Introduction

The objective of this project proposed by Southern Research Institute (SRI) is to investigate the enhancement of elemental mercury oxidation in coal-fired flue gas through catalysis. In addition to testing various catalyst materials, different catalysis implementation processes may be investigated, including duct injection of catalyst/sorbent hybrids, coated low-pressure-drop screens, and fundamental mechanisms associated with enhanced Hg-oxidation on SCR catalysts. Data obtained in this work will be provided to Niksa Energy Associates (NES) and Reaction Engineering International (REI) to develop and improve models to predict mercury speciation in full-scale boilers, burning different coal types, ranging from sub-bituminous to high-volatile bituminous coals. Where necessary, SRI will develop semi-empirical mechanistic model(s) describing the mechanisms associated with catalysis enhanced mercury oxidation. Results from the project will contribute to a greater understanding of mercury oxidation in boilers.

## Executive Summary

The Catalyst Research Test Facility (CRTF) continues to be used to derive fundamental kinetic information about each catalyst and catalyst material investigated for mercury oxidation and capture. The Catalyst Research Test Facility is described and illustrated in this quarterly report. At the core of the CRTF is an extensive flue-gas simulation, gas flow, and metering system. The catalyst sits on a quartz frit that traverses the diameter of a 1.5" quartz reaction chamber, through which the entire gas flow must pass. The CRTF simulates clean (no particles) flue gas with all the major flue-gas species present, including CO, CO<sub>2</sub>, H<sub>2</sub>O, O<sub>2</sub>, N<sub>2</sub>, HCl, NO, SO<sub>2</sub>, SO<sub>3</sub>, and Hg<sup>0</sup>, in concentrations that exist in the flue gases of existing power plants, burning specific coal types.

The simulated flue gas is originated from compressed gas cylinders. The gases from the cylinders are then mixed to known concentrations by use of precision mass-flow controllers. Evaporating liquid water generates the appropriate moisture content in the gas stream, and mercury is added to the system via a mercury-soaked porous-ceramic tube within an excess-volume chamber. The simulated flue-gas stream is well mixed and preheated before entering the reaction chamber. A 3"-diameter tube furnace heats the 3-ft reaction chamber, and a 1½"-tubular reactor carries the gases through the furnace and holds the catalyst samples.

Bench-scale carbon-catalyst tests were conducted in the first quarter of 2004 to obtain kinetic rates of mercury oxidation and sorption for different forms of carbon. The current quarterly report provides a more extensive quantitative analysis of the data obtained from the CRTF experiments on different carbon types and carbon/calcium mixtures than was presented in the last quarterly report. The procedure and basis for normalizing mercury removals, so that they could be compared on an equal residence time basis, is described. The chemisorption rate of mercury on carbon was found to be first order in mercury concentration and half order in HCl concentration, for the facility configuration investigated. The applicable temperature range of the kinetic rates obtained is from 300 °F to 700 °F, and the applicable chlorine concentration range is from 2 ppmv HCl to 250 ppmv HCl. All carbon types investigated behaved similarly with respect to Hg sorption, including the effect of temperature and chlorine concentration. Activated carbon was more effective at sorbing mercury than carbon black and unburned carbon (UBC), because the internal surface area of activated carbon is greater than the other carbon types. The synergistic relationship between Ca and C is also discussed in the report.

Next quarter, three types of SCR catalyst will be examined, plate, honeycomb, and a hybrid of these two types of catalyst. Hitachi America, Ltd. has provided the plate catalyst. Cormetech Inc. has provided the honeycomb type catalyst, and Haldor Topsoe Inc. has provided the hybrid catalyst, which is essentially a hybrid of the plate and honeycomb geometries. Each of these catalysts are commercial deNO<sub>x</sub> catalysts, currently in use in full-scale power plants. Currently, work is focusing on the impact of partial pressures of mercury and ammonia on mercury-sorption equilibrium times. Fundamental rates and mechanisms of mercury sorption and oxidation on SCR catalysts will be elucidated from the results of these experiments.

## Experimental

Figures 1 and 2 show pictures of the CRTF's quartz furnace (micro-reactor), gas-conditioning bubblers for mercury speciation and stabilization prior to mercury monitoring, flue-gas continuous emission monitors (CEMs), and gas-flow control systems. Both elemental and total mercury are measured at the outlet of the CRTF. The CRTF simulates clean (no particles) flue gas with all the major flue-gas species present, including CO, CO<sub>2</sub>, H<sub>2</sub>O, O<sub>2</sub>, N<sub>2</sub>, HCl, NO, SO<sub>2</sub>, SO<sub>3</sub>, and Hg<sup>0</sup>, in concentrations that exist in the flue gases of existing power plants, burning specific coal types. The simulated flue gas is originated from compressed-gas cylinders. The gases from the cylinders are then mixed to known concentrations by use of mass flow controllers. Evaporating liquid water generates the appropriate moisture content in the gas stream, and mercury is added to the system as elemental mercury vapor carried in a clean air stream. The simulated flue-gas stream is well mixed and preheated before entering the reaction chamber. A 3"-diameter tube furnace heats the reaction chamber, and a 1½"-tubular reactor carries the gases through the furnace and holds the catalyst samples.

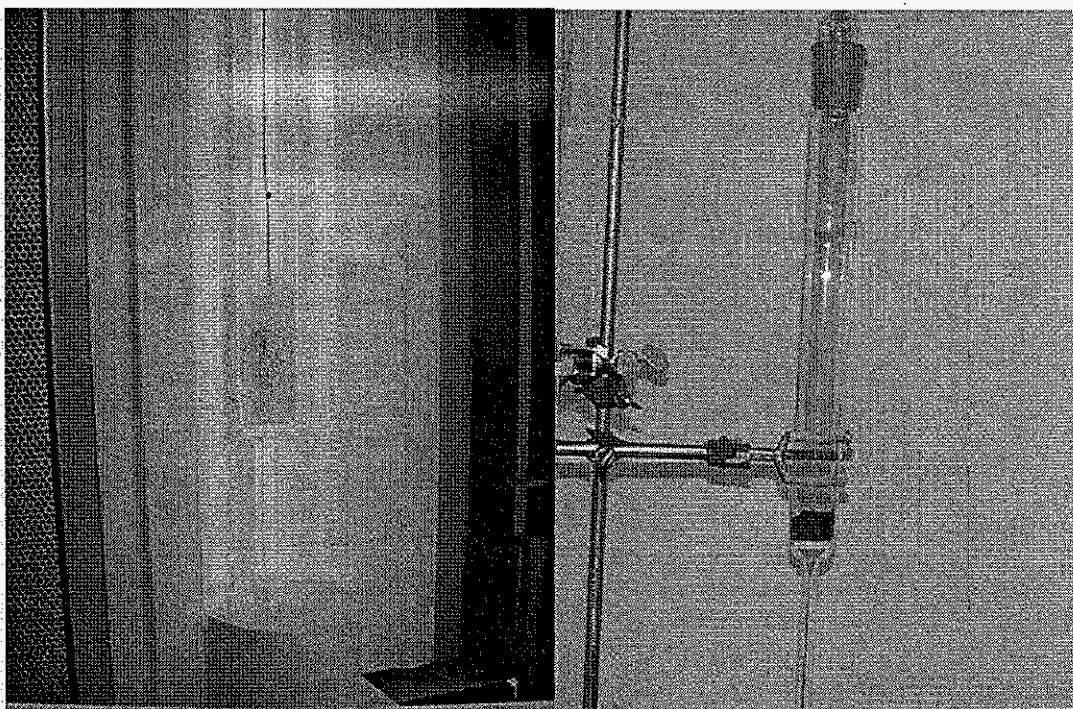
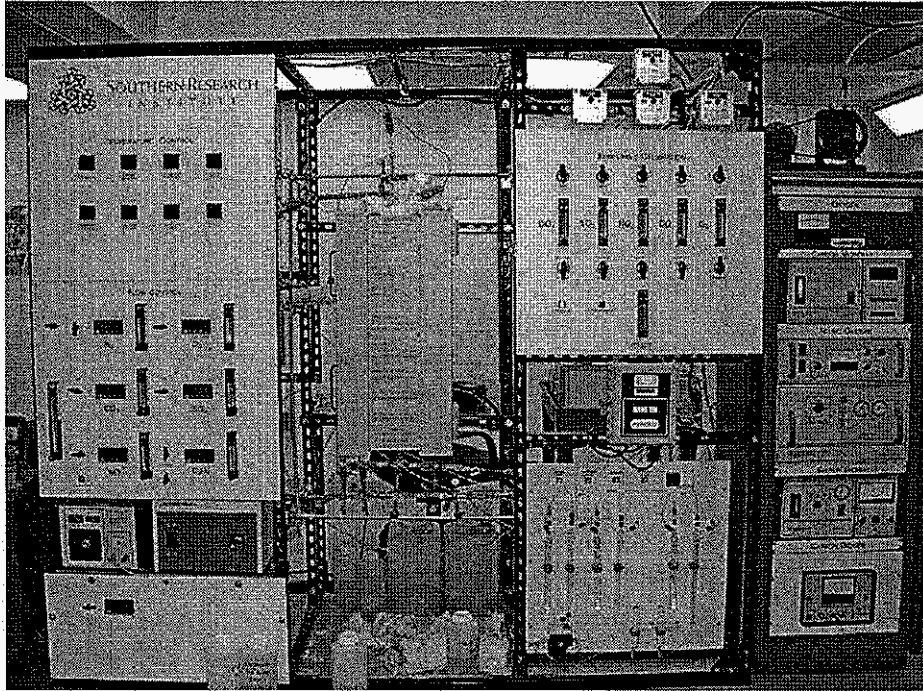
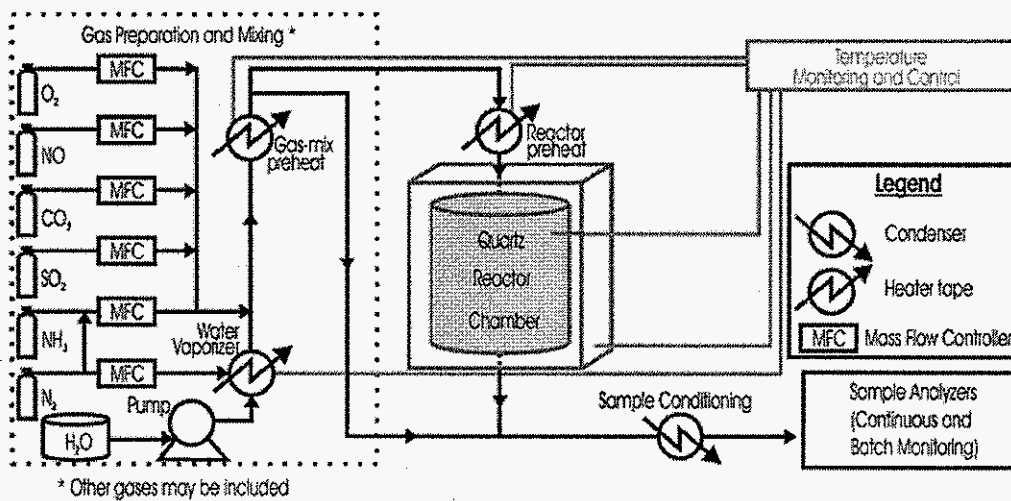


Figure 1. CRTF quartz furnace with catalyst at ~1000 °C (left) and outside of furnace (right).



**Figure 2.** CRTF furnace, gas-injection system, flue-gas CEMs, and Hg gas-conditioning system.



**Figure 3.** CRTF gas-flow system.

All heated sections of the micro-reactor within the CRTF system are made of quartz glass to limit side reactions that might occur as a result of wall effects. A semi-continuous emission monitor (SCEM) is employed to detect the mercury levels exiting the reaction chamber. A gas-conditioning system is used to convert all Hg into the elemental form, for detection using a combined gold-trap and atomic fluorescence monitor. A Tekran Model 2573A Mercury Vapor Analyzer is used to detect the elemental mercury. Along with mercury, simultaneous

measurements of oxygen, carbon dioxide, nitrogen oxides, and sulfur dioxide are made using continuous emission monitors. Figure 3 shows a schematic of the CRTF system layout.

For details concerning the validation and operation of the catalyst test facility, refer to the March 04 DOE Quarterly Report for the Calcium-Based Hg-Sorbents project conducted at Southern Research Institute [1] and the previous Quarterly Report on this project [2].

The flow rates, temperatures, and concentrations were continuously monitored and maintained throughout the test program. Catalyst samples were put into the quartz reactor with a quartz frit and quartz filter paper to prevent the sample from contaminating the gas-flow system. The bed depth of the catalysts was approximately one-third of an inch in the direction of gas flow. The precise bed depth was measured for each test. At the beginning of each experiment, a blank quartz reactor was inserted into the gas stream to collect baseline data. After sufficient data were collected, the blank reactor was removed and immediately replaced with the catalyst-packed reactor. The reactor was allowed to come to the initial 149 °C (300 °F) temperature, at which time the exposure experiment began. Subsequently, higher temperatures were investigated, up to 594 °C (1100 °F). At the conclusion of each experiment, the quartz filter paper and exposed sample was disposed of and the quartz reaction chamber was thoroughly cleaned and repacked with the next catalyst to be tested. These steps were precisely repeated for each catalyst.

## Results and Discussion

**Carbon Catalyst Test Parameters.** Four types of carbon were examined in this test matrix, unburned carbon (UBC), FGD activated carbon (AC), carbon black (CB), and soot. The UBC was obtained from separating the residual carbon from bituminous-coal flyash. This process resulted in enriching the UBC to over 50%. However, a significant amount of ash remained with the UBC, thus diluting the carbon content, which should lead to less mercury sorption than for the activated carbon.

Bituminous-coal flyash is generally higher in carbon than PRB flyash, and the UBC is primarily contained in separate carbon particles, whereas PRB-flyash UBC is generally intimately associated with its flyash mineral matter. Coal-blending and ash-injection investigations previously conducted at Southern Research Institute (SRI) have shown that UBC in ash has a significant effect on both catalytic oxidation of mercury and catalytic capture of mercury by calcium [1-6]. In fact, it was found in the previous work that the removal of both elemental and oxidized mercury by UBC was enhanced by the presence of calcium in PRB flyash and in calcium-based sorbents [4-6]. Hence, enhancement of Hg-oxidation and capture by different forms of carbon with several different forms of calcium were also examined in this test matrix.

Activated carbon was used as a comparative standard of mercury removal as well as a representative fine-pore-structure carbon. Carbon black and soot provided different types of carbon for comparison in terms of sorptive and catalytic activity. Soot is created during conditions of poor combustion in the furnace and to some extent during firing of some retrofit low-NO<sub>x</sub> technologies, such as low-NO<sub>x</sub> burners. Carbon black is derived from pyrolysis of fuel oil and is more graphitic in nature than UBC or activated carbon. As shown and discussed in the previous Quarterly Report [2], soot was found to be much less effective at sorbing mercury than activated carbon and UBC, as expected. Hence, the type of carbon generated through combustion modifications to enhance mercury removal will have a great impact on the



effectiveness of the Hg-mitigation strategy, and unburned coal char should be much more effective than unburned volatiles (i.e., soot).

The CRTF at Southern Research Institute (SRI) was used to conduct all bench-scale experiments in this work. The quartz reactor was filled with either 1.5 or 3 grams of sample in a packed bed for each test, depending on the expected rate of sorption. Ultimately, the samples were compared on a common gas-sorbent contact time, as described in the next section. This contact time was based on the average bulk residence time of gas passing through the sorbent bed rather than on a total surface area basis (considering pore diffusion times), because surface area is considered an inherent property and difference of each carbon type, and because practical application of these carbons will be compared on a cost/mass basis.

**Normalizing to Comparable Residence Time.** Each carbon type or calcium/carbon mixture tested had a different gas-contact time, which was a function of the density and compactness of material and sample. For example, activated carbon was generally very light, and thus did not pack down, thus allowing a significant void volume within the carbon bed through which the simulated flue gas could flow. On the other hand, limestone, which is very dense, packed down tight, leaving much less void volume for the gas to flow through. This difference in void volume directly affects the comparability of samples, because the gas-carbon contact time is proportional to the void volume within the material bed. In order to place the results of each carbon and carbon/calcium material on a comparable basis, the mercury removal values were adjusted to a common gas-carbon contact time (residence time), using the first order rate law.

Assuming that the reaction of mercury on the carbon sites is first order with respect to mercury concentration, and that the concentration of carbon sites is an inherent property of the system that does not change with time, then the concentration change of mercury across the reactor bed can be described by:

$$\frac{dC_{Hg}}{dt} = -kC_{Hg} \quad (1)$$

where the initial and boundary conditions are respectively:

$$@ t = 0.0 \quad C_{Hg} = C_{Hg}^o \quad \text{and} \quad @ t = \infty \quad C_{Hg} = 0.0$$

Hence, the fraction of mercury removed from the simulated flue gas as a function of time is:

$$X_{Rem} = 1 - X_{Hg} = 1 - e^{-\alpha t} \quad (2)$$

where  $\alpha$  is a constant, independent of time and the fraction of mercury removed. A value of  $\alpha$  was determined for each test condition, based on the residence time and fraction of mercury removed. Then, using that calculated- $\alpha$  value, the fraction of mercury removed was normalized for all conditions to a consistent residence time of 0.12 seconds, which was a calculated average of gas-carbon contact times for all experiments conducted in this specific investigation. This was a reasonable approach, because the total range of residence times measured was between 0.08 and 0.21 seconds.



The residence times were determined for each condition by dividing the bed-void volume by the gas flow rate through the bed. The void volume was obtained for each condition by subtracting the total particle volume from the total volume taken up by the carbon (or other powder) in the reactor bed, using the following particle densities for each material (see Table 1).

**Table 1.** Particle densities and surface areas for carbons and limes tested in CRF.

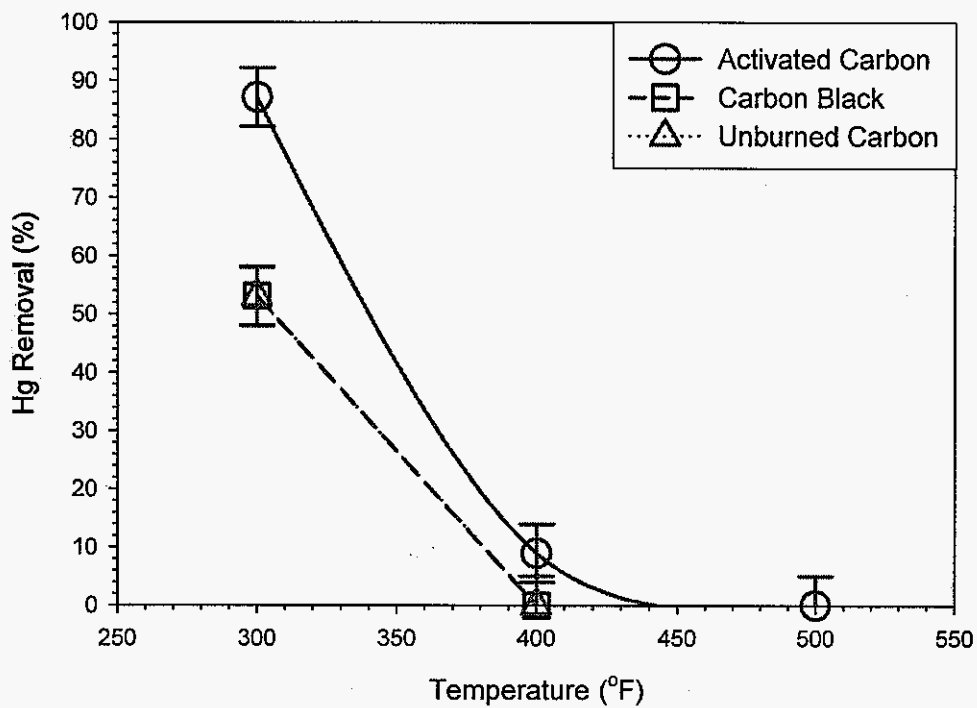
Powder Type	*Particle Density (g/cc)	BET Surface Area (m <sup>2</sup> /g)
Activated Carbon	0.77 +/- 0.22	600
Hydrated Lime	~2.2	18
Limestone	2.2 – 2.8	---
Carbon Black	~0.75	120
Unburned Carbon	~0.76	---
Soot	---	62

\*Values provided by manufacturer or supplier.

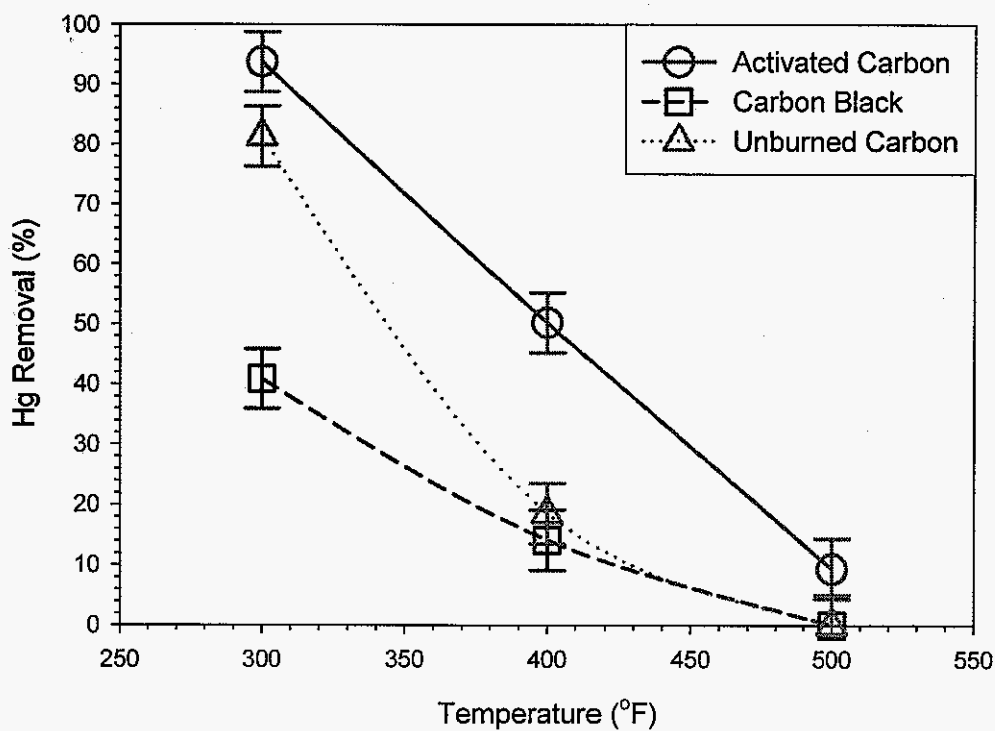
**Relevance to Full-Scale Residence Times.** The flue-gas contact time with the baghouse dust cake in full-scale baghouses ranges from approximately 0.09 seconds to 0.33 seconds, for the range of baghouse technologies and applications that exist in the United States, from reverse-gas and shaker-baghouses to COHPAC pulse-jet baghouses. Thus, the 0.12 seconds of gas/sorbent contact time in the CRF is within the range of full-scale baghouses, albeit on the low end of range. Furthermore, full-scale dust cakes are a mixture of carbon and flyash when activated carbon is injected. The inclusion of fly ash adds mostly inert material (i.e. silica, alumina, and iron) reducing the total concentration of carbon in the dust cake, thus effectively reducing the flue-gas contact time with the active material. Hence, the low end of the residence time range is the most appropriate to use for relevance to full-scale conditions.

**Carbon Catalyst Kinetics.** The last Quarterly Report compared the capture of mercury by four different carbon types, activated carbon, carbon black, unburned carbon (UBC), and acetylene soot (used to represent the nature of soot in general). The comparisons made were qualitative. It was found that UBC and activated carbon were similar in reactivity and yielded more mercury capture than carbon black or soot. Soot, although possessing a moderate measured surface area when loosely packed, is relatively inert and less reactive than other carbons. Soot, even though composed of long-chain polymers, has few nodes or active carbon sites where reactions could take place. In general, soot is difficult to oxidize once formed. The qualitative results from last quarter indicate that soot is also less reactive with mercury. These Hg-carbon data have been quantitatively processed this quarter, and further information has been extracted therefrom.

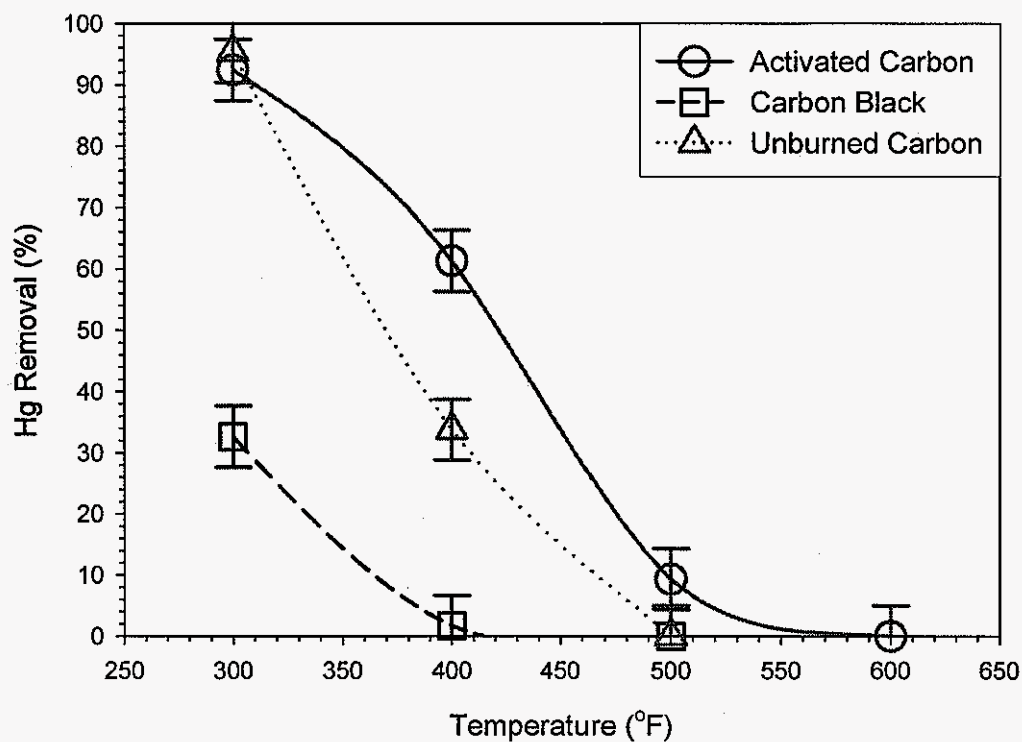
Figures 4-7 illustrate that mercury capture was much more effective at 300 °F than at higher temperatures. In addition, mercury removal was more effective with higher HCl concentrations, as discussed in the last Quarterly Report [2]. While the activated carbon was most effective at removing mercury, the UBC, with a smaller internal surface area (see Table 3), was also effective at removing mercury.



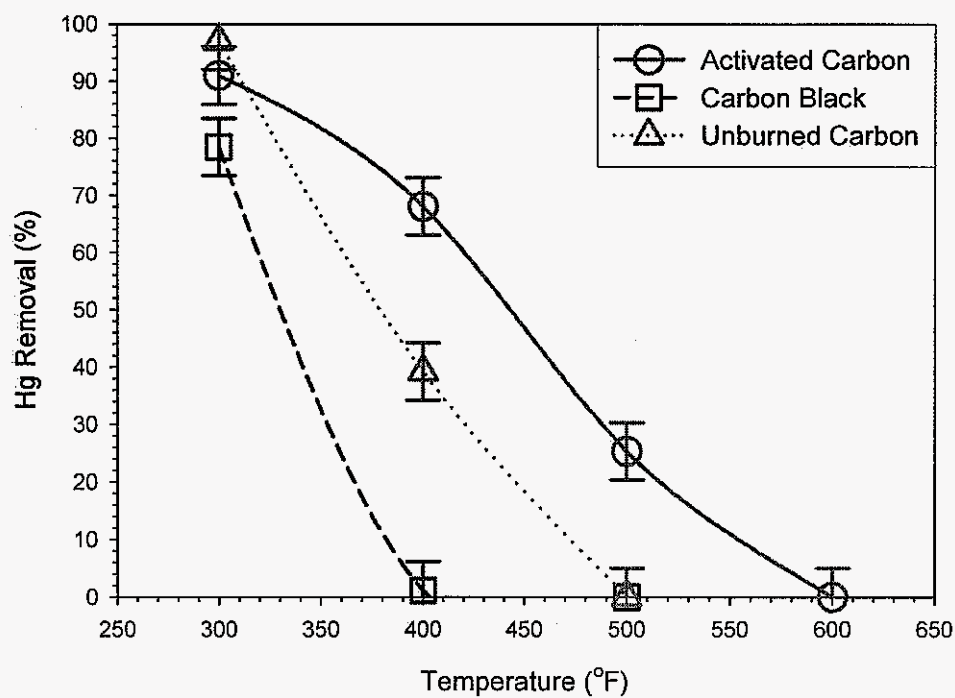
**Figure 4.** Three C-types compared in simulated flue gas with 2 ppmv HCl.



**Figure 5.** Three C-types compared in simulated flue gas with 50 ppmv HCl.



**Figure 6.** Three C-types compared in simulated flue gas with 100 ppmv HCl.



**Figure 7.** Three C-types compared in simulated flue gas with 250 ppmv HCl.

As discussed in the previous report [2], the separation between measured total mercury and measured elemental mercury was small and changed little, regardless of the flue-gas condition or bed material. Hence, it is not possible to directly isolate and consider the oxidized mercury separate from the removal data. However, the mechanisms by which mercury is oxidized and removed from flue gas are related. The first step in mercury oxidation in the duct of a coal-fired-boiler back pass is for HCl to chemisorb onto UBC in the ash particles, releasing the hydrogen and leaving chlorinated carbon sites. Mercury then reacts with the chlorinated carbon sites to form HgCl on the surface of the carbon sites, possibly followed by reaction with another chlorinated carbon site to form HgCl<sub>2</sub>. In any case, following oxidation of the mercury, the HgCl<sub>x</sub> may desorb back into the flue gas. The abundance of available and open carbon sites determines whether or not the mercury stays adsorbed or quickly desorbs. If there is an abundance of carbon, then the mercury adsorption will be much quicker than desorption, resulting in a net mercury removal. If carbon sites are scarce, desorption may be as rapid as adsorption, in which case very little mercury removal will occur, but significant mercury oxidation may take place.

Since the mercury oxidation pathway is intimately linked with the mercury adsorption process, the removal data taken in the CRTF can be used to develop quantitative information regarding mercury oxidation, as well as mercury capture. To this end, quantitative reaction constants for mercury adsorption were derived for each of the three major carbon types investigated in the CRTF, activated carbon, carbon black, and unburned carbon (UBC). The reaction of mercury with chlorinated carbon sites is first order with respect to mercury concentration. The order of the reaction in terms of HCl in the flue gas was unknown, since this depends on the process of forming chlorinated carbon sites, prior to reaction with mercury. Hence, the following equation was used to describe the reaction rate:

$$\frac{dC_{Hg}}{dt} = -k_{Hg,HCl} C_{Hg} C_{HCl}^n \quad (3)$$

where  $C_{Hg}$  and  $C_{HCl}$  represent the concentration (ppmv) of elemental mercury and hydrochloric-acid vapor in the simulated flue gas. The order of the reaction in terms of HCl was determined from the data to be  $n = 0.5$ , which is appropriate for the chlorine deposition process involved. However, this value (i.e.,  $n = 0.5$ ) was not speculated prior to determination by fitting the data. The Arrhenius law was used to describe the dependence of the rate constant on temperature:

$$k_{Hg,HCl} = A e^{-E_a/RT} \quad (1/\text{ppmv.s}) \quad (4)$$

The chlorine order of  $n = 0.5$  was found to work for all three carbon types. The pre-exponential factor,  $A$  (1/ppmv.s), and the activation energy,  $E_a$  (J/mol), are presented in Table 4, for each of the three carbon types. Notice the negative activation energy, which is necessary because the sorption driven Hg-oxidation reaction rate increases with decreasing temperature.

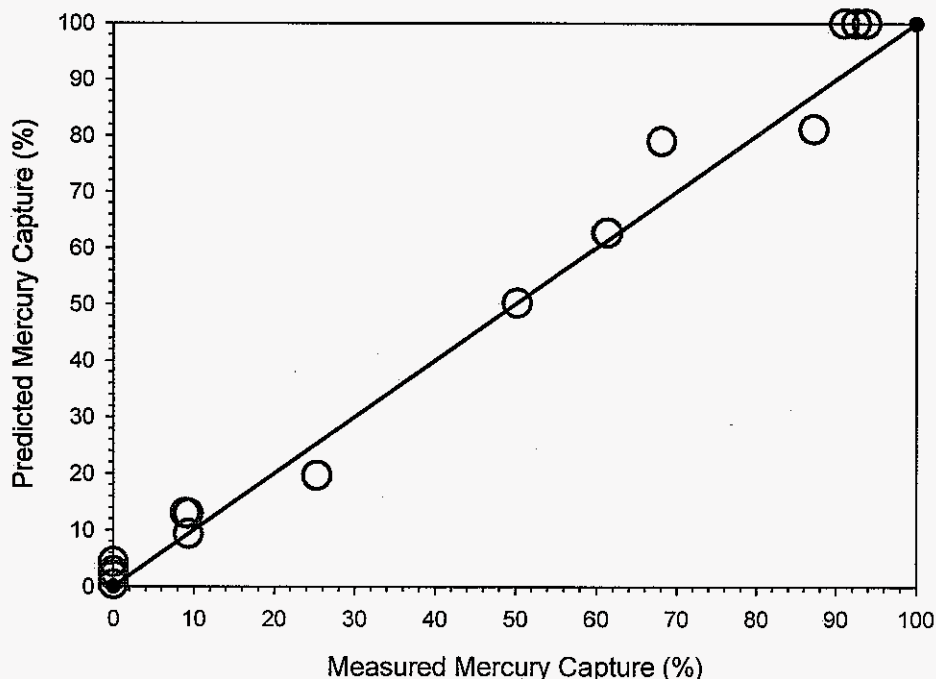
**Table 4.** Activation energies and rate constants for the three major carbon types.

Parameter	Activated Carbon	Carbon Black	Unburned Carbon
$A$ (1/ppmv.s)	$5.39 \times 10^{-9}$	$1.45 \times 10^{-5}$	$2.80 \times 10^{-8}$
$E_a$ (J/mol)	$-7.48 \times 10^4$	$-3.74 \times 10^4$	$-6.34 \times 10^4$

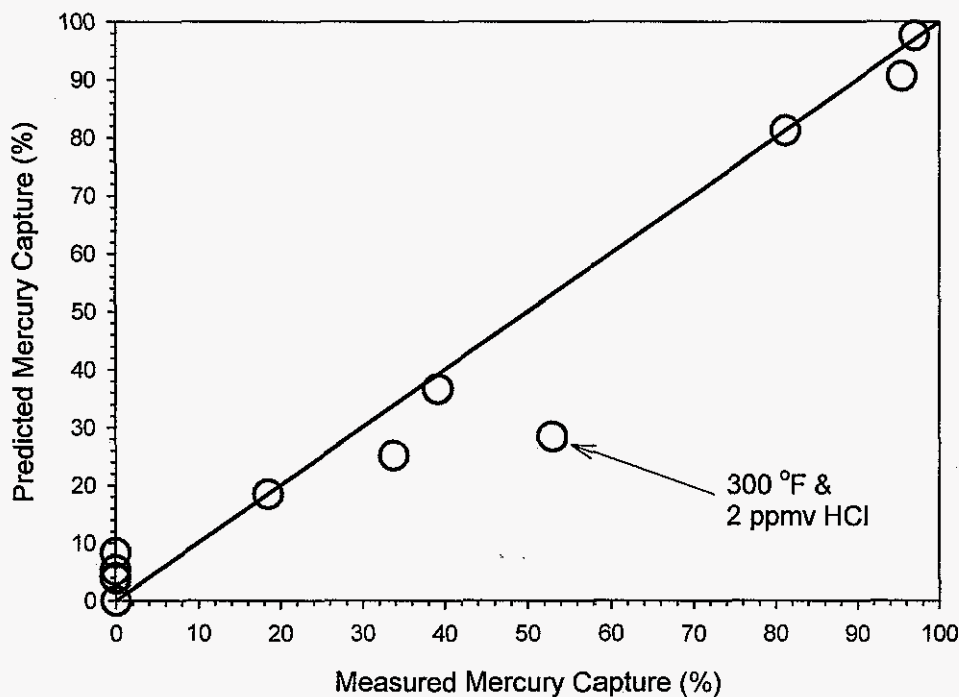
The reaction rate equation and constants shown in Eqs. 3 and 4 and Table 4 were used to predict all of the data measured in the CRTF with activated carbon and UBC. There was insufficient data on carbon black to make a comparison between predicted and measured values meaningful. As shown in Figs. 9 and 10, the model predicts the measured data effectively. The one data point in Fig. 10 that appears to be an outlier was taken under the lowest temperature and chlorine concentration condition, as annotated on the graph (see Fig. 10). At the lowest temperatures and chlorine levels, sorption mechanisms in the system other than the process investigated may begin to play a significant role in terms of measured mercury removal.

The carbons behaved similarly with respect to mercury sorption. The major difference between carbon types is the internal surface area of each carbon. Activated carbon, with the highest internal surface area (see Table 3), was most effective at sorbing mercury.

The model presented in Eqs. 3 and 4 and rate constants provided in Table 4 describe rate of sorption of mercury on three different types of carbon as a function of temperature, time, and flue-gas chlorine content. However, the sorption rates obtained are also relevant to mercury oxidation, since the Hg-oxidation rate is controlled by carbon catalysis, involving both sorption of HCl to form chlorinated carbon sites and the desorption of  $\text{HgCl}_x$  from the carbon surface. The packed bed environment for carbon tests is probably less likely to promote desorption of oxidized mercury back into the flue gas than the free-moving unburned carbon particles contained in a typical coal-derived flue gas. Nevertheless, the rate of elemental mercury adsorption onto the carbon (i.e., chemisorption onto chlorinated carbon sites) should be the same. Hence, the rate parameters derived in this work should supply the rate of the sorption step, which in many cases will dominate the oxidation process and rate. Future work will investigate the use of these rates to predict mercury oxidation within actual flue gas, produced under full-scale conditions.

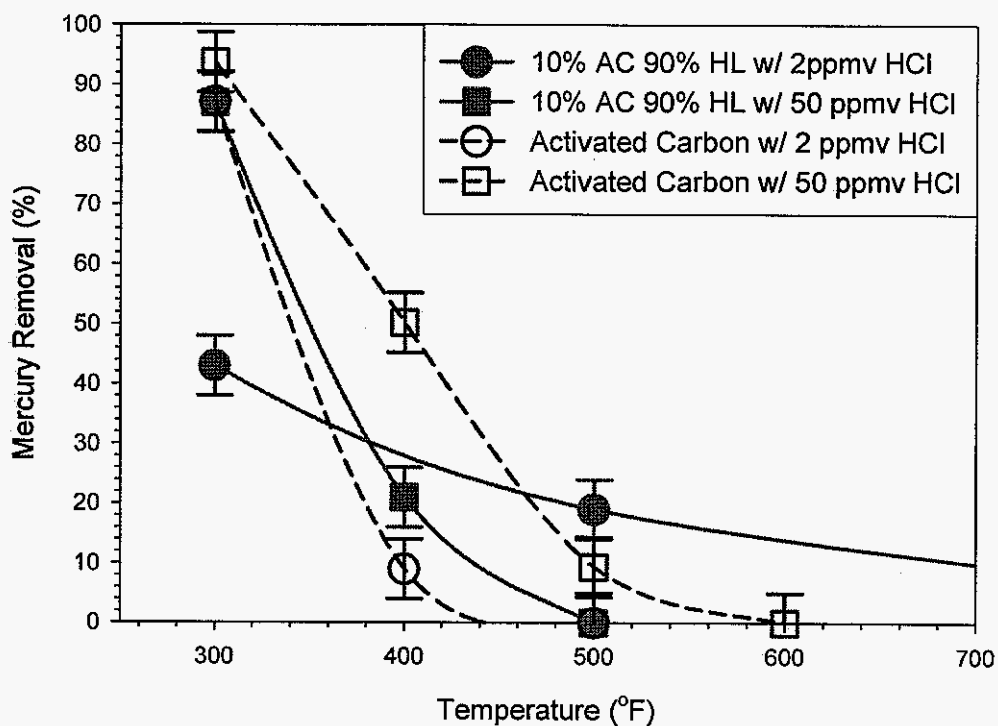


**Figure 8.** Predicted vs measured mercury capture on activated carbon.

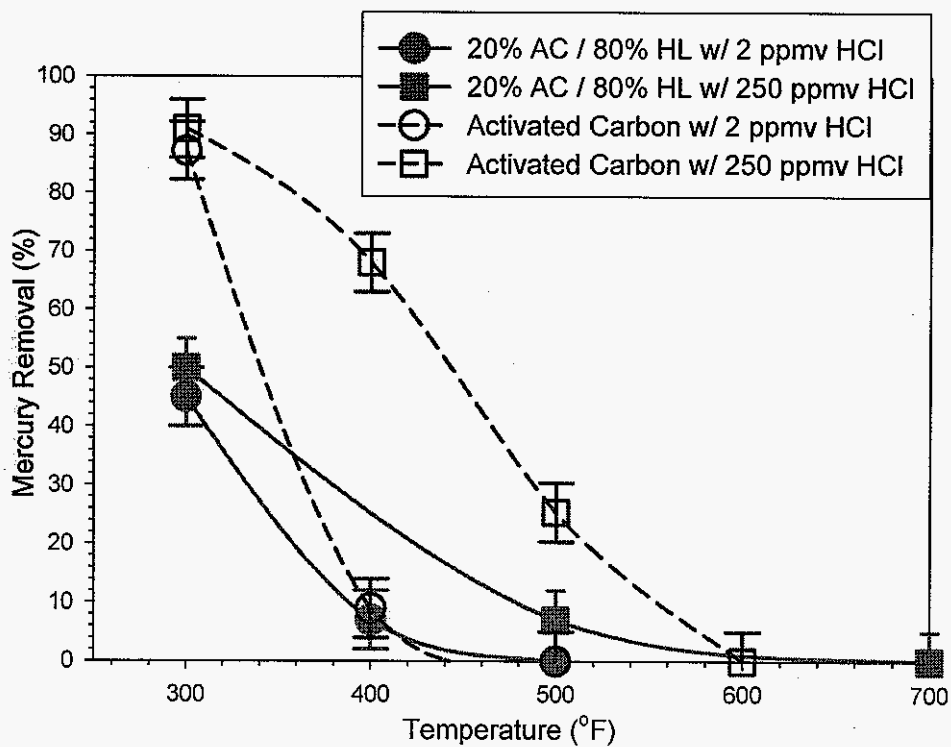


**Figure 9.** Predicted vs measured mercury capture on unburned carbon.

**Examination of Carbon/Calcium Catalytic Synergism.** Full- and pilot-scale data have shown that mercury capture is enhanced when both calcium and carbon are present, either in the disperse phase or in a filter cake [3-6]. A possible mechanism whereby calcium enhances mercury capture in the presence of carbon is by chemisorbing oxidized mercury prior to desorption from active carbon sites, thus eliminating the desorption step following mercury oxidation on chlorinated carbon sites. As shown in Figs. 11 and 12, mixing calcium with carbon did not appear to enhance the capture of mercury in the CRTF at 300 °F. This is expected, based on the theory proposed, since little mercury desorption took place in the CRTF tests, even for the carbon-only experiments conducted in this investigation. However, it should be remembered that the sorbents are compared on a common bed-residence time for each sorbent. Hence, the 10% C/ 90% hydrated-lime sorbent, only exposed the simulated flue gas to approximately 10% of the carbon used in the pure activated-carbon tests. Nevertheless, longer-exposure-time (breakthrough) tests would probably see a benefit of adding calcium to the bed material, by significantly extending the time to breakthrough. The lack of desorption results observed in the CRTF experiments differs from full- and pilot-scale data, thus emphasizing the difference between actual flue-gas conditions and bench- or laboratory-scale experiments.



**Figure 10.** Activated carbon compared with 10% AC/90% HL processed sorbent mixture.



**Figure 11.** Activated carbon compared with 20% AC/80% HL processed sorbent mixture.



As shown in Fig. 10, mercury sorption was more effective for activated carbon than for the C/Ca sorbent at 300 °F. However, the C/Ca sorbents appeared to be more effective at higher temperatures. This is reasonable, since the desorption step is more dominant and the sorption step less dominant as temperature increases. Also, the role of calcium in the synergistic mercury capture process is thought to prevent mercury desorption once the mercury has been simultaneously adsorbed and oxidized (i.e., chemisorption) on chlorinated carbon sites.

Figure 11 illustrates similar behavior for the 20% C/80% hydrated lime sorbent. Figure 11 illustrates the comparison of mercury capture at 2 and 250 ppmv HCl, whereas Fig. 10 illustrates the comparison of Hg capture at 2 and 50 ppmv HCl. At these high chlorine concentrations, activated carbon appears to be much more effective at sorbing mercury than Ca/C sorbents, even at the higher temperatures. The Ca/C sorbent appears to be much less effected by the presence of such high levels of chlorine. Higher levels of chlorine in the flue gas induce higher levels of chlorine on the carbon surface, although orders of magnitude lower than the concentration of chlorine in the flue gas, and the higher fraction of chlorinated-carbon sites significantly increases mercury chemisorption. The lower carbon concentration of the calcium-based sorbents limits the number of chlorinated carbon sites that can be formed per unit mass of sorbent. However, the presence of calcium may enhance the chances of oxidized mercury remaining adsorbed once oxidized.

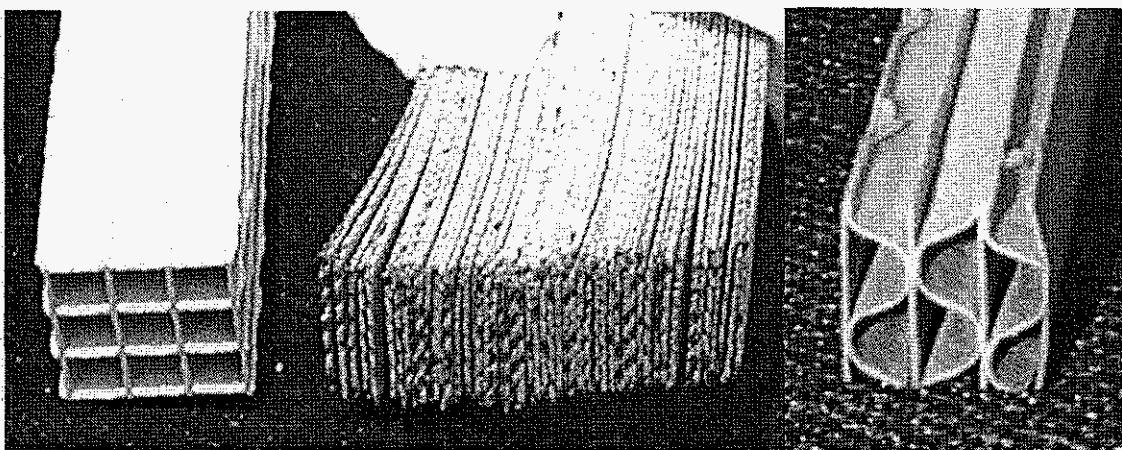
As discussed elsewhere [1-2], activated carbon was the most effective carbon in calcium/carbon sorbents and limestone behaved similarly to hydrated lime.

## Conclusions

The sorption of mercury by three different carbon types, activated carbon, carbon black, and unburned carbon from coal, have been shown to adsorb mercury according to a first order reaction in mercury, across a temperature range of 300 to 700 °F. Mercury sorption on carbon was found to be half order with respect to the concentration of HCl in the flue gas, which is reflective of the mechanism of adsorption of HCl on carbon sites to form  $C\cdot Cl^\cdot$  sites. Rate constants and reaction mechanisms describing the rate of mercury sorption on three carbon types were obtained and validated to be effective at predicting the data obtained in this work. Further evidence was found to describe the synergistic enhancement of mercury capture on carbon by calcium. In accordance with previous findings, calcium enhances mercury capture by slowing down or eliminating desorption, after mercury has been oxidized by chlorinated carbon sites.

## Future Work

Pictures of the three commercial SCR catalysts are shown in Fig. 12. Next quarter, these three commercial catalysts will be tested and compared, both to assess the relative difference between these catalysts in terms of potential for oxidizing mercury and generating  $SO_3$ , and to discover the fundamental mechanisms responsible for mercury oxidation across SCR catalysts. From mercury and ammonia partial pressure experiments, mercury sorption time constants and rates will be obtained, which will lead to the development of a clear understanding of mercury oxidation across SCR catalysts in full-scale boiler systems.



**Figure 12.** From left to right, honeycomb, plate, and hybrid SCR catalysts.

## References

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