DEVELOPMENT OF A PROCESS FOR COMBINED REMOVAL OF MERCURY AND NITRIC OXIDES FROM FLUE GAS

Marshall H. Mendelsohn
C. David Livengood

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

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OF MERCURY AND NITRIC OXIDES FROM FLUE GAS

M.H. Mendelsohn
C.D. Livengood
Argonne National Laboratory
9700 S. Cass Avenue
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Abstract

Continuing concern about the effects of mercury in the environment may lead to requirements for
the control of mercury emissions from coal-fired power plants. If such controls are mandated, the
use of existing flue-gas cleanup systems, such as wet scrubbers currently employed for flue-gas
desulfurization, would be desirable. Such scrubbers have been shown to be effective for capturing
oxidized forms of mercury, but cannot capture the very insoluble elemental mercury (Hg⁰) that can
form a significant fraction of the total emissions. At Argonne National Laboratory, we have
proposed and tested a concept for enhancing removal of Hg⁰, as well as nitric oxide, through
introduction of an oxidizing agent into the flue gas upstream of a scrubber, which readily absorbs
the soluble reaction products. When a dilute solution of this agent was introduced into a gas stream
containing Hg⁰ and other typical flue-gas species at 300°F, we found that about 100% of the mercury
was removed from the gas phase and recovered in process liquids. At the same time, approximately
80% of the nitric oxide was removed. The effect of sulfur dioxide on this process was also
investigated and the results showed that it had only minor negative effects. Preliminary economic
projections based on the results to date indicate that the chemical cost for nitric oxide oxidation
could be less than $5,000/ton removed, while for Hg⁰ oxidation it would be less than $25,000/lb
removed. Testing of the process at a pilot-plant scale is needed to further refine the concept and
address a number of engineering questions. Such tests have been proposed in collaboration with an
industrial partner and could start in 2001.

Introduction

Mercury is one of many trace elements that occur naturally in coal at very low levels. While the
concentrations are highly variable even within a given coal type, typical values are only on the order
of 0.2 ppm. Nevertheless, the large amount of coal that is used as fuel, particularly in the electric
utility industry, has led the U.S. Environmental Protection Agency (EPA) to conclude that coal-fired
utility boilers generate on the order of 1/3 of the total anthropogenic mercury emissions in the U.S.
Those utility sources are widely dispersed and seem extremely dilute by typical air-pollution
standards. However, coal-fired utility plants represent one of the few remaining unregulated sources
doing mercury in the U.S.

Mercury has become a significant environmental concern for several reasons. Once emitted into the
atmosphere, mercury can have a lifetime of many months or even years and is therefore subject to
long-range transport. Thus, its control is a national and even international issue. Once deposited in the terrestrial/aquatic environment, the mercury concentration in organisms can be magnified many times through the process of bioaccumulation until it becomes a potent neurotoxin for organisms near the top of the food chain (including man). Although the relationships between exposure and health effects are still topics of considerable debate, there is significant pressure to regulate all sources of mercury emissions. The EPA has committed to making a decision on whether to regulate utility mercury emissions before the end of 2000 and many informed observers feel that some degree of control will be required.

If control of mercury emissions is required, the means to achieve it are likely to be both varied and expensive. Some degree of removal (typically on the order of 1/3) can be obtained through coal preparation ("washing"). However, additional removal would have to be obtained in a flue-gas cleanup (FGC) system. Mercury is a particular problem in that regard because it belongs to a group of elements and compounds denoted as Class III, which remains primarily in the vapor phase within the boiler and subsequent FGC system. It can also exist as several chemical species. In particular, the presence of chlorine in coal means that mercury can be found in both the elemental and oxidized forms, with the relative amounts depending on such factors as the ratio of chlorine to mercury, the gas temperature, and the gas residence time at various temperatures. At this time, it appears that elemental mercury (Hg^0) and mercuric chloride (HgCl_2) are the most significant species for control considerations. The much greater solubility of HgCl_2 relative to Hg^0 is particularly important in wet scrubbing applications.

In order to minimize costs and decrease operational complexity, it would be desirable to utilize existing FGC systems in an integrated (multi-pollutant) process controlling mercury and other pollutants such as particulate matter (PM), sulfur dioxide (SO_2), and/or nitrogen oxides (NO_x). However, data from field tests at utility plants with typical FGC systems have given widely varying results. Combustion modifications (for NO_x control) have little if any effect on mercury emissions. Particulate-matter collectors have not been shown to be very effective at capturing mercury except in a few cases where the fly ash has an (unexplained) affinity for mercury. The performance of wet scrubbers installed for flue-gas desulfurization (FGD) has been highly variable, with removal results ranging from about 10% to over 80%. This variation may be due to changes in the relative amounts of Hg^0 and HgCl_2, which vary considerably with system characteristics and coal types.

Means to enhance the ability of existing systems to control mercury could take several forms. The most commonly cited approach would be the injection of activated carbon into the flue-gas duct upstream of a PM collector. However, the very large amounts of carbon that must be used give costs estimated to range from about $25,000/lb - $70,000/lb of mercury removed and could compromise the commercial value of the fly ash. These costs can be contrasted with those for nitrogen oxides control, which tend to be less than $5000/ton of pollutant removed (and that is usually considered expensive).

Argonne has been investigating a different approach to improving the mercury control performance of FGD systems. In particular, we have studied the performance of various oxidizing agents that could enhance the capture of Hg^0 in wet scrubber systems by altering the chemical form of the mercury to a water-soluble oxidized species. Since it appears that the naturally occurring oxidized species are already being effectively captured by wet scrubbers, this approach could lead to nearly
100% elimination of mercury emissions. In addition, some of the agents studied have shown the ability to oxidize nitric oxide (NO), the principal NO\textsubscript{x} species, as well and could therefore provide the basis for a combined mercury/NO\textsubscript{x}/SO\textsubscript{2} control process. In this paper, we give recent laboratory results obtained at Argonne and describe plans for pilot-scale tests of a process based on duct injection of an oxidizing agent upstream of a wet FGD scrubber.

**Background**

Argonne's recent research on mercury control has focused on improving the capture of Hg\textsuperscript{0} in wet scrubbing systems.\textsuperscript{4} Initially, a laboratory-scale scrubber was used to study Hg\textsuperscript{0} removal by water, a calcium hydroxide solution, or a calcium hydroxide plus potassium polysulfide solution as the scrubbing liquor. Several types of packing in the scrubber were also investigated. Very little Hg\textsuperscript{0} removal was found in any of these cases and the program emphasis was shifted to the study of techniques for changing the chemical form of mercury in order to produce a more soluble species.

Tests were conducted in the scrubber with several additives that combine strong oxidizing properties with relatively high vapor pressures. Promising results obtained with chlorine and the apparent significance of coal-chloride concentrations for mercury capture led to further tests with a strongly oxidizing chloric-acid (HClO\textsubscript{3}) solution marketed by Olin Corporation under the name NOXSORB\textsuperscript{TM}. With a simulated flue gas containing SO\textsubscript{2}, NO, and carbon dioxide (CO\textsubscript{2}) in addition to Hg\textsuperscript{0}, removals approaching 100\% were obtained for both NO and Hg\textsuperscript{0}. An apparent correlation between the two removals indicated that the mercury could be reacting with a product or intermediate of the NO removal process. Subsequent tests with and without NO in the flue gas suggested that NO was not solely responsible for Hg\textsuperscript{0} removal by NOXSORB\textsuperscript{TM}, but it seemed to promote additional reactions that enhanced the capture of mercury. The results of those tests indicated that not only could effective mercury removal be achieved via this approach, but that a combined process that also removed NO might be feasible.

The interactions between Hg\textsuperscript{0}, several oxidizing additives, and the various flue-gas species were studied further in a series of experiments using bubblers.\textsuperscript{5} In those experiments, a simulated flue gas was first passed through a bubbler containing a solution of the reactive chemical to be tested and then through two bubblers in series containing distilled water. The degree of Hg\textsuperscript{0} conversion was determined by comparing the amount of mercury found in the bubbler solutions with the total amount of Hg\textsuperscript{0} fed in the flue gas. Mercury removal with chloric-acid solutions appeared to increase with increasing chloric-acid concentration regardless of gas composition. In addition, the presence of NO greatly increased Hg\textsuperscript{0} removal. In this case, the important gas-phase reaction may involve nitric acid (HNO\textsubscript{3}) formed from the reaction of NO and chloric acid. The presence of SO\textsubscript{2} decreased Hg\textsuperscript{0} removal somewhat, but it remained intermediate to that with and without NO.

Additional tests that utilized different degrees of gas-liquid contacting in the bubblers indicated that both gas-gas and gas-liquid reactions were operating, with the gas-phase reactions involving NO becoming increasingly important as the solute concentration was raised. In that situation, some degree of NO removal might also be obtained as part of the reaction mechanism.

The cumulative results of the scrubber and bubbler studies indicated that even higher Hg\textsuperscript{0} removals might be obtained if more of the reagent was made available for reactions in the gas phase. For this
reason, a series of "duct injection" experiments was carried out using an ultrasonic atomizer to inject small droplets of the oxidizing solutions into a flowing gas stream containing Hg\textsuperscript{0} vapor and other typical flue-gas components. A downstream scrubber was used to collect the soluble reaction products. This configuration represents a feasible retrofit for many wet FGD systems. A simplified diagram of the experimental apparatus is shown in Figure 1.

Using the concentrated NOXSORB\textsuperscript{™} solution (which contains about 18\% HClO\textsubscript{3} and 22\% NaClO\textsubscript{3}) as the stock solution, five different solution strengths were prepared for testing. These diluted solutions ranged from 1\% to 40\% of the concentrated solution. Removal results for the tests conducted at room temperature are given in Table 1 and show that significant simultaneous removals are possible in this approach. Other tests verified that the Hg\textsuperscript{0} removal performance was significantly enhanced by the presence of NO (which agreed with results obtained in our earlier bubbler tests) and that SO\textsubscript{2} appeared not to degrade Hg\textsuperscript{0} removal.

Figure 1  Diagram of Experimental Apparatus for Atomization Tests
In order to investigate the effects of flue-gas temperature on reagent utilization, a few tests were performed using the ultrasonic atomizer in which the inlet gas stream and the reaction chamber were heated to between 300 and 350°F. The results are summarized in Table 2 for three different combinations of variables. By comparing the results in Table 2 with those for a similar NOXSORBTM concentration in Table 1, one can see an approximate four- to six-fold increase in the Hg⁰ removal performance at the elevated temperatures. Up to a ten-fold increase was observed in NO removal performance for the 4% NOXSORBTM solution.

Analysis of these results led to the development of a new injection method for the oxidizing reagent. In this approach, the reagent solution was vaporized prior to injection into the flue-gas stream in order to maximize its availability for gas-phase reactions. Experiments utilizing this method are described in the following section.

Table 2 Hg⁰ and NO Removals Using an Elevated Reaction Temperature

<table>
<thead>
<tr>
<th>Atomizer Solution</th>
<th>Reaction Zone Temperature (°F)</th>
<th>Hg⁰ Removed (%)</th>
<th>NO Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1% NOXSORB™</td>
<td>300°F</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>1% NOXSORB™</td>
<td>350°F</td>
<td>56</td>
<td>8</td>
</tr>
<tr>
<td>4% NOXSORB™</td>
<td>300°F</td>
<td>96</td>
<td>40-60</td>
</tr>
</tbody>
</table>

* for this test L/G = 18; *b for this test L/G = 4.

Recent Laboratory Results

Experimental Setup and Procedures

A simplified diagram depicting the experimental apparatus used for the “vapor injection” tests is shown in Figure 2. The majority of the apparatus is identical to that used for the atomization tests.
described above. However, the vapor injection point was upstream of the previously used atomizer injection point so that the effective reaction zone was longer (greater residence time) for a given length of duct.

The vaporizer consisted of approximately 10 ft of 1/8 in. diameter stainless steel tubing coiled inside a glass vessel containing high-temperature oil. The oil was heated to about 200°C (~400°F) and solution containing the oxidizing agent was pumped through the coil to give almost 100% vaporization of the incoming solution. This vapor was then passed through an insulated Teflon line to join the incoming simulated flue gas at a point about 3 in. upstream of the glass reaction vessel ("duct").

The source of Hg\(^0\) was a calibrated and certified permeation tube from VICI Metronics, which was placed in a constant-temperature water bath controlled to ± 0.5°C. For the majority of the tests, the Hg\(^0\) concentration in the gas was about 40 µg/Nm\(^3\). Bottled, high-purity (99.998%) nitrogen gas (N\(_2\)) flowed around the permeation tube to produce a gas stream with a constant concentration of Hg\(^0\). When other flue-gas components were desired, this stream was combined with another gas stream containing N\(_2\) and components such as CO\(_2\), NO, and SO\(_2\). Carbon dioxide was used as a carrier gas for the NO. Carbon dioxide, NO, and SO\(_2\) were obtained from bottled gases without further purification. The nominal purities for these gases were as follows: CO\(_2\), 99.5%; NO, >99.0%; and SO\(_2\), >99.98%.

![Diagram](image-url)  
**Figure 2** Diagram of Experimental Apparatus for Vapor Injection Tests
After blending, the initial gas composition was checked with standard flue-gas analyzers from Beckman instruments: oxygen, Model 755 Oxygen Analyzer; CO₂, Model 864 Infrared Analyzer; NO, Model 951A NO/NOₓ Analyzer; and SO₂, Model 865 Infrared Analyzer. Typical concentrations of the various gas components were as follows: oxygen, 0-1%; CO₂, 15-20%; NO, 300-450 ppm; and SO₂, 750-1500 ppm. The gas temperature was kept at about 120 to 150°C (250-300°F).

Once the feed-gas composition was measured and stabilized, a 3-way valve was turned to divert the gas from the analyzers to the inlet (feed) line. Gas flow rates ranged from about 6 LPM to 10 LPM, which gave residence times in the reaction zone ranging from 2 to 9.5 sec. Gaseous reactants and products were then directed to a bubbler ("scrubber") that contained 150 mL of a 0.15 wt% sodium hydroxide solution to remove any soluble species before exiting to the gas analyzers and a vent.

Commercial solutions of NOXSORB™ were diluted as necessary and used without further purification as the feed solutions for the vaporizer. Liquid flow rates through the vaporizer were about 2 mL/min. These flow conditions yield an L/G (liquid to gas flow rate ratio) of about 2.5 GPM/1000 cfm. Any liquid remaining at the exit of the reaction zone was collected in the liquid sump.

The test duration was typically 15 min. Following each test, liquid samples were either saved individually from the sump and the bubbler or combined into one sample for later total mercury analysis. Analyses were performed by a standard cold-vapor atomic absorption spectrophotometric method (U.S. EPA Method 7470A, SW-846). The estimated accuracy for this method is ± 10% or ± 0.02 μg/L, whichever is greater.

**Results**

Table 3 shows data for NO removal using the two different methods of introducing the chloric acid oxidizing agent. Note that in this case the reagent concentration is expressed as a weight percent of chloric acid rather than as a percent of a stock solution. A dramatic reduction in reagent consumption was observed when the oxidizing agent was vaporized into the gas phase and injected as versus injection of small droplets from the ultrasonic atomizer. Vapor injection gave about the same NO removal performance with a 20 times lower concentration of chloric acid solution.

<table>
<thead>
<tr>
<th>Chloric acid solution Concentration</th>
<th>NO Removal (%)</th>
<th>Contacting Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80 wt%</td>
<td>~50</td>
<td>Atomization</td>
</tr>
<tr>
<td>0.04 wt%</td>
<td>64</td>
<td>Vaporization</td>
</tr>
</tbody>
</table>
Similar results were obtained for Hg\textsuperscript{0} removal, as shown in Table 4. In that case, vapor injection gave about the same Hg\textsuperscript{0} removal performance as atomization with a 5 times lower chloric acid solution concentration. This again points out the potential reduction in reagent consumption when vaporization is used as an injection method.

<table>
<thead>
<tr>
<th>Chloric acid solution Concentration</th>
<th>Hg\textsuperscript{0} Removal (%)</th>
<th>Contacting Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20 wt%</td>
<td>56</td>
<td>Atomization</td>
</tr>
<tr>
<td>0.04 wt%</td>
<td>57</td>
<td>Vaporization</td>
</tr>
</tbody>
</table>

Most of the experiments conducted at Argonne used Hg\textsuperscript{0} concentrations in the synthetic flue gas of about 40 μg/Nm\textsuperscript{3}. However, results of numerous field tests on coal-fired boilers have shown that typical mercury concentrations in the flue gas are less than 10 μg/Nm\textsuperscript{3}. Several experiments were conducted to determine what, if any, effects this difference might have on the performance of the process. Table 5 gives a comparison of some of the results for three tests that were identical except for the inlet Hg\textsuperscript{0} concentration. As expected, the total amount of Hg\textsuperscript{0} removed decreased as the inlet Hg\textsuperscript{0} concentration decreased. However, what was unexpected was that the amount of Hg\textsuperscript{0} removed was greater than what would be observed for a linear decrease in proportion to the decrease in the inlet Hg\textsuperscript{0} concentration. This less than linear decrease results in an increase in the Hg\textsuperscript{0} removal performance when expressed as a percentage of the total inlet Hg\textsuperscript{0}.

<table>
<thead>
<tr>
<th>Inlet Hg\textsuperscript{0} Concentration (μg/Nm\textsuperscript{3})</th>
<th>Total amount Hg\textsuperscript{0} removed (μg)</th>
<th>Hg\textsuperscript{0} Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>1.12</td>
<td>33.1</td>
</tr>
<tr>
<td>22</td>
<td>0.83</td>
<td>40.9</td>
</tr>
<tr>
<td>9</td>
<td>0.52</td>
<td>60.5</td>
</tr>
</tbody>
</table>

The laboratory tests performed to date have been used to estimate reagent costs for Hg\textsuperscript{0} and NO removal. These costs are based on a price of $.70 per pound of NOXSORB\textsuperscript{TM} quoted by Olin Corporation. The corresponding costs for Hg\textsuperscript{0} removal are in the range of $20,000 to $25,000 per pound of mercury removed. Under similar conditions, the cost to oxidize NO would be in the range of $4,050 to $4,300 per ton of NO. Some additional costs would be incurred for solution handling and injection equipment, but these are expected to be relatively minor compared to the reagent cost. Although these costs appear to be very competitive with other technologies for control of mercury and nitrogen oxides, alternate techniques for producing chloric acid are currently being evaluated with the objective of further lowering process costs. For example, one estimate based on on-site
production of chloric acid gave Hg\textsuperscript{0} removal costs of $10,000/lb and NO removal costs of $2,000/ton.

**Process Development**

Additional laboratory work on the oxidation process is continuing to support further development of the concept. However, larger scale tests utilizing actual coal-combustion flue gas and an operating FGD system are needed to provide data for refined economic estimates and to reveal any potential operational issues. During the past year, Argonne worked with a private company in Illinois to develop a proposal for testing of the process at a pilot scale. The work would be conducted at a scrubber research facility owned by the company and would utilize a 1 MW slipstream from a nearby boiler. The goals for this project include a total Hg removal of about 90\% and an NO removal of about 80\%. Important features of the proposed tests are described below.

Because the boiler uses Illinois bituminous coal as its fuel source, we expect that the mercury in its flue gas will consist primarily of oxidized species. In order to demonstrate our Hg\textsuperscript{0} oxidation and removal technology, it is necessary to have a significant fraction of the mercury in the test stream present in the elemental form. To achieve this and to be able to vary the fraction of Hg\textsuperscript{0} in the test stream, we plan to spike the native flue gas stream with Hg\textsuperscript{0}. We plan to test two different levels of total mercury having two different ratios of Hg\textsuperscript{0} to oxidized mercury. It is important to note that the total mercury level (even after spiking) will be kept to less than 10 \(\mu\)g/Nm\textsuperscript{3}. As noted previously, a mercury concentration of less than 10 \(\mu\)g/Nm\textsuperscript{3} is typical of coal-fired systems that have been characterized thus far. Therefore, the results presented in Table 5 indicate that the performance achieved in the pilot-scale tests may well be superior to many of the tests conducted in the laboratory.

In order to assess the effectiveness of our oxidation method, we need to perform speciated mercury analyses. Because we are changing the speciation of the mercury compounds in the incoming flue gas, we require accurate measurements of the concentrations of both Hg\textsuperscript{0} and oxidized mercury fractions both before and after the injection point for the oxidizing agent. These data will allow us to directly assess the effectiveness of the oxidation method. Currently, the most widely known and utilized analytical method for mercury speciation is the “Ontario Hydro Method” (OH). The OH method is listed by the U.S. EPA as a “Preliminary Method.” Classification as a Preliminary Method means that the EPA “expects the method to work under the conditions of the applicability statement, but is uncertain without additional data on broader application.” The method is relatively expensive, but it has been found to be reliable for speciation of mercury and is proposed for our pilot-scale tests.

Another part of the mercury balance around the system will be obtained by measuring the amount of mercury that is removed in the wet scrubber. Argonne intends to measure total mercury concentrations in both the wet scrubber liquid and scrubber solids. The U.S. EPA’s Toxicity Characteristic Leaching Procedure will also be used to assure that the by-product solids produced during these tests are not hazardous and can be sold or disposed of in accordance with typical commercial practices.

In addition to the various mercury measurements described above, we intend to perform NO and NO\textsubscript{x} measurements before and after the wet scrubber. Although this is not a direct measurement of
the NO oxidation efficiency (because some oxidized NO might not be captured by the wet scrubber), these data will provide important information on the fate of the incoming NO. For example, by noting the change in NO concentration from the inlet to the outlet, we can determine how much of the incoming NO has been converted to another form (whether through direct oxidation or through other chemical processes). Note that very little NO removal should be observed under baseline conditions because of the low solubility of NO in an aqueous solution.

In addition to changing the Hg\(^0\) concentration in the flue-gas stream, we intend to vary two other important process parameters. One is the residence time from the injection point to the wet scrubber. Laboratory tests have indicated that Hg\(^0\) removal performance decreases significantly for shorter residence times. Therefore, we plan to perform the pilot-scale tests using two residence times that differ by at least 1 sec. On the other hand, laboratory tests appeared to show that NO removal did not change much with residence time. This indicates that reactions with NO may be faster than the shortest residence times studied to date (i.e., about 2 sec). In any case, pilot-scale tests will be very important in confirming these laboratory-scale results.

A second important parameter for this process is the ratio of reagent to reactant needed to achieve a certain level of removal performance. The primary variable we will use to achieve these goals is the ratio of reagent added to reactant present. This parameter is obviously the key to the economics of the process since the primary cost associated with this process will be the cost of the oxidizing agent. That is because this process is intended as a retrofit to an existing wet scrubber system and relatively minimal capital costs are anticipated. In the proposed project, we will start with a high reagent to reactant ratio to quickly achieve the removal goal. This will be followed by tests designed to identify the minimum reagent required for a given removal under various process conditions.

There are some process parameters that will not be varied during the tests due to system characteristics. These include flue-gas composition (other than mercury speciation), gas velocity, and flue-gas temperature. In the latter case, an auxiliary heater may be employed to minimize variations due to load changes for the boiler.

**Summary and Future Directions**

The initial tests involving the atomization of chloric-acid solutions into a flowing stream of simulated flue gas confirmed the potential for enhanced Hg\(^0\) removal that was identified in the earlier bubbler and scrubber tests. At the highest reagent concentration studied, approximately 100% of the gaseous Hg\(^0\) was transferred to the liquid phase. Addition of NO appeared to significantly enhance Hg\(^0\) removal and simultaneous removal of NO (up to about 80%) was also observed. The presence of SO\(_2\) in the flue gas did not have a significant negative effect on Hg\(^0\) or NO removals.

The use of elevated temperatures (typical of flue-gas temperatures downstream of an air preheater) significantly improved the removal of both Hg\(^0\) and NO. This tended to confirm earlier data that suggested gas-phase reactions are a key element of this process. This led to investigation of direct injection of the reagent in a vapor form, which dramatically improved process performance and reagent utilization.

Both Hg\(^0\) and NO removals were found to depend upon the reagent concentration. The Hg\(^0\) removal
was found to depend strongly on residence time while NO removal was relatively insensitive to residence time within the range studied.

The effects of changing the inlet concentration of Hg\textsuperscript{0} was studied over a range of about four to one. Total mercury removed was found to decrease as expected, but the percentage removal actually increased as the Hg\textsuperscript{0} concentration dropped.

Estimates for reagent costs presented here should be viewed as extremely preliminary. However, they appear to be well within the ranges established by other control technologies for mercury and NO. Furthermore, this approach offers the possibility of a combined process that could be integrated into a wet scrubbing system for enhanced mercury removal and moderate degrees of NO control.

Continuing work at Argonne is currently focused on experiments that will refine our estimates of reagent requirements for combined Hg\textsuperscript{0} and NO removal. In addition, we are attempting to identify the key reaction pathways and products in order to improve the process concept definition and evaluate any potential secondary effects.

Pilot-scale testing of the process concept is appropriate at this time to refine the process design and investigate engineering issues that cannot be studied in the lab. A test program has been proposed in cooperation with an industrial partner. If approved, the program should be initiated in 2001.

**Acknowledgments**

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**References**


