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# High $SO_2$ Removal Efficiency Testing

## Quarterly Report
## April 1 - June 30, 1997


## By
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# 1.0 INTRODUCTION

This document provides a discussion of the technical progress on DOE/PETC project number DE-AC22-92PC91338, "High Efficiency $SO_2$ Removal Testing", for the time period 1 April through 30 June 1997. The project involves testing at six full-scale utility flue gas desulfurization (FGD) systems to evaluate low capital cost upgrades that may allow these systems to achieve up to 98% $SO_2$ removal efficiency. The upgrades being evaluated mostly involve using performance additives in the FGD systems.

The "base" project involved testing at the Tampa Electric Company's Big Bend Station. All five potential options to the base program have been exercised by DOE, involving testing at Hoosier Energy's Merom Station (Option I), Southwestern Electric Power Company's Pirkey Station (Option II), PSI Energy's Gibson Station (Option III), Duquesne Light's Elrama Station (Option IV), and New York State Electric and Gas Corporation's Kintigh Station (Option V). The originally planned testing has been completed for all six sites. However, additional testing is being conducted at the Big Bend Station.

The remainder of this document is divided into four sections. Section 2, Project Summary, provides a brief overview of the status of technical efforts on this project. Section 3, Results, summarizes the outcome from technical efforts during the quarter, or results from prior quarters that have not been previously reported. In Section 4, Plans for the Next Reporting Period, an overview is provided of the technical efforts that are anticipated for the third quarter of calendar year 1997. Section 5 contains a brief acknowledgment.

## 2.0 PROJECT SUMMARY

On the base program, testing was completed at the Tampa Electric Company's (TECo's) Big Bend Station in November 1992. The upgrade option tested was DBA additive. Additional testing is being conducted at this site, and that testing was begun during the current quarter (April through June 1997). Preliminary results are included in this report.

For Option I, at the Hoosier Energy Merom Station, results from another program co-funded by the Electric Power Research Institute (EPRI) and the National Rural Electric Cooperative Association have been combined with results from DOE-funded testing. Three upgrade options have been tested: DBA additive, sodium formate additive, and high pH set-point operation. All testing was completed by November 1992. There were no activities for this site during the current quarter.

Option II involved testing at the Southwestern Electric Power Company Pirkey Station. Both sodium formate and DBA additives were tested as potential upgrade options. All of the testing at this site was completed by May 1993.

On Option III, for testing at the PSI Energy Gibson Station, testing with sodium formate additive was completed in early October 1993, and a DBA additive perfomance and consumption test was completed in March 1994. There were no efforts for this site during the current quarter.

Option IV is for testing at the Duquesne Light Elrama Station. The FGD system employs magnesium-enhanced lime reagent and venturi absorber modules. An EPRI-funded model evaluation of potential upgrade options for this FGD system, along with a preliminary economic evaluation, determined that the most attractive upgrade options for this site were to increase thiosulfate ion concentrations in the FGD system liquor to lower oxidation percentages and increase liquid-phase sulfite alkalinity, and to increase the venturi absorber pressure drop to improve gas/liquid contacting. Parametric testing of these upgrade options was conducted in March 1994. There were only reporting activities for this site during the current quarter.

Option V is for testing at the NYSEG Kintigh Station. Baseline testing was conducted in July 1994. Parametric testing at this site was conducted in late August, and a sodium formate additive consumption test was conducted in September 1994. There were no activities related to this site during the current quarter.

## 3.0 RESULTS

Results from the base program (at the TECo Big Bend Station) and the first optional site (Hoosier Energy Merom Station) were presented in detail in the April 1993 quarterly Technical Progress Report, and updates were included in the July 1993 and October 1993 reports. Additional testing at the Big Bend site began in October 1996, but was stopped after four days because of various problems. This effort was briefly described in the January 1997 Technical Progress Report. This additional testing resumed during the current quarter. Preliminary test results are discussed below.

For the second optional site (the Southwestern Electric Power Company Pirkey Station), results were presented in the July 1993 quarterly Technical Progress Report and updated in the October 1993 and January 1997 reports.

For the third optional site (the PSI Energy Gibson Station), baseline testing was conducted in May 1993, and those results were presented in the July 1993 quarterly report. Parametric testing at this site was completed in early October of 1993, and these results were discussed in the January 1994 Technical Progress Report. A DBA performance and consumption test was conducted in February and March of 1994. Preliminary results from this test were discussed in the April 1994 Technical Progress Report. An update of the results from this site was presented in the April 1995 quarterly report.

Baseline testing at the fourth optional site (Duquesne Light's Elrama Station) was completed in July 1993. Those results were discussed in the October 1993 quarterly report. The results of EPRI-funded FGDPRISM modeling and preliminary economic evaluations of potential upgrades for this FGD system were discussed in the January 1994 Technical Progress Report. In March of 1994 parametric testing of the most promising upgrade options was conducted. The preliminary results of these tests were discussed in the April 1994 Technical Progress Report. A draft Technical Note for this site was submitted to DOE in January 1995. An overview of new results presented in this draft Technical Note was included in the Technical Progress Report for the time period October through December 1994, dated 3 February 1995.

For the fifth optional site, at the New York State Electric and Gas Corporation's (NYSEG's) Kintigh Station, baseline, parametric, and additive consumption tests were completed during the third quarter of 1994. Results from the baseline testing at this site were discussed in the Technical Progress Report for the third quarter of calendar year 1994, dated December 1994. The parametric and additive consumption tests at this site were also completed late in the third quarter. These results were discussed in the April 1995 quarterly Technical Progress Report. Late in the fourth quarter of calendar year 1994, FGDPRISM modeling of the Kintigh FGD system was completed, as were the economic evaluations of potential upgrade options for this site. A draft report discussing these results was submitted to DOE and to NYSEG in the first quarter of calendar year 1995. These results were discussed in the quarterly Technical Progress Report dated July 1995.

The only new project results to present this quarter are preliminary results from the additional testing at Tampa Electric's Big Bend Station, as was mentioned above. These results are briefly summarized below.

## 3.1 Tampa Electric's Big Bend Station

### 3.1.1 Introduction

Based on the results of DOE-sponsored testing of DBA additive at Big Bend Station during November 1992, Tampa Electric Company (TECo) has successfully completed modifications to treat flue gas from 445 MW Unit 3 as well as that from 485 MW Unit 4 in the original Unit 4 FGD system. Currently, the integrated Unit 3 and 4 FGD system is treating twice the design amount of flue gas by operating all four modules (instead of three) at a maximum flue gas velocity of about 10 to 11 ft/s, which is about 50% higher than the original design. A nominal level of 1000 mg/L DBA additive is maintained in the upper loop scrubbing liquor to improve $SO_2$ removal efficiency

Recent tests at EPRI's ECTC and by others have shown that operation at higher flue gas velocity improves mass transfer effectiveness. One system vendor, ABB, has built a "second-generation" limestone FGD system that is designed to operate at an absorber velocity of 15 ft/s. Tampa Electric is now considering scrubbing flue gas from 445 MW Unit 2 as well as Units 3 and 4 in the existing FGD system. Integrating Unit 2 into the FGD system would increase the absorber flue gas velocity to about 16 ft/s.

In order to evaluate the feasibility of integrating Unit 2 into the Big Bend FGD system, TECo has modified a single module of the FGD system to permit operation at flue gas velocities as high as 17 ft/s. This report describes results of additional tests to evaluate the $SO_2$ removal capability of the modified test module at high flue gas velocity.

### 3.1.2 Test Approach and Measurements

#### Test Approach

The Big Bend FGD system was described in the April 1993 quarterly Technical Progress Report. Modifications to Module D to permit higher-velocity operation included:

- Installing a larger booster fan motor and fan rotor;
- Modifying the upper-loop recycle piping and nozzles to increase liquid flow (L/G);
- Improving the upper-loop drain bowl capacity by installing a vortex breaker and extending the depth of the drain in the recycle tank;
- Upgrading the upper-loop hydroclones to control upper-loop density;
- Increasing the capacity of the upper-loop oxidation air headers; and
- Increasing the flow rate of the mist eliminator wash system.

The Module D recycle pump and piping configuration was modified to increase the liquid flow to the upper loop. Based on pump power calculations and pump performance curves, each of the three absorber section recycle pumps provides a flow of about 15,000 gpm.

Some changes were also made to the Module D operating and control strategy. Previously, the upper-loop recycle tank level was fixed by overflow into the lower-loop tank and the upper-loop density was controlled by directing the hydroclone underflow either back to the upper loop or to the lower loop. With the higher oxidation air flow, the upper-loop recycle tank operating level had to be decreased from the normal overflow level of 26 ft to 21 ft. The tank level is no longer fixed by overflow, and is now controlled by directing all of the hydroclone underflow to the lower loop, and opening or closing the hydroclone feed valve to control level. The upper-loop density is not controlled and is allowed to vary with the amount of $SO_2$ removed.

Table 3-1 shows the test plan for the high-velocity tests. The tests began with two days of mist eliminator performance measurements. Mist eliminator performance was expected to be the limiting factor in high-velocity absorber operation. At high velocity, mist droplets that are collected on the chevron mist eliminator blades can be stripped from the blades and reentrained by the flue gas before they can drain back into the absorber.

Mist eliminator performance was monitored by a test crew from Koch Engineering using their Phase Doppler Particle Analyzer (PDPA), which measures mist droplet size and velocity using an optical laser technique. The PDPA probe was traversed along two cables suspended about 2 ft. above the upper mist eliminator stage.

During the first test day (Test ME-1), the module was operated at a nominal flue gas velocity of 12 ft/s, and the module was traversed using the PDPA. The objective of this test was to examine the velocity profile through the mist eliminator to locate areas of locally high velocity.

**Table 3-1**

**High-Velocity Test Plan**

| Test | Objective | Duration | Velocity (ft/s) | DBA (mg/L) |
|---|---|---|---|---|
| ME-1 | Traverse mist eliminator to locate high-velocity areas. | 1 day | 12 | Normal (1000) |
| ME-2 | Measure reentrainment to establish maximum sustainable operating velocity. | 1 day | Variable | Normal |
| ME-3 | Measure reentrainment at maximum sustainable operating velocity. | 4 hrs | 13.5 | Normal |
| 1 | Measure system performance at normal velocity. | 2 days | Normal (10.5) | Normal |
| 2,3,4 | Measure $SO_2$ removal versus velocity. | 2 hours | 10.5, 13, 16 | Normal |
| 5 | Measure FGD system performance at maximum sustainable velocity. | 2 days | 13.5 | Normal |
| 6,7,8 | Measure $SO_2$ removal versus DBA concentration. | 2 hours | 13.5 | 1000,1500, 2000 |
| 9 | Measure FGD system performance with higher sulfur fuel. | 2 days | 13.5 | Normal |

During the second test day (Test ME-2), the PDPA probe was fixed at the highest-velocity location and the flue gas velocity was increased incrementally until reentrained droplets were detected. During the third test day (Test ME-3), the absorber module was operated at the highest velocity that could be sustained without reentrainment during the previous test, and the module was traversed with the PDPA probe to verify the single-point results.

Following the mist eliminator testing, the remaining tests were designed primarily to examine the effects of absorber flue gas velocity on system performance. Two types of tests were done. Three two-day tests were done to enable complete evaluation of absorber performance and slurry chemistry at different steady-state conditions. The first two-day test (Test 1) was run at normal operating conditions (11 ft/s absorber velocity, 1000 mg/L DBA, 4.5 to 4.7 lb/mm Btu inlet $SO_2$). For the second two-day test (Test 5), the absorber flue gas velocity was increased to about 13.5 ft/s, which was the maximum sustainable operating velocity with the existing mist eliminator configuration. For the third two-day test, the velocity was maintained at 13.5 ft/s, and the inlet $SO_2$ was increased from the normal 4.5 lb/mm Btu to 6.1 lb/mm Btu. These conditions were intended to evaluate absorber chemistry under the higher $SO_2$ loading that would be encountered with the normal fuel at higher velocities.

Two groups of three two-hour tests were done to measure changes in absorber $SO_2$ removal efficiency with changes in either flue gas velocity or DBA concentration. For Tests 2, 3, and 4, the absorber flue gas velocity was set at 10, 13, and 16 ft/s, respectively, with other conditions remaining constant. For Tests 6, 7, and 8, the velocity was maintained at 13.5 ft/s and the DBA concentration was set at 1000, 1500, and 2000 mg/L, respectively.

**Test Measurements**

Test measurements included flue gas sampling and analyses, slurry sampling and analyses, and process data obtained from on-line monitors.

$SO_2$ removal efficiency for the absorber module was measured by continuous emissions monitors (CEM). A certified monitor was already in place to measure inlet $SO_2$ concentration for the Unit 4 FGD system. Results from this CEM were available on line through the plant data acquisition system. The $SO_2$ concentration at the absorber outlet was measured by a crew from TECo’s Central Testing Laboratory using a portable CEM. The absorber module outlet duct was traversed with the CEM probe, and the results for the 24 points were averaged to calculate the outlet $SO_2$ concentration.

Table 3-2 summarizes the slurry sampling and analytical schedule for the tests. Each of the samples designated in the table includes a sample from both the lower loop (quench) slurry and the upper-loop (absorber) slurry tanks. For each sample, slurry pH was measured at the sample points using a portable pH meter. For the two-day tests, the two sets of samples were taken during the afternoon of the second test day.

## Table 3-2

## Slurry Sampling and Chemical Analyses

| Test | Performance Indicators | Number of Samples | Liquid Analyses | Solid Analyses |
|---|---|---|---|---|
| 1 | $SO_2$ Removal, Utilization, Oxidation, Gypsum R.S., Chloride Balance, Solids Properties | 2 | pH, Ca, Mg, Na, Cl, $SO_3$, $SO_4$, $CO_3$, DBA | Wt % Solids, Acid Insolubles, Ca, Mg, $SO_3$, $SO_4$, $CO_3$, SEM |
| 2,3,4 | $SO_2$ Removal | 1 | pH, DBA | Wt % Solids, $CO_3$ |
| 5 | Same as Test 1 | 2 | Same as Test 1 | Same as Test 1 |
| 6,7,8 | $SO_2$ Removal | 1 | Same as Test 2 | Same as Test 2 |
| 9 | Same as Test 1 | 2 | Same as Test 1 | Same as Test 1 |

Complete liquid and solid analyses were done for samples from the two-day tests. Results were used to calculate important process performance parameters including limestone utilization, sulfite oxidation and gypsum relative saturation. Settling tests were also done with samples from the two-day tests, and scanning electron microscopy was used to examine the size and shape of the gypsum byproduct.

For the short-term tests, during which $SO_2$ removal efficiency was measured, samples were analyzed only for liquid-phase DBA concentration and solid-phase carbonate (limestone) content, both of which affect removal efficiency.

### 3.1.3 Test Results

**Mist Eliminator Performance Tests**

The flue gas velocity measurements made using the PDPA during Test ME-1 show that the flue gas velocity at the center of the tower was about 20% higher than the average velocity. Based on these results, subsequent carryover measurements were performed at the center of the tower, where carryover would first be expected to appear.

During Test ME-2, the PDPA probe was placed at the center point and the absorber flue gas velocity was incrementally increased until significant numbers of large-diameter droplets were detected, indicating reentrainment of collected mist from the mist eliminator. Results showed that reentrainment became significant at absorber superficial velocities greater than about 13.5 ft/s. Allowing for a 15% area reduction due to support structure and wash headers, and assuming that the center velocity was 20% higher than the average velocity, this limit corresponds to a mist eliminator "breakthrough" velocity of about 19 ft/s, which agrees well with the expected performance of this mist eliminator type.

**$SO_2$ Removal Performance Tests**

Preliminary results from the $SO_2$ removal performance tests are summarized in Table 3-3. Operating conditions for performance Test 1 were established at 1800 on Saturday, May 31, but steady-state operation was not achieved until Tuesday morning, 6/3 because operators had lowered the pH set point during the night of 6/1. After operating at the correct pH set point (5.4) during the day on Monday, 6/2, the $SO_2$ removal efficiency measurement was completed that afternoon. The inlet $SO_2$ concentration was 4.75 lb/mm Btu (2040 ppmv), and the outlet concentration averaged 0.116 lb/mm Btu, for a removal efficiency of 97.6%. The absorber flue gas velocity for Test 1 was 10.3 ft/s. Steady-state samples for chemical analyses were taken early in the morning of 6/3.

**Table 3-3**

**$SO_2$ Removal Efficiency Test Results**

| Test | Date | Time | Velocity (ft/s) | pH | DBA (mg/L) | $SO_2$ In (lb/mm Btu) | $SO_2$ ôut (lb/mm Btu) | Eff (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 6/2 | 1447-1613 | 10.3 | 5.56 | TBD* | 4.8 | 0.116 | 97.6 |
| 2 | 6/3 | 1147-1349 | 10.5 | 5.39 | TBD | 4.6 | 0.124 | 97.3 |
| 3 | 6/3 | 1505-1647 | 12.9 | 5.26 | TBD | 4.5 | 0.074 | 98.4 |
| 4 | 6/3 | 1746-1927 | 15.1 | 5.24 | TBD | 4.5 | 0.039 | 99.1 |
| 5 | 6/5 | 1019-1201<br>1300-1440 | 13.6<br>13.5 | 5.31<br>5.17 | TBD<br>TBD | 4.45<br>4.45 | 0.114<br>0.101 | 97.4<br>97.7 |
| 6 | 6/6 | 1002-1145 | 13..5 | 5.35 | TBD | 4.8 | 0.264 | 94.5 |
| 7 | 6/6 | 1233-1417 | 13.5 | 5.45 | TBD | 4.85 | 0.117 | 97.6 |
| 8 | 6/6 | | 13.5 | | TBD | 4.4 | 0.060 | 98.6 |

Test 2 was conducted during the morning of 6/3. Because the absorber gas velocity for Test 1 was close to the desired velocity for Test 2, conditions were not changed for Test 2. The measured $SO_2$ removal efficiency for Test 2 was 97.3% (4.6 lb/mm Btu inlet, 0.124 lb/mm Btu outlet). This result was close to that for Test 1, indicating good reproducibility for the tests.

After samples were collected at Test 2 conditions, the absorber flue gas velocity was increased to 12.9 ft/s for Test 3. All other operating conditions remained the same. However, it was observed on the control-room recorder that the quench slurry pH increased somewhat because of reagent carryover from the AFT into the quench tank. $SO_2$ removal efficiency for Test 3 increased to 98.4% (4.66 lb/mm Btu inlet, 0.074 lb/mm Btu outlet).

Test 4, the final test in the series at increasing flue gas velocity, was conducted at 15.1 ft/s. Again, all other operating conditions remained the same. For this test, $SO_2$ removal efficiency increased to 99.1% (4.5 lb/mm Btu inlet, 0.039 lb/mm Btu outlet).

Following Test 4, the absorber flue gas velocity was decreased to 13.5 ft/s, which was the maximum allowable for sustained operation, and Test 5 began. This was a two-day test to evaluate steady-state performance. Two successive measurements of $SO_2$ removal efficiency for this test yielded 97.4 % and 97.7 % removal.

The tests labeled 6 through 8 were conducted the day after Test 5 was completed. These were short-term tests conducted to determine the effects of varied DBA concentration at the 13.5 ft/s flue gas velocity. The $SO_2$ removal performance measured varied from 94.5% to 98.6% as the DBA concentration in the absorber was increased from nominal levels of 1000 ppm to 2000 ppm. These results will be further evaluated when the actual DBA concentrations from those tests are available from off-site chemical analysis results.

## 4.0 PLANS FOR THE NEXT REPORTING PERIOD

Scheduled efforts during the third quarter of calendar year 1997 will consist of project management and reporting, and completion of the additional testing at the TECo Big Bend (base program) site. A two-week intensive test period was completed in June, and longer term monitoring of the system performance should continue through July. During the current quarter, chemical analyses of the FGD system samples taken during the two-week intensive test period will be completed, an engineering analysis of the data will be completed, and a test report will be prepared. At the completion of the longer-term monitoring period, the test absorber will be brought off line for inspection. The results of this inspection should be included in the test report.

Options I, II, and III (Hoosier Energy's Merom Station, SWEPCo's Pirkey Station, and PSI Energy's Gibson Station, respectively) are completed. No efforts are expected for these options during the next quarter.

A draft Topical Report for the Duquesne Light Elrama site (Option IV) was submitted to DOE and to Duquesne Light during the current quarter. For Option V, testing at the NYSEG Kintigh Station, a draft Topical Report for this site was submitted to DOE during the previous quarter (March 1997). No action is expected for these options until review comments are received on the draft reports.

## 5.0 ACKNOWLEDGEMENTS

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