

DCN 97.21321001.08

**Results of High Velocity Tests at
Tampa Electric Company's
Big Bend 4 FGD System**

Topical Report

DE-AC22-92PC91338

Prepared for:

**U.S. Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh, PA 15236**

Prepared by:

**David P. DeKraker
Radian International LLC
P.O. Box 201088
Austin, TX 78720-1088**

October 15, 1997

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United State Government or any agency thereof.

Table of Contents

1.0 Introduction	1-1
2.0 Summary	2-1
3.0 Test Conditions and Results	3-1
3.1 Test Approach	3-1
3.2 Test Measurements.....	3-5
3.2.1 Flue Gas Sampling	3-5
3.2.2 Slurry Sampling and Chemical Analyses	3-6
3.3 Test Results	3-6
3.3.1 Mist Eliminator	3-6
3.3.2 FGD System Performance Tests.....	3-8
3.3.3 Analytical Results for Slurry Samples.....	3-10
3.3.4 Other Process Data.....	3-17
3.3.5 Long-Term High Velocity Testing	3-18
APPENDIX A: ANALYTICAL DATA	A-1

List of Figures

Figure 3-1. Recycle Slurry Pump Configuration.....	3-2
Figure 3-2. Mist Eliminator Gas Velocity and Carryover Measurement Locations	3-4
Figure 3-3. Effect of Gas Velocity on SO ₂ Removal	3-11
Figure 3-4. Effect of DBA Concentration on SO ₂ Removal	3-12
Figure 3-5. Effect of pH on Quench Calcium Sulfite Relative Saturation.....	3-14
Figure 3-6. Effect of pH on Limestone Utilization	3-16

List of Tables

Table 3-1. High-Velocity Test Plan.....	3-3
Table 3-2. Slurry Sampling and Chemical Analyses	3-6
Table 3-3. Mist Eliminator Velocity and Carryover Results.....	3-7
Table 3-4. SO ₂ Removal Efficiency Test Results	3-8
Table 3-5. Comparison of Radian and TECo Calcium Carbonate Analyses	3-18
Table 3-6. Settling Test Results	3-18

1.0 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 flue gas desulfurization (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. This velocity is about 50% greater than the original design velocity.

Recent tests at EPRI's Environmental Control Technology Center (ECTC) and by others have shown that operation at higher flue gas velocity improves mass transfer effectiveness. EPRI is currently evaluating an advanced limestone FGD system that is designed to operate at an absorber velocity of 18 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, or about double the original design value.

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 SO₂ removal capability of the modified test module at high flue gas velocity.

Two sections follow this introduction: Section 2 provides a summary of the test results, and Section 3 provides details of the testing and results. Lab data are presented in Appendix A.

2.0 Summary

Tests were conducted at the Big Bend Station on May 27 through June 6, 1997, to determine the feasibility of scrubbing gas from an additional boiler (Unit 2) in the existing FGD system. Testing was accomplished by increasing the gas flow through the D absorber tower and measuring the performance of this module. Key performance aspects evaluated during the testing include mist eliminator performance, SO₂ removal efficiency, oxidation of absorbed SO₂, and limestone utilization (and its impact on gypsum purity). Oxidation and limestone utilization performance characteristics are especially important at Big Bend, since the station sells its gypsum byproduct commercially and must meet gypsum purity specifications.

Mist eliminator performance was assessed using a Phase Doppler Particle Analyzer (PDPA) probe to measure gas velocity and carryover through the mist eliminator. These tests showed that the existing mist eliminators could handle a gas velocity of up to 13.5 ft/s without excessive carryover. This falls short of the 16.5 ft/s which would occur if gas from Unit 2 was scrubbed in the existing absorbers. However, mist eliminator vendors reportedly have more advanced mist eliminator designs which are capable of handling the increased gas velocity. The advanced mist eliminator designs have not been tested at Big Bend, but assuming they perform as well as vendors claim, mist eliminator performance should not be an obstacle to scrubbing the flue gas from an additional unit in the existing FGD system absorbers.

SO₂ removal performance was measured during short-term tests at gas velocities up to 15 ft/s and in longer-term tests at gas velocities up to 13.5 ft/s. Dibasic acid (DBA) was added to the test module as a performance additive during all of these tests. The results of these tests indicate that it is possible to achieve high SO₂ removal efficiencies at the higher gas velocities. Removal efficiency tended to increase as gas velocity increased, a result that is consistent with other data from laboratory- and full-scale testing. In particular, a removal efficiency of 99% was measured at the highest gas velocity tested, 15 ft/s. Thus the ability to achieve adequate SO₂ removal while scrubbing flue gas from an additional unit should not be a problem.

The FGD system at Big Bend operates in a forced oxidation mode to produce a gypsum byproduct that is used as a feedstock for producing wallboard. Achieving complete oxidation of the SO₂ removed is an important part of meeting the gypsum purity specifications. Oxidation efficiency is normally determined by measuring the composition of the solids produced in the FGD system. However, the tests performed were mostly short-term, and did not allow time for the solids

composition to come to steady state. Oxidation was instead assessed by looking at liquid phase chemistry, specifically, the calcium sulfite relative saturation. The calcium sulfite relative saturation was consistently less than 1.0 in the upper loop; this is an indicator of complete oxidation in this loop. On the other hand, in the lower loop the calcium sulfite relative saturation frequently increased to above 1.0. This indicates that a mixture of calcium sulfite hemihydrate and gypsum solids could be precipitated within this loop, and that oxidation was not complete. The high relative saturations occurred only at high lower loop pH. This suggests that complete oxidation could be achieved in the lower loop if the pH consistently remained low. Maintaining lower pH values would require minimizing the amount of calcium carbonate carried into the lower loop from the upper loop. Additional testing would be required to determine how to best do this on an ongoing basis. One possible solution would be absorber modifications to reduce slurry carry-up from the lower loop to the upper loop, thus minimizing the amount of upper-loop slurry that has to be feed to the lower loop to maintain slurry levels. Another would be to operate the upper loop with less excess calcium carbonate (higher limestone utilization) in the recirculating slurry.

Calcium carbonate concentration, especially in the lower loop, is also important because of its direct impact on gypsum byproduct purity. Calcium carbonate concentration is commonly reported in terms of limestone utilization: high limestone utilization indicates a low calcium carbonate concentration. The limestone utilization was generally high during the testing. However, during three tests (Tests 3, 7 and 8) the limestone utilizations were low enough that the lower loop calcium carbonate concentrations exceeded the value allowed by the gypsum purity specification (1.5% CaCO₃ maximum). During Tests 7 and 8, the low utilization was thought to be due to a blinding episode induced by the rapid addition of DBA to the absorber. Though the mechanism for this blinding is not well understood, blinding has been observed at other FGD systems when DBA is added to a scrubber rapidly. Since rapid addition of DBA was related to this short-term testing and would not typically occur during normal operation, the blinding which occurred during these two tests should not be a concern. The cause of the low utilization during Test 3 was not obvious, although plant personnel indicated that incidents of low limestone utilization recur occasionally during normal operation. Further testing is warranted to determine if it is possible to consistently avoid a repeat of the low utilization observed during this test.

Results from this program suggest that the analytical accuracy of the on-site calcium carbonate measurements should be verified: these measurements are important because they are used to determine if the gypsum byproduct meets its purity specification. A comparison of the test sample analyses conducted off site and the daily on-site analyses showed that the on-site analyses consistently measured higher calcium carbonate concentrations. Since these two types of samples

were collected at different times during the day, some differences are to be expected. However, the consistently higher results obtained in the daily on-site analyses suggest that there could be some bias in the measurement method. This could easily be checked by splitting samples for comparison of results with one or more outside labs.

In summary, this test program did not conclusively determine whether or not gas from Unit 2 could be successfully scrubbed in the existing FGD system on a continuing basis. The ability to achieve sufficient SO₂ removal, perhaps the most important aspect of scrubber performance, does not appear to be a concern. However, the sulfite oxidation and limestone utilization performance did not consistently meet the requirements of the gypsum byproduct purity specifications. Operational changes to improve the oxidation and limestone utilization performance were identified, but there was not sufficient time during the test program to make and test these changes.

3.0 Test Conditions and Results

3.1 Test Approach

The Big Bend FGD system uses dual-loop, countercurrent absorbers with packing in the upper loop. The system was originally configured with the upper-loop slurry recycle pumps feeding a common manifold to deliver slurry to three internal spray levels (see Figure 3-1). Two of the upper-loop pumps were in service during normal operation; they delivered a total slurry flow of approximately 30,000 gpm to give an upper-loop liquid to gas (L/G) ratio of 65 (gpm per thousand acfm treated) and an overall L/G of 87.

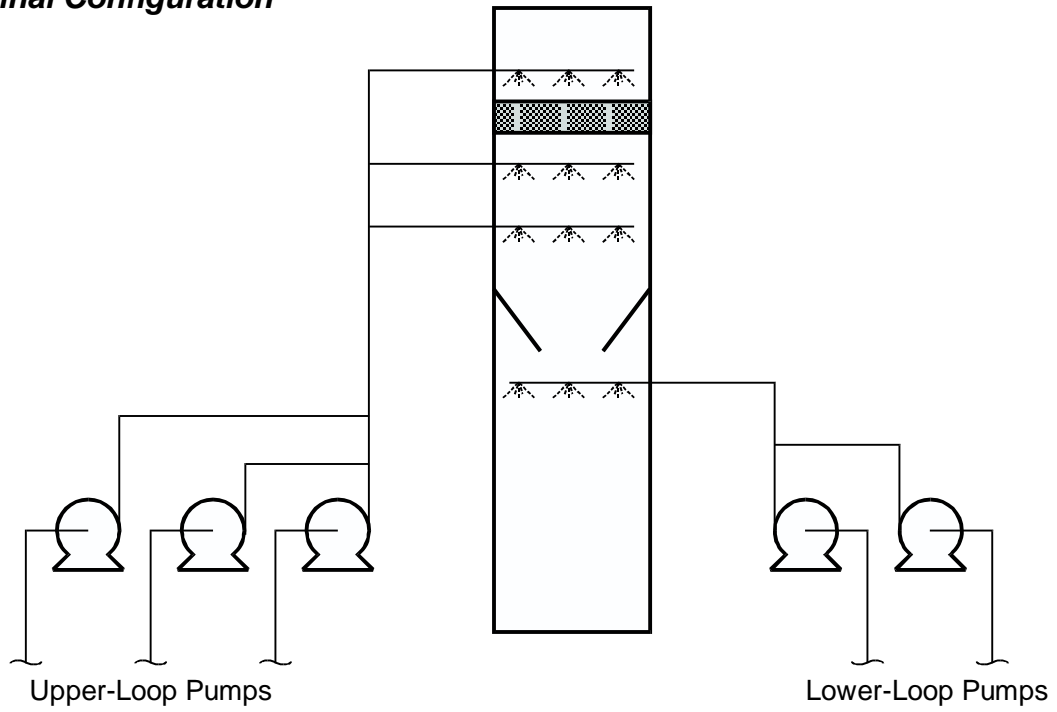
The FGD system was subsequently modified to scrub both Units 3 and 4. To scrub this additional flue gas, all four absorber modules are operated (no spare now), DBA is used as a performance additive (DBA is a mixture of adipic, glutaric, and succinic acids), and the absorber slurry piping was modified. The latter included revisions so that all three pumps would be in service, with pumps #1 and #3 providing slurry to the header above the packing and pump #2 providing slurry below the packing. This revision is also shown in Figure 3-1.

Prior to this most recent test program, additional modifications were made to one absorber module (Module D) to permit the scrubbing of additional gas. These included:

- Installing a larger booster fan motor and fan rotor;
- Replacing the upper-loop nozzles to increase liquid flow, to maintain liquid-to-gas ratio (L/G) at the high gas velocity conditions;
- 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 hydrocyclones 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.

Based on pump power calculations and pump performance curves, each of the three upper-loop recycle pumps provides a flow of about 15,000 gpm. The lower-loop recycle pumps and piping were not modified. The total slurry flow to the lower loop was previously measured at about 10,000 gpm. With these changes, the overall L/G for the scrubber would be approximately 56 at the gas

Original Configuration



Current Configuration

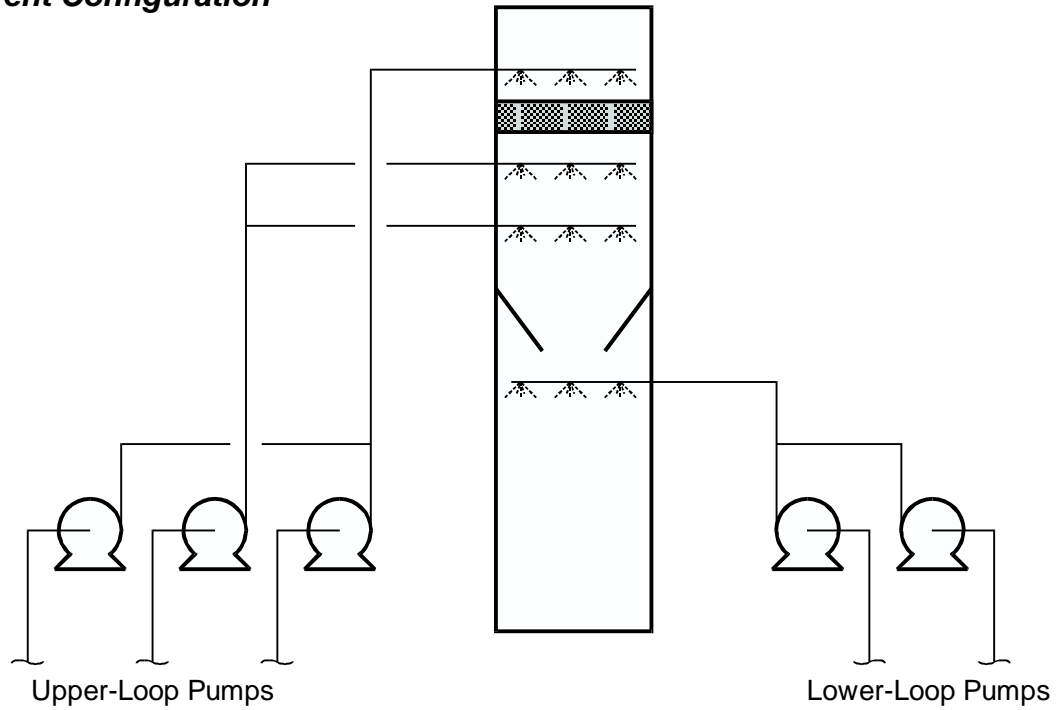


Figure 3-1. Recycle Slurry Pump Configuration

flow expected if the FGD system were modified to scrub Unit 2 as well (16.5 ft/sec gas velocity). This L/G is about 35% lower than the original design value.

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 SO₂ removal.

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.

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 hrs.	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 hrs.	13.5	1000, 1500, 2000

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 two feet above the upper mist eliminator stage. Figure 3-2 shows the location of the test cables relative to the absorber module cross section.

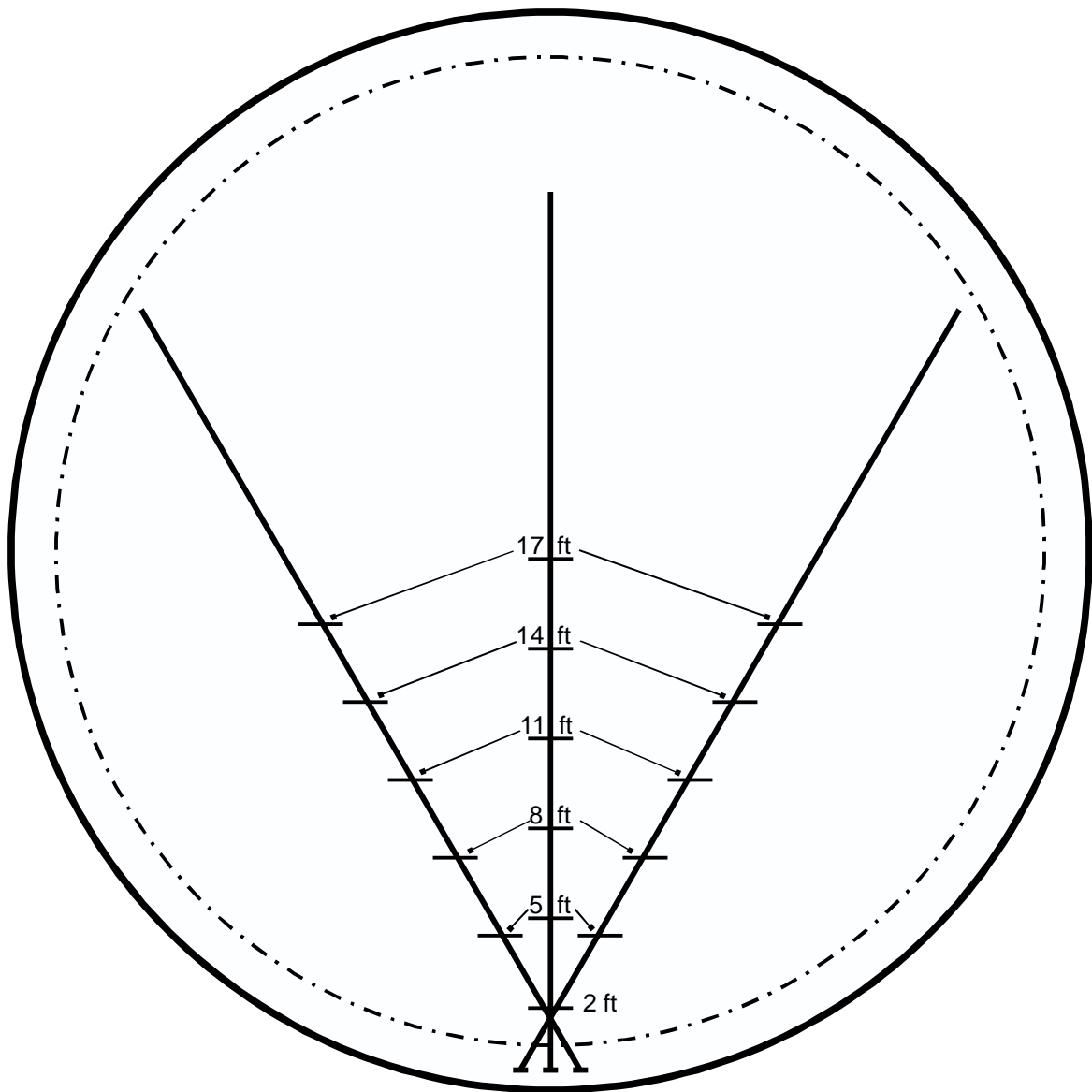


Figure 3-2. Mist Eliminator Gas Velocity and Carryover Measurement Locations

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. 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 SO₂). 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 SO₂ was increased from the normal 4.5 lb/mm Btu to 6.1 lb/mm Btu by switching the coal fired in the boilers. These conditions were intended to evaluate absorber chemistry under the higher SO₂ loading that would be encountered with the normal fuel at velocities of 16 ft/sec or greater.

Two groups of three two-hour tests were done to measure changes in absorber SO₂ 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.

3.2 Test Measurements

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

3.2.1 Flue Gas Sampling

SO₂ removal efficiency for the absorber module was measured by continuous emissions monitors (CEMs). A certified monitor was already in place to measure inlet SO₂ concentration for the Unit 4 FGD system. Results from this CEM were available on line through the plant data

acquisition system. The SO₂ 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 SO₂ concentration.

3.2.2 Slurry Sampling and Chemical Analyses

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 and upper-loop 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	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
6, 7, 8	SO ₂ removal	1	pH, DBA	Wt.% solids, CO ₃

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 SO₂ 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.

3.3 Test Results

3.3.1 Mist Eliminator

The mist eliminator tests were performed to determine the maximum velocity at which the D absorber could be operated without experiencing excessive carryover. This was determined

through flue gas velocity and mist carryover measurements made by Koch Engineering using the Phase Doppler Particle Analyzer (PDPA); results from the testing are summarized in Table 3-3.

Table 3-3. Mist Eliminator Velocity and Carryover Results

Test	Date	PDPA Lens (mm)	Distance from Wall (ft)	Traverse Line	Velocity (ft/s)	Carryover (gr/acf)
ME1	5/28/97	100	2	Center	11.9	0.00031
ME1	5/28/97	100	5	Center	11.6	0.01628
ME1	5/28/97	100	8	Center	11.8	0.00057
ME1	5/28/97	100	11	Center	12.0	0.00034
ME1	5/28/97	100	14	Center	13.0	0.01746
ME1	5/28/97	100	17	Center	14.0	0.00038
ME1	5/28/97	100	2	Left	11.4	0.00373
ME1	5/28/97	100	5	Left	11.6	0.00351
ME1	5/28/97	100	8	Left	11.0	0.02094
ME1	5/28/97	100	11	Left	11.2	0.00074
ME1	5/28/97	100	14	Left	11.3	0.00127
ME1 Averages					11.9	0.006
ME2	5/29/97	300	17	Center	13.6	2.02e-6
ME2	5/29/97	300	17	Center	13.6	1.10e-5
ME2	5/29/97	300	17	Center	14.0	0.00189
ME2	5/29/97	300	17	Center	16.0	0.03114
ME3	5/30/97	300	5	Center	12.0	4.71e-5
ME3	5/30/97	300	8	Center	13.4	0.00039
ME3	5/30/97	300	11	Center	12.6	2.68e-6
ME3	5/30/97	300	14	Center	14.0	0.00920
ME3	5/30/97	300	17	Center	15.2	9.82e-5
ME3 Averages					13.4	0.00195

The first series of tests (Test Series ME1) was designed to obtain an average velocity and carryover rate for the tower and also to identify the location of the highest flue gas velocity. Measurement data collected along two traverse lines in the tower (Figure 3-2) showed an average carryover rate of 0.006 gr/acf at an average superficial velocity of 11.9 ft/s at the mist eliminator, resulting in a unit rate of about 9×10^{-5} gpm/ft². These tests also showed that the highest velocity within the tower occurred at the center, where the velocity was roughly 20% higher than the average.

The second series of tests (Test Series ME2) was designed to determine the average flue gas velocity at which carryover became excessive. For this test series, the PDPA probe was located at the center of the tower (the highest velocity location), and measurements were then made at a several gas velocities. These tests showed that increased carryover rates began to occur

at average velocities greater than 13.5 ft/s. The test data also indicated that large droplets (indicative of mist eliminator reentrainment) began to be seen at velocities exceeding 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 (Munters T272/T271).

The third series of tests (Test Series ME-3) was a partial traverse of the mist eliminator with the flue gas velocity set at about 13.5 ft/s. This series of tests was intended to confirm the results of test ME2, that the mist eliminators do have satisfactory performance at a gas velocity of 13.5 ft/s. Results of this test series showed that an average carryover rate of 0.0019 gr/acf occurred at a gas velocity of 13.4 ft/s. This performance was considered to be right at the “edge” at which carryover becomes significant (based on carryover rate and the presence of large diameter droplets which are suggestive of re-entrainment from the mist eliminators) and was thus selected as the highest velocity at which any subsequent long-term test could be performed.

It is important to note that the mist eliminator tests reflect the current mist eliminator performance; different mist eliminators may be able to handle higher gas velocities. In particular, discussions with vendors suggest that newer mist eliminator designs could accommodate the gas velocities that would occur if all of the gas from Unit 2 was scrubbed in the existing FGD system.

3.3.2 FGD System Performance Tests

The objective of the FGD system performance tests was to determine the SO₂ removal efficiency of the D tower as a function of gas velocity and DBA concentration. Tests were performed at gas velocities ranging from 10.3 to 15.1 ft/s and at DBA concentrations ranging from 1470 to 3850 ppm. A summary of the removal efficiency test results is shown in Table 3-4.

Table 3-4. SO₂ Removal Efficiency Test Results

Test	Date	Time	Velocity (ft/s)	pH	Upper Loop DBA (mg/L)	SO ₂ In (lb/mm Btu)	SO ₂ Out (lb/mm Btu)	Eff. (%)
1	6/2	1447-1613	10.3	5.56	1470	4.8	0.116	97.6
2	6/3	1147-1349	10.5	5.39	1570	4.6	0.124	97.3
3	6/3	1505-1647	12.9	5.26	1860	4.5	0.074	98.4
4	6/3	1746-1927	15.1	5.24	1910	4.5	0.039	99.1
5	6/5	1019-1201	13.6	5.31	2060	4.45	0.114	97.4
		1300-1440	13.5	5.12	2310	4.45	0.101	97.7
6	6/6	1002-1145	13.5	5.35	1530	4.8	0.264	94.5
7	6/6	1233-1417	13.5	5.45	2860	4.85	0.117	97.6
8	6/6	1455-1638	13.5	5.27	3850	4.4	0.060	98.6

Operating conditions for performance Test 1 were established at 1800 on Saturday, 5/31/97, but steady-state operation was not achieved until Tuesday morning, 6/3/97, because the pH set point had been lowered during the night of 6/1/97. After operating at the correct pH setpoint (5.4) during the day on Monday, 6/2/97, the SO₂ removal efficiency measurement was completed that afternoon. The inlet SO₂ 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 6/3/97.

Test 2 was conducted during the morning of 6/3/97. 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 SO₂ 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 lower-loop slurry pH increased somewhat because of reagent carryover from the upper loop into the lower-loop recycle tank. SO₂ 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 (also on 6/3/97). Again, all other operating conditions remained the same. For this test, SO₂ 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 (6/3/97). This was a two-day test to evaluate steady-state performance. Two successive measurements of SO₂ removal efficiency performed on 6/5/97 for this test yielded 97.4 % and 97.7 % removal. Two sets of slurry samples were collected concurrently with the SO₂ removal measurements.

Tests 6, 7, and 8 were conducted on the final day of testing, 6/6/97. These three two-hour tests were done to measure the effect of increasing DBA concentration on SO₂ removal efficiency. Test 6 was conducted at the DBA concentration that was present in the test module as a result of normal operations. For Tests 7 and 8, about 200 gallons of 50% DBA solution were added to the upper-loop recycle tank of the test module prior to each test. All other test conditions remained the same during these three tests.

The most important result of these tests is demonstrating that it is possible to achieve 97% removal (or higher) over a range of gas velocities and DBA concentrations. Only one test (Test 6) recorded an SO₂ removal of less than 97 percent.

The effect of gas velocity on SO₂ removal for Tests 1-4 is shown in Figure 3-3. These data indicate that the SO₂ removal increases as a function of velocity. Measured SO₂ removals ranged from slightly over 97% at approximately 10 ft/s gas velocities to roughly 99% at a gas velocity of 15 ft/s. The DBA concentration also trended slightly higher with the higher gas velocities; however it does appear that the primary factor leading to the increase in removal is the increase in gas velocity.

The effect of DBA concentration on SO₂ removal for Test 3 and Tests 5 through 8 (all tests at ~13 ft/s gas velocity) is shown in Figure 3-4. The most noticeable aspect of this figure is that the measured removal for Test 6 is surprisingly low compared to the other data obtained at ~13 ft/s. Some decrease in removal is expected at lower DBA concentrations, but the SO₂ removal measured during Test 6 is lower than expected, considering that removals measured during all other tests exceed 97 percent. The reason that the measured removal was low during Test 6 is not known; a review of the chemistry and operational data from the test did not provide any obvious explanations.

Excluding the Test 6 results, the data in Figure 3-4 suggest that SO₂ removal is fairly insensitive to DBA concentration over this range. Specifically, even at very high DBA concentrations (3850 ppm), the maximum removal that was achieved with DBA alone was 98.6%. Since a very high SO₂ removal (99.1%) was achieved at a comparatively low DBA concentration (1910 ppm) during Test 4, it seems clear that the primary factor leading to the high SO₂ removal was the high velocity.

With almost all of the data falling within the 97% to 99% removal range, it is possible that a substantial portion of the variability among the measured removals is a result of measurement inaccuracy and normal process variability. However, with almost all of the data showing removal above 97%, it is clear that the scrubbers are capable of achieving a high level of SO₂ removal when operating at increased gas velocities.

3.3.3 Analytical Results for Slurry Samples

The slurry analyses provide insights into a number of important aspects of operating with increased gas velocities. These include the ability to oxidize the slurry, maintaining high

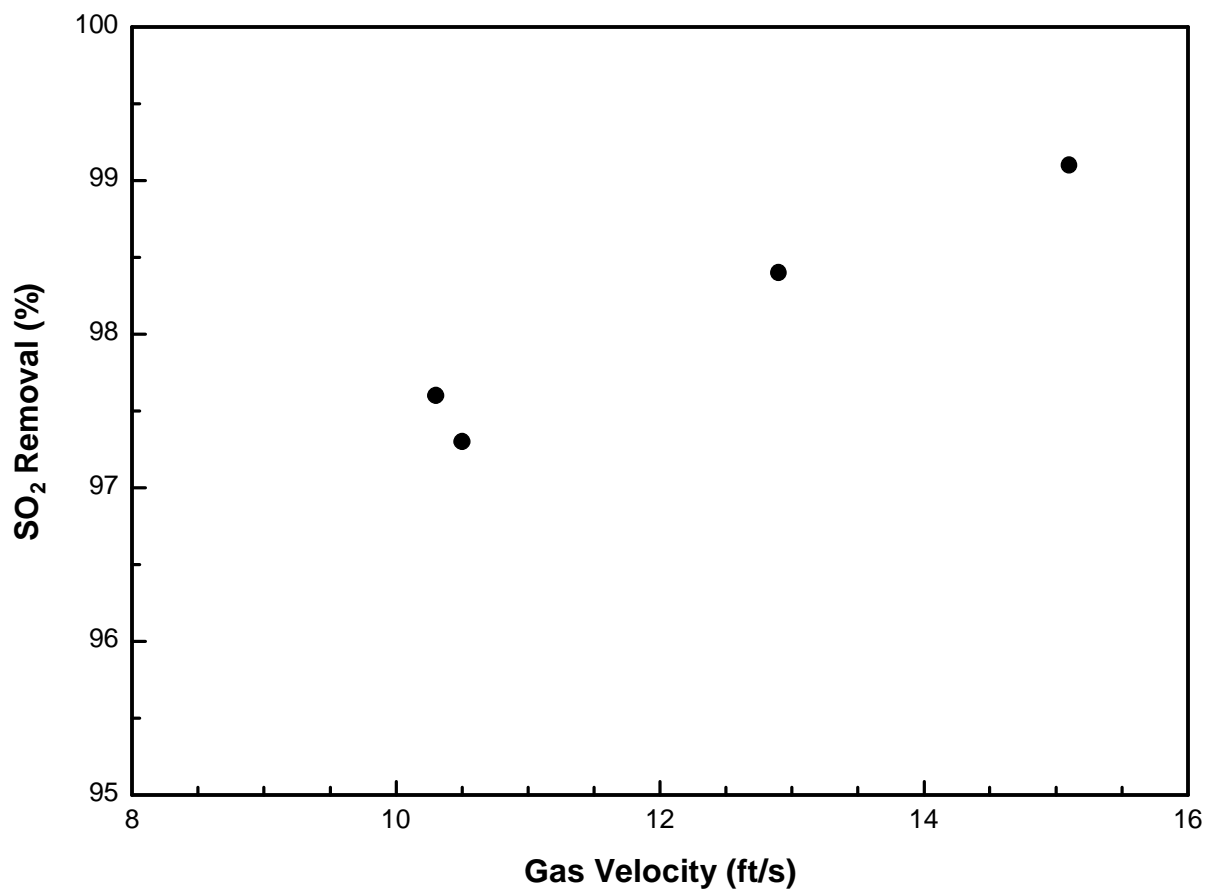


Figure 3-3. Effect of Gas Velocity on SO₂ Removal

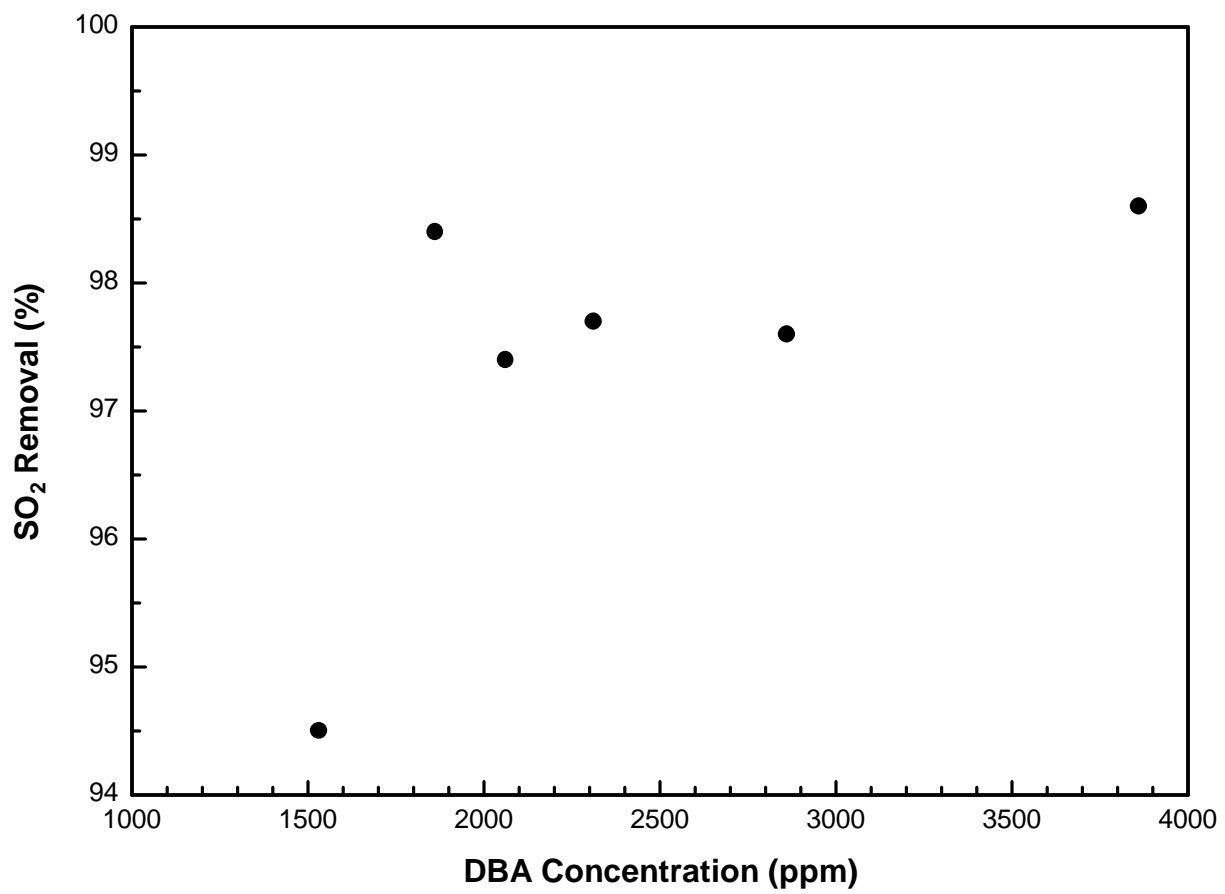


Figure 3-4. Effect of DBA Concentration on SO₂ Removal

limestone utilizations in both the upper loop and lower loop, and the increased amount of slurry carry-up that occurs at higher gas velocities. The liquid- and solid-phase analyses are presented in Appendix A. Important results are discussed below.

One of the most important issues associated with increasing the amount of gas treated by the scrubbers is the ability to oxidize all of the SO₂ absorbed. In normal operation, this would be evaluated by looking at the solids oxidation results. However, since most of the tests were short term tests, there was usually not sufficient time to allow the solids to come to steady state at the operating conditions. So for these tests, oxidation is instead being evaluated based on liquid phase analyses, which respond much more quickly to changes in operating conditions.

The liquid-phase result that is most important for evaluating oxidation percentage is the calcium sulfite relative saturation. As long as the calcium sulfite relative saturation is below 1.0, calcium sulfite solids will not form, and under these conditions the oxidation will be close to or equal to 100 percent. If the calcium sulfite relative saturation exceeds 1.0, calcium sulfite solids will form and the oxidation percentage will be less than 100.

The calcium sulfite relative saturation in the upper loop was less than 1.0 for all tests. This indicates that the oxidation in the upper loop was adequate for the full range of the test conditions. On the other hand, the calcium sulfite relative saturation in the lower loop was often above 1.0. As shown in Figure 3-5, this generally occurred when the pH of the lower-loop slurry exceeded 4.0. However, because the high lower-loop pH levels corresponded with the high velocity tests, it may be that the increased sulfur loading and greater SO₂ removal also contributed to the difficulty in achieving complete oxidation. Because several variables changed at once, it is not possible to determine how each of these factors affects the oxidation. Additional testing would be required to confirm that complete oxidation in the lower loop can be achieved by maintaining the pH at 4.0 or lower. Since the pH in the lower loop is largely dependent on the amount of calcium carbonate carried over from the upper loop, this would entail minimizing the amount of calcium carbonate carried over from the upper loop.

The amount of carry-up from the lower loop to the upper loop is another aspect of performance that can be determined from the chemical analyses. In particular, the chloride concentration in the upper loop is an indication of the amount of carry-up that is occurring in the absorber. Chloride concentrations in the upper loop ranged from about 8300 ppm to over 14,000 ppm, roughly 70% to 80% of the lower loop concentrations. Since the primary way in which chloride enters the upper loop is through carry-up from the lower loop, the amount of carry-up

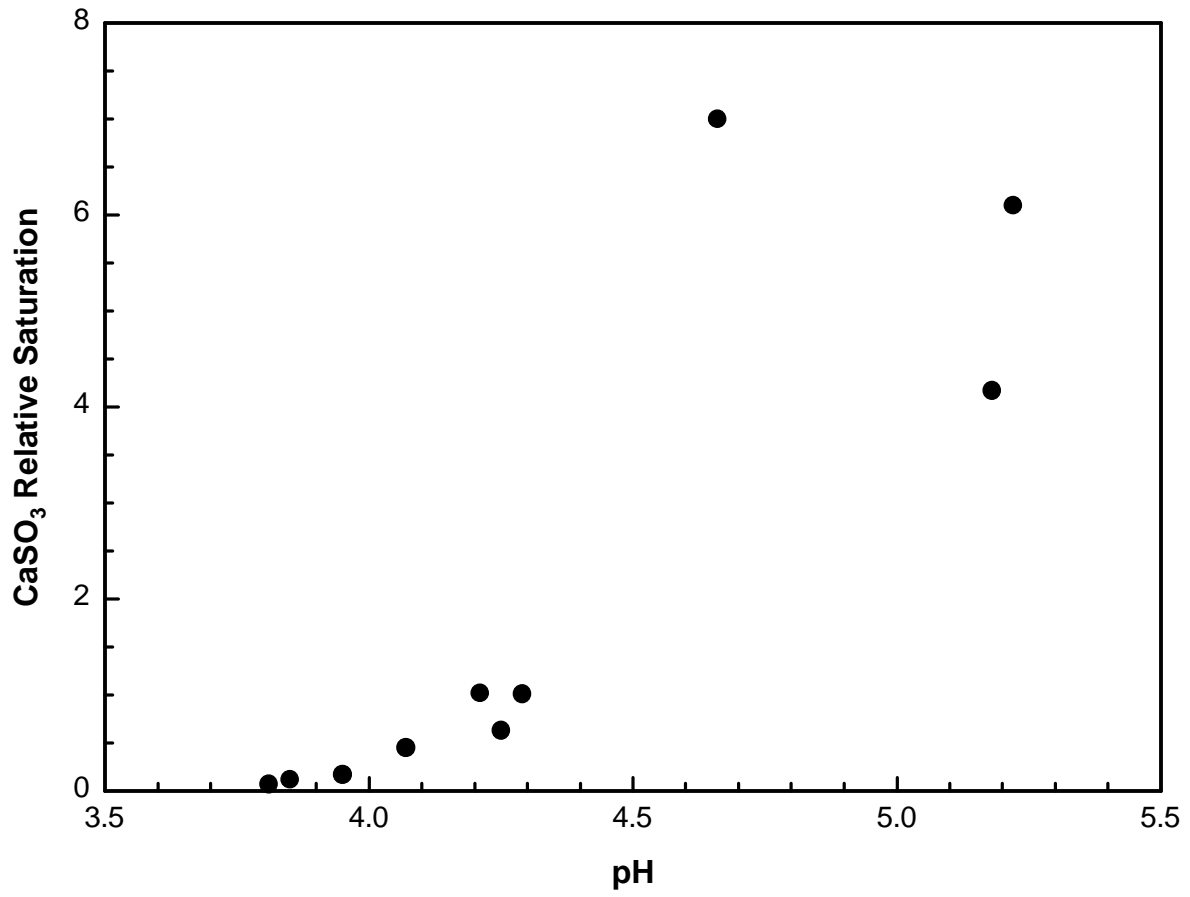


Figure 3-5. Effect of pH on Quench Calcium Sulfite Relative Saturation

must be substantial. For comparison purposes, during the 1992 performance testing, conducted at ~7.5 ft/s gas velocities, upper-loop chloride concentrations were typically 20% to 30% of the lower-loop concentrations. During the month prior to the June performance tests, with the tower operated at ~10.5 ft/s, the upper-loop chloride concentrations were typically 55% to 70% of the lower-loop concentrations. The actual chloride concentrations are not a concern, since the absorber materials are capable of handling chloride concentrations as high as 20,000 ppm. However, the impact of carry-up on the absorber material balance is a concern.

Specifically, the concern caused by increased carry-up from the lower loop to the upper loop is that this carry-up must be balanced by feeding slurry from the upper loop to the lower loop to maintain slurry levels in the two recycle tanks. Feeding slurry from the upper loop to the lower loop is a problem in that the upper-loop slurry has a comparatively high calcium carbonate concentration. This increases the amount of carbonate in the lower loop, which increases the pH. This causes difficulty in maintaining complete oxidation and may also increase the carbonate concentration (potentially making the gypsum byproduct unsuited for reuse). Minimizing the amount of carbonate fed from the upper loop to the lower loop will thus be a key part of scrubbing gas from an additional unit. Possible ways this might be accomplished include operating the upper loop at lower excess carbonate concentration and/or making mechanical changes in the absorber to reduce the amount of slurry carry-up from the lower loop to the upper loop. Further evaluation would be required to determine how to best address the problems associated with this carry-up.

Another important performance indicator is limestone utilization measured in the upper-loop and lower-loop solids. Maintaining high limestone utilization (low excess calcium carbonate concentration) is especially important in the lower loop, since high calcium carbonate concentrations can make the gypsum unsuitable for reuse. High limestone utilizations are also important in the upper loop, since upper-loop slurry added to the lower loop to maintain recycle tank levels can lead to excessive calcium carbonate concentrations in the lower loop.

The limestone utilizations for both the upper- and lower-loop sections are plotted as a function of pH in Figure 3-6. With the exception of Tests 3, 7, and 8, the lower-loop utilization values are over 98% (and CaCO_3 concentrations are less than 1.0%). During Test 3, a slightly lower utilization of ~97% (CaCO_3 concentration of 1.9%) was measured in the lower loop. The lower utilization of Test 3 appears to be caused by the addition of relatively high calcium carbonate content slurry from the upper loop to the lower loop to maintain level. However, the reason for the relatively high calcium carbonate content in the upper loop in Test 3 is not known.

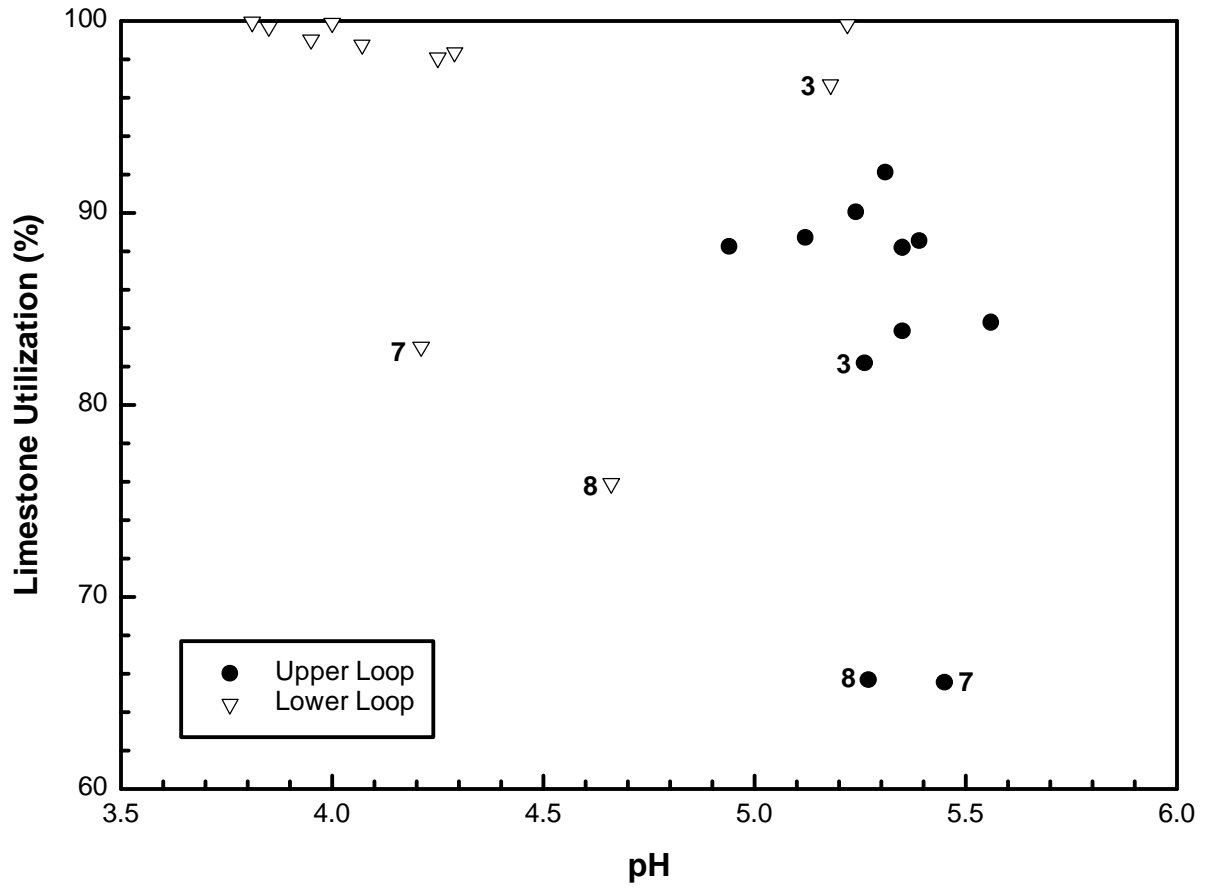


Figure 3-6. Effect of pH on Limestone Utilization

During Tests 7 and 8, the upper-and lower-loop sections each experienced limestone blinding, apparently resulting from the very rapid addition of DBA to the test absorber. Though the mechanism for this blinding is not well understood, this is a relatively common occurrence when DBA is added to a scrubber rapidly. The blinding led to very low utilization and high calcium carbonate concentrations for both of these tests. Because DBA was added to the test absorber at such a rapid rate only to facilitate these short-term tests, this blinding is not representative of what might be seen under normal conditions.

The solids analyses therefore indicate that it should be possible to meet the gypsum byproduct purity specifications while operating with the increased gas flows. Long-term operation at high gas velocities would be desirable to determine if it is possible to avoid the recurrence of the low utilization that was encountered during Test 3.

Comparison of the test data to the daily lab analyses also yield some interesting results. A summary of the calcium carbonate concentrations (wt. %) measured by Radian and by TECo is presented in Table 3-5. First, it is important to note that the samples being compared were not collected at the same time, so some variation between the analyses is to be expected. However, the analyses reported by TECo are consistently higher than those measured by Radian during the test runs. This tends to suggest that there may be some bias in the analytical methods. Because of the importance of accurate calcium carbonate analyses (which are used to assess whether or not the gypsum meets its purity specification), it may be worthwhile to perform comparative analyses on splits of the same sample to verify that accurate calcium carbonate measurements are being obtained.

3.3.4 Other Process Data

Other data collected during the high velocity performance tests include settling test measurements and process data. Settling test data were collected daily, with the objective of detecting gross changes in the solids properties. Settling test results are summarized in the Table 3-6. Results are presented in terms of unit areas; the unit area represents the amount of thickener area (in square feet) that would be required to settle one ton per day of solids to a concentration of 30 wt. %. The corrected unit areas are adjusted to account for the difference in initial weight percent solids; in this case they are all adjusted to an initial concentration of 9 wt. % solids.

The differences between tests in the measured unit areas are relatively small; they are comparable to the “scatter” seen in previous settling test data from this site. The data thus indicate that the high velocity testing did not produce any substantial changes in solids properties.

Table 3-5. Comparison of Radian and TECo Calcium Carbonate Analyses

Sample	Radian Analyses		CaCO ₃ (wt. %)	TECo Analyses	
	Date	Time		Date	CaCO ₃ (wt. %)
Upper Loop	6/2/97	15:17	9.2	6/2/97	10.9
Lower loop		15:25	0.1		1.9
Upper Loop	6/3/97	7:10	7.0	6/3/97	18.9
Lower loop		7:20	0.0		1.0
Upper Loop	6/5/97	11:05	4.6	6/5/97	18.3
Lower loop		11:15	0.1		3.0
Upper Loop	6/6/97	11:00	6.9	6/6/97	12.4
Lower loop		11:10	1.1		1.5

Table 3-6. Settling Test Results

Date	Initial wt. % Solids	Unit Area (sq. ft/tpd)	Corrected Unit Area (sq. ft/tpd)
6/3/97	9	1.1	1.1
6/4/97	13	1.0	1.5
6/5/97	14	0.8	1.8

Process data collected during these performance tests included measurements of D tower booster fan vane position, upper and lower loop pH, inlet and outlet temperatures, upper loop oxidation air flow, pump motor watts, and lower loop density. Also included were Unit 4 load, inlet SO₂ concentration, and outlet SO₂ concentration. Because the process data collected are quite voluminous, they have not been included in this Topical Report.

3.3.5 Long-Term High Velocity Testing

Following the mist eliminator and scrubber performance testing described above, TECo began a long-term test of high velocity operation. This long-term test was stopped prematurely after approximately three weeks. The objective of the long-term test was to monitor Module D performance at sulfur loadings similar to what would occur if an additional unit were scrubbed in the existing FGD system. The high sulfur loadings were obtained by firing a high sulfur fuel (in the 5.5 to 6.0 lb/MM Btu range) and operating Module D at a gas velocity of 13.5 ft/s. These conditions produce a sulfur loading that is similar to what would be seen if the scrubber operated at 16 to 17 ft/s with an inlet sulfur of 4.5 to 5.0 lb/MM Btu, the expected scrubber operating conditions if an additional unit were scrubbed.

Results of these tests showed that at the high sulfur loadings in the test absorber, the oxidation air rate available was inadequate. This apparently led to high liquid-phase sulfite concentrations, and limestone blinding became a recurrent problem. As a result, calcium carbonate concentrations in the lower loop section were frequently above the 1.5% level in the gypsum byproduct specification. According to TECo personnel, the limestone blinding was severe enough that continuing the high sulfur loading tests became difficult, so the long term testing was suspended.

Limestone blinding is reportedly a recurring problem even under the current, normal operating conditions, but the high sulfur loading to Module D made the problem significantly worse. Although no other problems were reported during these three weeks of operation, a longer duration test would be desirable to assure that scaling does not occur at the high sulfur loadings.

Because of the limestone blinding problem which caused the testing to be discontinued after three weeks, it was not conclusively determined whether the Big Bend Unit 4 FGD system can operate successfully at the high gas velocities required to also scrub flue gas from Unit 2. Further testing is warranted to determine if it is possible to consistently avoid limestone blinding episodes. Potential solutions to this problem include increasing the oxidation air rate available in each loop, reducing the amount of slurry carry-up from the lower loop to the upper loop, and operating at higher limestone utilization in the upper loop.

Appendix A
Analytical Data

Table A-1. Liquid-Phase Analyses

Description	Test 1 SO ₂ Upper Loop	Test 1 SO ₂ Lower Loop	Test 1 Run 1 Upper Loop	Test 1 Run 1 Lower Loop	Test 1 Run 2 Upper Loop	Test 1 Run 2 Lower Loop	Test 2 Upper Loop	Test 2 Lower Loop	Test 3 Upper Loop	Test 3 Lower Loop	Test 4 Upper Loop	Test 4 Lower Loop
Date	6-2-97	6-2-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97
Time	15:17	15:25	07:10	07:20	07:40	07:55	12:45	13:00	16:05	16:15	18:30	18:40
Ca, mm/L			37.1	34.9	36.8	36.2	33.9	39.0	36.8	35.4	37.9	44.6
Mg, mm/L			138.3	169.1	141.1	168.2	138.2	177.8	148.0	190.2	165.3	196.8
Na, mm/L			81.7	101.7	82.9	99.6	82.0	104.5	86.7	112.2	96.3	115.8
Cl, mm/L			236.7	307.5	251.3	310.2	235.1	325.4	253.7	348.6	280.8	355.7
CO ₃ , mm/L			2.6	2.5	3.0	2.4	3.2	2.7	3.2	3.3	4.3	3.6
SO ₃ , mm/L			0.1	5.7	0.2	9.1	0.2	9.6	0.4	19.5	1.0	24.4
SO ₄ , mm/L			63.8	61.7	58.8	60.6	55.7	62.6	55.7	61.0	60.8	61.1
Succinic, mm/L	2.3	3.3	2.1	3.2	2.8	3.2	2.6	3.6	3.7	4.0	3.7	4.2
Glutaric, mm/L	7.2	7.5	7.1	7.3	6.6	7.4	7.8	8.4	8.6	9.5	8.9	9.9
Adipic, mm/L	1.7	1.7	1.6	1.6	1.4	1.6	1.7	1.8	2.0	2.2	2.0	2.2
pH	5.56	4.00	5.35	3.81	4.94	3.85	5.39	3.95	5.26	5.18	5.24	4.29
Temp, C	55.4	55.2	54.0	54.3	54.1	54.1	54.8	54.6	54.8	54.6	54.8	54.9
Ca, mg/L			1487	1399	1476	1451	1358	1565	1475	1418	1519	1787
Mg, mg/L			3362	4111	3429	4088	3359	4321	3598	4623	4019	4784
Na, mg/L			1879	2338	1905	2289	1885	2403	1994	2580	2215	2663
Cl, mg/L			8390	10901	8910	10998	8336	11534	8994	12356	9955	12611
CO ₃ , mg/L			158	147	181	146	193	160	193	195	256	218
SO ₃ , mg/L			12	455	13	731	13	770	35	1562	81	1956
SO ₄ , mg/L			6128	5928	5645	5818	5352	6010	5352	5857	5839	5866
Succinic, mg/L	277	390	244	376	331	376	310	429	434	476	442	493
Glutaric, mg/L	947	986	932	970	871	972	1024	1116	1139	1258	1173	1309
Adipic, mg/L	245	249	229	235	205	238	242	262	290	317	299	321
Relative Saturation												
Gypsum			1.23	1.05	1.14	1.06	1.01	1.13	1.04	0.89	1.08	1.14
CaSO ₃ *0.5H ₂ O			0.05	0.07	0.03	0.12	0.06	0.17	0.13	4.17	0.27	1.01
CaCO ₃			0.01	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.01	0.00

Table A-1 (continued)

Description	Test 5 Run 1 Upper Loop	Test 5 Run 1 Lower Loop	Test 5 Run 2 Upper Loop	Test 5 Run 2 Lower Loop	Test 6 Upper Loop	Test 6 Lower Loop	Test 7 Upper Loop	Test 7 Lower Loop	Test 8 Upper Loop	Test 8 Lower Loop
Date	6-5-97	6-5-97	6-5-97	6-5-97	6-6-97	6-6-97	6-6-97	6-6-97	6-6-97	6-6-97
Time	11:05	11:15	13:45	13:55	11:00	11:10	13:25	13:35	15:45	15:55
Ca, mm/L	37.4	43.0	39.2	42.0	34.3	38.9	41.2	45.9	44.9	61.3
Mg, mm/L	224.7	265.1	229.8	270.3	185.9	238.4	204.8	274.4	224.3	293.2
Na, mm/L	129.1	155.4	133.2	159.2	109.7	137.7	118.9	160.4	131.0	169.6
Cl, mm/L	403.8	497.6	407.0	494.4	315.3	421.4	359.8	510.9	393.9	546.3
CO ₃ , mm/L	3.8	3.6	4.0	3.3	3.7	2.9	4.4	3.0	4.4	4.7
SO ₃ , mm/L	1.3	24.6	1.2	20.4	0.5	19.8	1.0	31.5	0.4	65.2
SO ₄ , mm/L	72.9	75.9	72.8	79.0	68.5	74.1	68.6	75.4	67.6	64.7
Succinic, mm/L	3.9	4.5	4.3	4.9	2.8	3.7	5.4	6.0	7.3	8.0
Glutaric, mm/L	9.4	11.2	10.7	12.1	6.9	9.0	13.1	14.7	17.7	19.3
Adipic, mm/L	2.5	2.5	2.6	2.6	2.0	2.0	3.4	3.3	4.4	4.4
pH	5.31	5.22	5.12	4.07	5.35	4.25	5.45	4.21	5.27	4.66
Temp, C	55.3	55.1	55.4	55.4	55.5	55.5	55.5	56.1	55.4	56.4
Ca, mg/L	1501	1723	1571	1683	1373	1560	1652	1838	1798	2456
Mg, mg/L	5463	6445	5586	6571	4520	5796	4979	6670	5452	7129
Na, mg/L	2968	3573	3062	3661	2521	3165	2735	3688	3011	3899
Cl, mg/L	14315	17641	14429	17528	11178	14939	12756	18112	13965	19366
CO ₃ , mg/L	227	215	240	196	223	175	267	183	263	280
SO ₃ , mg/L	104	1972	99	1635	43	1589	79	2521	36	5221
SO ₄ , mg/L	7001	7288	6991	7593	6582	7115	6587	7244	6491	6215
Succinic, mg/L	456	536	510	574	330	435	632	712	865	949
Glutaric, mg/L	1240	1484	1414	1594	913	1185	1735	1947	2340	2552
Adipic, mg/L	365	363	384	384	291	294	492	479	641	636
Relative Saturation										
Gypsum	1.03	1.06	1.07	1.15	1.03	1.09	1.10	1.16	1.09	1.17
CaSO ₃ *0.5H ₂ O	0.36	6.10	0.25	0.45	0.16	0.63	0.38	1.02	0.13	7.00
CaCO ₃	0.02	0.01	0.01	0.00	0.02	0.00	0.04	0.00	0.02	0.00

Table A-2. Solid-Phase Analyses

Description	Test 1 SO ₂ Upper Loop	Test 1 SO ₂ Lower Loop	Test 1 Run 2 Upper Loop	Test 1 Run 1 Lower Loop	Test 1 Run 2 Upper Loop	Test 1 Run 2 Lower Loop	Test 2 Upper Loop	Test 2 Lower Loop	Test 3 Upper Loop	Test 3 Lower Loop	Test 4 Upper Loop	Test 4 Lower Loop
Date	6-2-97	6-2-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97	6-3-97
Time	15:17	15:25	07:10	07:20	07:40	07:55	12:45	13:00	16:05	16:15	18:30	18:40
Ca, mm/g	6.25	6.05	6.35	5.93	6.24	5.98	6.18	6.01	6.34	5.98	6.04	6.07
Mg, mm/g	0.02	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.02	0.01	0.01	0.00
SO ₃ , mm/g	0.01	0.01	0.01	0.01	0.00	ND	0.01	0.01	0.01	0.02	ND	0.01
SO ₄ total, mm/g	4.95	5.65	5.05	5.67	5.27	5.66	5.26	5.66	5.03	5.57	5.32	5.60
SO ₄ , mm/g	4.95	5.65	5.05	5.66	5.27	5.66	5.25	5.65	5.02	5.56	5.32	5.58
CO ₃ , mm/g	0.92	0.01	0.97	0.00	0.70	0.02	0.68	0.06	1.09	0.19	0.59	0.09
Inerts, Wt. %	1.24	1.08	1.36	1.12	1.20	1.16	1.24	1.32	1.32	1.28	0.88	1.04
Solids, Wt. %	10.65	10.72	8.81	7.87	12.30	9.02	9.50	10.68	11.01	11.50	12.00	13.00
pH	5.56	4	5.35	3.81	4.94	3.85	5.39	3.95	5.26	5.18	5.24	4.29
Temp, C	55.4	55.2	54	54.3	54.1	54.1	54.8	54.6	54.8	54.6	54.8	54.9
Reagent util, %	84.3	99.9	83.9	99.9	88.3	99.7	88.5	99.0	82.2	96.7	90.0	98.4
Reagent ratio	1.19	1.00	1.19	1.00	1.13	1.00	1.13	1.01	1.22	1.03	1.11	1.02
Oxidation, %	99.9	99.9	99.9	99.9	100.0	100.0	99.8	99.8	99.8	99.7	100.0	99.8
Solid solution, Wt.%	0.1	0.1	0.1	0.1	0.0	0.0	0.2	0.2	0.2	0.2	0.0	0.2
Gypsum, Wt. %	85.1	97.1	86.8	97.4	90.6	97.4	90.2	97.2	86.3	95.5	91.5	96.0
CaCO ₃ , Wt. %	9.2	0.1	9.7	0.0	7.0	0.2	6.8	0.6	10.9	1.9	5.9	0.9
Inerts, Wt. %	1.2	1.1	1.4	1.1	1.2	1.2	1.2	1.3	1.3	1.3	0.9	1.0
Closures												
Weight, %	-2.8	-0.1	-0.7	-0.3	-0.1	-0.1	-0.6	0.4	-0.4	-0.2	-1.2	-0.3
Molar, %	3.2	3.4	2.8	2.3	2.3	2.6	2.1	2.5	2.0	1.9	1.2	3.3
Acceptable, %	6.6	7.1	6.6	7.1	6.7	7.1	6.7	7.0	6.5	6.9	6.7	7.0

Table A-2 (continued)

Description	Test 5 Run 1 Upper Loop	Test 5 Run 1 Lower Loop	Test 5 Run 2 Upper Loop	Test 5 Run 2 Lower Loop	Test 6 Upper Loop	Test 6 Lower Loop	Test 7 Upper Loop	Test 7 Lower Loop	Test 8 Upper Loop	Test 8 Lower Loop
Date	6-5-97	6-5-97	6-5-97	6-5-97	6-6-97	6-6-97	6-6-97	6-6-97	6-6-97	6-6-97
Time	11:05	11:15	13:45	13:55	11:00	11:10	13:25	13:35	15:45	15:55
Ca, mm/g	6.28	5.96	6.19	6.02	6.27	5.92	6.83	6.36	6.90	6.52
Mg, mm/g	0.01	0.00	0.02	0.00	0.01	0.00	0.04	0.02	0.04	0.03
SO ₃ , mm/g	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.08
SO ₄ total, mm/g	5.39	5.65	5.27	5.62	5.16	5.62	4.30	5.04	4.34	4.79
SO ₄ , mm/g	5.39	5.63	5.26	5.60	5.15	5.60	4.28	5.02	4.32	4.71
CO ₃ , mm/g	0.46	0.01	0.67	0.07	0.69	0.11	2.26	1.03	2.27	1.52
Inerts, Wt. %	0.68	0.80	0.48	0.68	0.68	0.36	0.80	0.76	0.52	0.76
Solids, Wt. %	13.13	14.46	14.01	15.16	12.33	14.54	17.75	20.51	20.48	25.13
pH	5.31	5.22	5.12	4.07	5.35	4.25	5.45	4.21	5.27	4.66
Temp, C	55.3	55.1	55.4	55.4	55.5	55.5	55.5	56.1	55.4	56.4
Reagent util, %	92.1	99.8	88.7	98.8	88.2	98.1	65.5	83.0	65.7	75.9
Reagent ratio	1.09	1.00	1.13	1.01	1.13	1.02	1.53	1.20	1.52	1.32
Oxidation, %	99.9	99.8	99.8	99.8	99.8	99.7	99.5	99.6	99.5	98.3
Solid solution, Wt.%	0.1	0.2	0.1	0.2	0.2	0.2	0.3	0.3	0.3	1.3
Gypsum, Wt. %	92.6	96.8	90.5	96.3	88.5	96.3	73.5	86.3	74.3	80.7
CaCO ₃ , Wt. %	4.6	0.1	6.7	0.7	6.9	1.1	22.6	10.3	22.7	15.2
Inerts, Wt. %	0.7	0.8	0.5	0.7	0.7	0.4	0.8	0.8	0.5	0.8
Closures										
Weight, %	-0.2	-0.9	-1.1	-0.7	-2.0	-1.2	-1.6	-1.1	-0.9	-1.1
Molar, %	3.7	2.6	2.1	2.9	3.6	1.7	2.3	2.5	2.4	1.8
Acceptable, %	6.8	7.1	6.7	7.0	6.7	7.0	6.2	6.6	6.2	6.4