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High SO₂ Removal Efficiency Testing

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**Topical Report
Results of DBA and Sodium Formate Additive Tests
at Southwestern Electric Power Company's
Pirkey Station**

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

Page

LIST OF FIGURES (Continued)

LIST OF TABLES

ACKNOWLEDGMENT

SUMMARY

Tests were conducted at Southwestern Electric Power Company's (SWEPCo) Henry W. Pirkey Station wet limestone flue gas desulfurization (FGD) system to evaluate options for achieving high sulfur dioxide removal efficiency. The Pirkey FGD system includes four absorber modules, each with dual slurry recirculation loops and with a perforated plate tray in the upper loop. The options tested involved the use of dibasic acid (DBA) or sodium formate as a performance additive. The effectiveness of other potential options was simulated with the Electric Power Research Institute's (EPRI) <u>F</u>GD <u>PR</u>ocess <u>I</u>ntegration and <u>S</u>imulation <u>M</u>odel (FGDPRISM) after it was calibrated to the system. An economic analysis was done to determine the cost effectiveness of the high-efficiency options. Results are summarized below.

<u>SO$_2$ Removal Performance.</u> Baseline tests on one module of the Pirkey FGD system showed that, at normal full-load operating conditions, the SO$_2$ removal efficiency of Module C was about 96%. Normal operating conditions include inhibited oxidation, pH set points of 6.3 in the upper loop and 5.5 in the lower loop, a superficial flue gas velocity of 8 ft/s through the absorber, and liquid-to-gas ratios (L/G) of 19 gallons/1000 actual ft^3 (gal/kacf) of flue gas in the lower loop and 48 gal/kacf in the upper loop.

Tests with DBA additive showed that Module C's SO$_2$ removal efficiency could be increased to 99.5+% at an upper-loop DBA concentration of about 2300 ppm. An upper-loop DBA concentration of about 400 ppm was required for 98+% SO$_2$ removal at the normal pH set points. Tests with sodium formate additive resulted in similar performance at equal additive concentrations (comparing DBA concentrations with formate ion concentrations).

DBA and sodium formate additives both had significant beneficial effects on process chemistry. Both of the additives acted as sulfite oxidation inhibitors, which is an important result for Pirkey where it has been difficult to maintain low sulfite oxidation percentages using the conventional sulfur additive. Both DBA and formate reduced oxidation

S-1

percentages from the 15 to 20% range normally experienced in the Pirkey FGD system to about 10%. Both additives also increased limestone utilization at a given operating pH.

Both of the additives appeared to increase the settling rate of the slurry solids, but the effect of DBA was much greater. Solids produced with DBA in the system were larger and thicker than the baseline solids. The slurry settling rate, final settled solids density, and filter cake solids content all increased during operation with DBA additive.

Additive Consumption. A long-term, system-wide additive, consumption test showed that at an average load of 520 MW, a DBA feed rate of about 100 lb/hr was required to maintain a DBA concentration of 1100 ppm in the reaction tanks . About 80% of the total DBA consumption was accounted for by nonsolution losses (losses other than with liquor leaving the FGD system). On an SO_2 removal basis, the measured DBA consumption rate was 11 ± 4 lb DBA per ton of SO_2 removed. Although a long-term test was not done with sodium formate, a consumption estimate using the parametric test data showed that the formate consumption rate was about the same as the DBA consumption rate. The delivered price of formate (as sodium formate) at Pirkey is about 50% higher than that for DBA, however, so DBA appears to be the preferred additive for this FGD system.

SO_2 Removal Upgrade Economics. The economics of DBA addition were evaluated based on a capital cost of $300,000 for a 100 lb/hr additive storage and delivery system, operating costs provided by SWEPCo, and a delivered DBA cost of $0.26/lb provided by DuPont. At Pirkey, the FGD system is normally operated with about 30% flue gas bypass. The baseline test results and economic evaluation showed that more than 90% of the current SO_2 emissions (approximately 20,000 tons/yr) could be removed merely by operating the system without bypass, even without DBA. The marginal cost of additional SO_2 removal obtained solely by operating without bypass would be about $50/ton.

An additional 500 to 800 tons/yr of SO_2 removal can be obtained using DBA at essentially no net marginal cost. The cost of DBA additive is offset by savings due to increased

limestone utilization and decreased fan power (because of the anticipated effects of reduced gypsum scaling with DBA addition). The optimum removal efficiency with DBA addition appears to be about 99%. The net value of additional SO_2 removed by closing the bypass and using DBA is about $4 million per year if allowances are valued at $250, and $2 million per year if allowances are valued at $150.

Additional results of the economic evaluation suggest that DBA addition at Pirkey could be cost effective even without increasing the system SO_2 removal. Depending on what value is assumed for the baseline limestone utilization, an annual savings of up to $200,000 could be realized using DBA additive while operating the system in its current mode, with partial flue gas bypass.

These costs for achieving upgraded SO_2 removal levels appear to be very attractive. The incremental costs for Pirkey Station to implement the DBA additive options are less than $50 per additional ton of SO_2 removed. In the first EPA auction for SO_2 allowances, the average successful bid price was about $150/ton. EPRI estimates that during the "transition" period for Phase 2 of the Clean Air Act Amendments (the years 2000 through 2005), emission allowance market prices will range from $250 to $500/ton SO_2 (in 1992 dollars).[1] Furthermore, we estimate that the cost of generating SO_2 allowances by installing new FGD capacity on units firing Texas lignite would be at the upper end of this $250/ton to $500/ton range. Thus, SO_2 allowances generated at a cost of less than $50/ton in existing FGD systems should be very desirable.

Reference

1.   I. Torrens and J. Platt, "Update on Electric Utility Response to the CAA, "ESC Update, No. 30, Fall 193, p. 3.

1.0 INTRODUCTION

This report describes the results of tests conducted at Southwestern Electric Power Company's (SWEPCo) Henry W. Pirkey Power Station to evaluate options for upgrading the flue gas desulfurization (FGD) system's SO_2 removal efficiency. The use of dibasic acid (DBA) or sodium formate as a performance additive was investigated. The objective of these tests was to obtain performance data needed to evaluate the cost-effectiveness of upgrading an existing FGD system as part of a utility's strategy for meeting Phase I or II requirements of the Clean Air Act Amendments.

1.1 Background

Provisions of the Clean Air Act Amendments of 1990 call for a ten-million ton per year reduction in U.S. SO_2 emissions (from a 1980 baseline) in two phases. Phase I calls for a five-million ton per year reduction by 1995, and the remainder of the reductions are to be completed by the year 2000 for Phase II. Affected utilities have a number of options for achieving these reductions, such as switching to lower sulfur-content coals, installing new FGD systems, and improving the SO_2 removal performance of existing FGD systems. Some utilities may employ a combination of these and other options as part of an overall compliance strategy.

The Flue Gas Cleanup (FGC) Program at the U.S. Department of Energy Pittsburgh Energy Technology Center (DOE PETC) helps to maintain and foster the widespread use of coal by developing technologies that will mitigate the environmental impacts of coal utilization. The program focuses on post-combustion technologies for the control of SO_2, oxides of nitrogen, particulates, and air toxics generated from coal combustion. A portion of the FGC Program, including this project, involves enhancing the SO_2 removal efficiencies of existing wet FGD systems. The results from this project will allow utilities to better consider enhanced performance of existing FGD systems as an option for achieving compliance with Phase I and/or Phase II of the Clean Air Act Amendments.

In this project, Radian Corporation has conducted tests at six full-scale FGD systems to evaluate options for achieving high SO_2 removal efficiencies (95 to 98% removal). Each system is being characterized under baseline operation, and then with additives or with other modifications to enhance SO_2 removal performance.

The systems evaluated are at the Tampa Electric Big Bend Station, the Hoosier Energy Merom Station, the Southwestern Electric Power Company Pirkey Station, the PSI Energy Gibson Station, the Duquesne Light Elrama Station, and the New York State Electric and Gas Corporation Kintigh Station. A wide variety of FGD system vendors and designs are represented in the program. Most of these systems were designed to achieve 85 to 90% SO_2 removal.

This topical report includes only the results from the third site, at Southwestern Electric Power Company's Henry W. Pirkey Station near Hallsville, Texas.

1.2 Project Description

Three types of performance tests were completed at Pirkey. First, "baseline" tests were done to obtain performance data without the additives. Then, "parametric" tests were done to obtain performance data using DBA or sodium formate additive at various concentrations. The baseline and parametric tests were conducted using only one of the four scrubber modules. Following the parametric tests, a steady-state DBA consumption test was done, during which DBA was added to the entire FGD system.

Under a separate project funded by the Electric Power Research Institute (EPRI), the results of the baseline and parametric tests were used to calibrate the Electric Power Research Institute's (EPRI's) FGD PRocess Integration and Simulation Model (FGDPRISM) to the Pirkey scrubber configuration. FGDPRISM was then used to predict system performance for evaluating conditions other than those tested.

Economic calculations were conducted to determine the most cost-effective approach for achieving the project target of 95 to 98% SO_2 removal with the Pirkey FGD system. Actual and predicted performance results, along with the actual steady-state DBA consumption data, plus other pertinent cost information provided by SWEPCo, provided the basis for the economic evaluation. In this evaluation, the net marginal cost of additional tons of SO_2 removed was estimated for different operating conditions and DBA concentrations. These costs can be compared with the expected market value of SO_2 allowances or the expected cost of allowances generated by other means, such as fuel switching or new scrubbers, to arrive at the most cost-effective operating conditions for Clean Air Act compliance.

1.3   Report Organization

The performance tests are described and the results are presented and discussed in Section 2 of this topical report. The FGDPRISM calibration procedure and performance predictions are discussed in Section 3, and the economic evaluation is addressed in the final section. Detailed results and calculations are included as Appendices A through F.

2.0 FULL-SCALE TESTING DESCRIPTION AND RESULTS

This section describes the full-scale FGD system tests conducted at SWEPCo's Pirkey Station and provides an overview of the results. The tests were conducted to evaluate methods of achieving high SO_2 removal efficiency at Pirkey, and followed a methodology that has been used for other sites included in this DOE-PETC program.

The testing began with baseline tests on a single module of the FGD system. This established the "as-found" performance of the system. Next, two series of short-term parametric tests were conducted, also on a single module, to demonstrate performance with DBA and sodium formate additives. Following these tests, an additive consumption test was done with DBA being added to the entire FGD system. In this test, the DBA addition rate required to maintain high SO_2 removal efficiency was measured so that the cost of this upgrade approach could be more accurately determined.

This section presents and discusses the results from each of these four test series at the Pirkey site. In Section 2.1, the FGD system is briefly described. The test approach and measurement methods are outlined in Sections 2.2 and 2.3. Results for the baseline, DBA, and formate performance tests are presented in Sections 2.4, 2.5, and 2.6, respectively. In Section 2.7, the results from the system-wide DBA consumption test are described. Section 2.8 discusses the effects of the DBA and sodium formate additives on FGD byproduct solids dewatering properties.

2.1 FGD System Description

Figure 2-1 illustrates the arrangement of a single scrubber module of the FGD system at SWEPCo's Pirkey Power Plant. The system includes four modules that typically treat about 70 to 80% of the flue gas from a 720-MW lignite-fired boiler. Each scrubber module is a dual-loop unit supplied by UOP Air Correction Division and modified by SWEPCo to incorporate a perforated plate tray in the upper loop. The lower loop has two spray headers, and
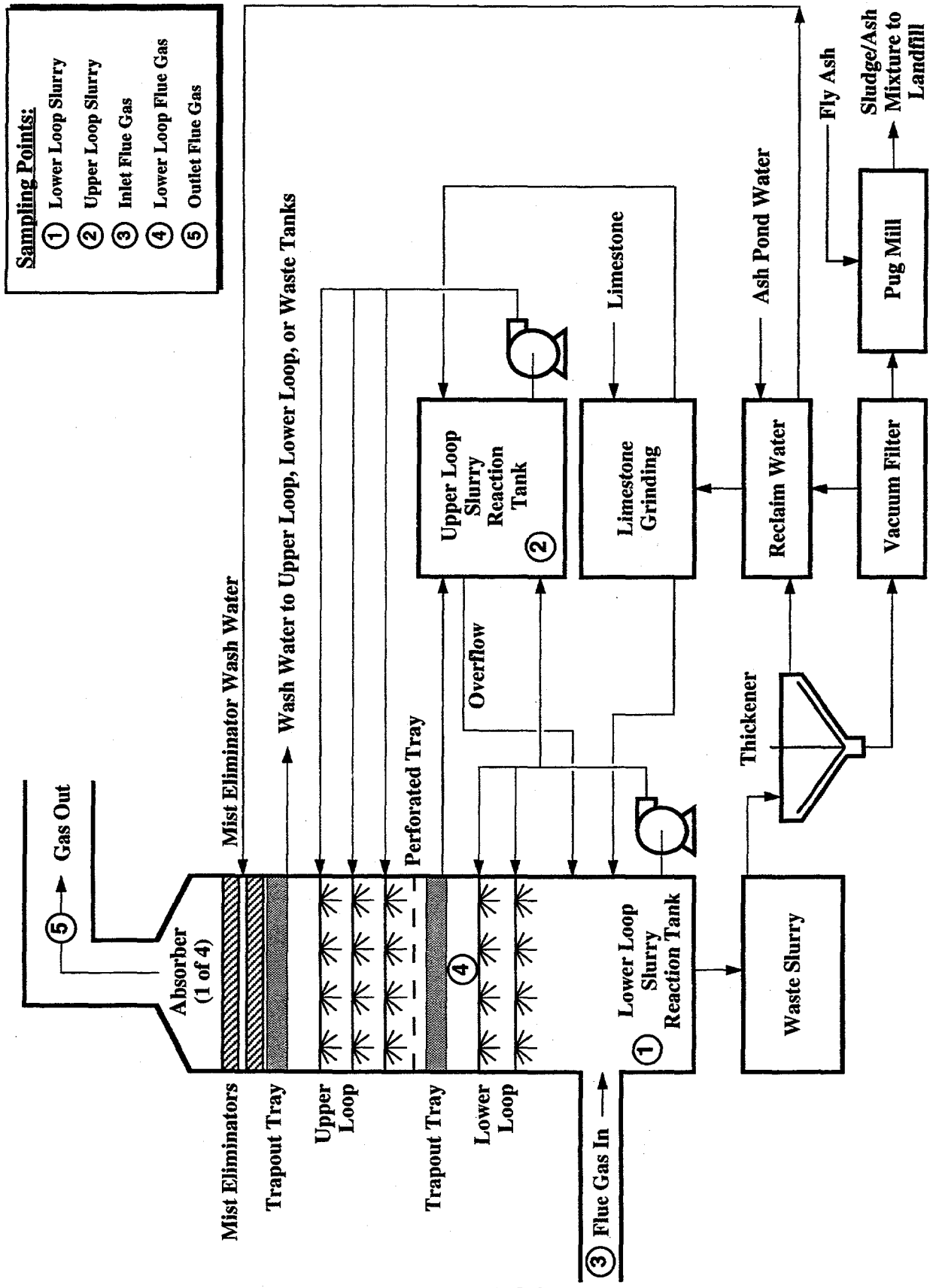
Figure 2-1. Simplified Process Flow Diagram for Pirkey FGD System

slurry is recycled to these headers from an integral reaction tank in the base of the module. The upper loop has three spray headers located above the tray. Slurry is recycled to the upper headers from one of two large reaction tanks, each of which serves two modules. The slurry flow rate to the lower-loop spray headers corresponds to a liquid-to-gas ratio (L/G) of about 19 gallons/1000 actual cubic feet of gas. The upper-loop L/G is about 48 gal/kacf.

Mist eliminator wash water is supplied at a constant rate to each of the modules. The wash water is collected on troughs below the mist eliminator and is distributed to either the upper- or lower-loop reaction tank or bypassed to the waste slurry sump, as required to control the slurry densities in the module. The upper- and lower-loop tanks are set up to maintain level by gravity overflow, where the upper tank overflows to the lower tank and the lower tank overflows to the waste slurry sump. During operation though, a portion of the upper-loop slurry tends to overflow from the trap-out trays directly into the lower loop, causing the level of the upper-loop tank to drop. A portion of the lower-loop slurry is returned to the upper-loop tank from the lower-loop spray header as required to make up level. As a result of this configuration, the two loops have similar dissolved species concentrations and cannot be operated at completely independent slurry pH set points. However, the upper loop is typically maintained at a higher pH than the lower loop.

Waste slurry from the lower-loop tanks of the four modules flows to a common waste sump and is pumped to two parallel thickeners. Underflow from the thickeners is stored in a waste slurry surge tank and processed by vacuum filters. Filter cake is combined with fly ash in a pug mill and the stabilized product is landfilled. Thickener overflow and filtrate are returned to the reclaim tank for use as mist eliminator wash and for limestone grinding. System makeup water from the ash pond is added to the reclaim tank to maintain level.

2.2 Test Approach

During the baseline and parametric tests, the performance of a single module (Module C) was measured by sampling the flue gas at the module inlet, outlet, and between the two loops.

Slurry samples from the upper- and lower-loop reaction tanks were obtained concurrently with the flue gas samples. Sampling locations are indicated on Figure 2-1. The flue gas volume treated by Module C was held constant at a specified operating condition by adjusting the total system bypass damper to maintain a constant pressure drop across the Module C mist eliminator. In this manner, the Module C test conditions could be maintained independent of boiler load.

2.2.1 Baseline Tests

For the baseline tests, planned independent variables included upper- and lower-loop slurry pH and flue gas velocity. The first baseline test was conducted at SWEPCo's normal operating conditions, which were held constant for two days. This test duration was adequate to approach steady-state conditions with respect to solids properties in the test module. For this two-day test, performance indicators included SO_2 removal efficiency, limestone utilization, extent of oxidation, slurry relative saturations, and solids dewatering properties. The remaining baseline tests were of half-day duration. For these shorter tests, SO_2 removal efficiency and limestone utilization were the primary performance indicators, as solids properties were not expected to reach steady-state conditions during these tests.

The conditions for Baseline Tests 2 through 4 were chosen to represent extremes of the operating range of interest. Measurements of SO_2 removal efficiency and limestone utilization over a wide pH range are most useful for calibrating FGDPRISM. Tests 5 and 6 were planned at high flue gas velocity in the test module to simulate three-module operation, which was the original design configuration for the system. In practice, the flue gas velocity in the test module could not be increased significantly during Test 5 due to operating limits on the inlet duct pressure. Therefore, the conditions for Test 1 were repeated in Test 6.

2.2.2 Parametric Tests

For the parametric tests, independent variables were the same as those for the baseline tests with slurry liquor DBA or sodium formate concentration as an additional variable.

Each of the two parametric test series was arranged in groups of two tests each at three increasing levels of additive concentration. At each additive level, the pair of tests included one at higher upper- and lower-loop slurry pH set points and one at lower set points. A single test at a fourth DBA concentration was included in the DBA parametric tests.

The first parametric test at both the lowest and highest additive levels (Tests 1 and 5) were two-day tests so that the effect of increasing additive concentration on solids properties could be evaluated. All of the other tests were one-day tests for which the major performance indicators were SO_2 removal efficiency and limestone utilization.

The additives were introduced into the upper-loop reaction tank of the test module from a tanker-trailer parked adjacent to the FGD system. Additives were fed continuously to the upper-loop reaction tank of the test module to maintain the desired concentrations during the parametric tests. Prior to each test, additive concentrations were measured by buffer capacity titration, and adjusted if necessary by pumping more DBA or sodium formate from the tanker to the upper-loop reaction tank.

Because the parametric tests were conducted on a single module, additive concentrations did not reach steady-state levels in other portions of the FGD system. As the tests proceeded, the additive concentration gradually increased in the process water returning to the module with the limestone slurry feed and mist eliminator wash. This concentration was measured daily and the additive feed rate to the test module was adjusted accordingly.

2.2.3 Additive Consumption Test

The objective of the consumption test was to measure the DBA addition rate required to maintain overall system SO_2 removal at 98% without flue gas bypass. This would be the desired operating mode to earn excess SO_2 allowances. A target DBA concentration (1000 ppm) and lower than normal pH set points (6.0 upper loop, 5.2 lower loop) were selected based on the results of the DBA parametric tests. These conditions were expected to yield the desired

SO$_2$ removal performance while maintaining high limestone utilization (95+%) and, as discussed later in this section, low oxidation percentages.

The consumption rate of DBA was determined by performing a DBA mass balance on the entire FGD system. This required monitoring DBA addition rates, DBA losses with liquor adhering to the filter cake, and changes in DBA inventory over the duration of the test. Just prior to the test, sufficient DBA was added to the entire FGD system to bring the concentration to the target level. After the initial spike was completed, DBA was added continuously to both of the system upper-loop reaction tanks for a period of seven days.

The DBA addition term was obtained by measuring the change in the DBA tanker level and using the results of the tanker DBA component chemical analysis. DBA is a mixture of adipic, glutanic, and succinic acids. The DBA solution loss term was obtained by multiplying the total filter cake production for a given test period by the average filter cake moisture content and filtrate DBA concentration.

DBA inventories were conducted once each day and consisted of recording all tank levels and taking samples from each tank. All of the samples were analyzed for DBA on site by buffer capacity titration. Four of the seven inventory sample sets were also analyzed in Radian's Austin FGD laboratory. The DBA inventory change term in the material balance for a given test period was calculated as the difference in the total DBA inventory at the beginning and end of the period.

2.3   Test Measurements

2.3.1   Flue Gas Sampling

The primary performance measurements obtained at the site included inlet, outlet, and lower-loop exit flue gas SO$_2$ concentrations. Inlet concentrations were measured using SWEPCo's existing on-line certified SO$_2$ analyzer. The accuracy of this analyzer was verified by

pre-test Method 6 samples at the FGD system inlet. Lower-loop SO_2 concentrations were measured by Radian using EPA Method 6, with a flue gas sample pulled from a single pressure tap port penetrating the module wall below the trap-out trays. Outlet concentrations were measured by Radian using Method 6 with a gas sample obtained by a 24-point traverse across the outlet duct.

During a typical half-day baseline test, duplicate Method 6 traverses were done at the outlet sample location, while duplicate single-point Method 6 samples were obtained at the lower-loop exit gas sample location. Flue gas velocity was also measured at the outlet location. For baseline and parametric tests with longer durations, the half-day gas-sampling routine was repeated, so that four sets of lower-loop exit and outlet flue gas SO_2 measurements were usually obtained for the one-day tests and eight sets were obtained for the two-day tests.

Flue gas SO_2 concentrations were determined on site from the Method 6 samples using the barium perchlorate titration procedure. These on-site analyses were used to verify that the results were reasonable and to make testing decisions. The remaining Method 6 impinger solutions were shipped to Radian's Austin laboratory where the analyses were repeated using the more accurate ion chromatography (IC) method.

2.3.2   Slurry Sampling

During each half-day test, three sets of upper- and lower-loop recycle slurry samples were obtained by Radian concurrent with the two Method 6 samples. The first set of slurry samples was taken at the beginning of the first Method 6 sample set, the second set was taken in between the two Method 6 sample sets, and the third slurry sample set was taken following the second Method 6 sample set. The second slurry sample set included filtered and whole stabilized slurry samples, which were analyzed for liquid-phase species.

During one-day parametric tests, two sets of filtered slurry samples and three sets of slurry samples were taken. The filtered slurry sample sets were concurrent with the first and

third slurry samples and were taken approximately midway through the morning and afternoon Method 6 sample sets. The second whole slurry sample set was taken between the morning and afternoon sample sets.

During the two-day baseline test, three sets of slurry and filtered slurry samples were obtained, all on the second day of the test. These samples were taken midway through each of three sets of duplicate Method 6 samples.

During the two-day parametric tests, the one-day slurry sampling schedule was repeated. Four sets of filtered slurry samples and six sets of slurry samples were taken.

2.3.3 Chemical Analyses of Slurry and Filtrate Samples

For the baseline and parametric tests, all of the slurry samples were analyzed for solids content and solid-phase carbonate. These results were used to calculate limestone loading and utilization, which are important performance parameters. Limestone utilization can change relatively quickly with operating pH.

Complete solid-phase analyses including calcium, magnesium, sulfite, and sulfate were done for only one of the half-day test slurry samples and two of the one- and two-day test slurry samples. The complete solid-phase analyses are used to calculate the oxidation fraction. This is also an important performance parameter, but the time constant for changes in slurry solids composition is much longer than for changes in utilization alone. The oxidation fraction is also not as sensitive to minor changes in operating pH.

All of the filtrate samples were analyzed for liquid-phase calcium, sulfite, sulfate, and carbonate. These results were used to estimate calcium sulfite, sulfate, and carbonate relative saturations, which are important process chemistry indicators that can change relatively quickly with changes in test conditions, especially pH. Only one filtrate sample per day was analyzed for soluble species such as magnesium, sodium, and chloride. The time constant for

2-8

changes in these soluble species concentrations is usually on the order of weeks. Therefore, these concentrations were not expected to vary significantly during a test day.

One upper- and lower-loop liquor sample from the baseline test series and two from each of the parametric test series were analyzed for 26 elements using inductively coupled plasma emissions spectroscopy (ICPES).

For the additive consumption test, samples were analyzed for DBA components by ion exclusion chromatography to determine the FGD system DBA inventory and to determine DBA solution losses with the filter cake. Concentrations of the three DBA component acids-- succinic (C4), glutaric (C5), and adipic (C6)--were determined. Additional slurry solid and liquor samples were analyzed to evaluate the same process parameters (e.g., utilization, oxidation, and relative saturations) that were evaluated during the short-term tests.

2.3.4   Other Process Data

Other appropriate process data including stream temperatures, pressures, and flow rates were gathered from plant instrumentation where available. Slurry flow rates to the spray headers in the lower and upper loops were measured using a portable ultrasonic flowmeter. During the additive consumption test, the FGD system was operated without flue gas bypass so that SO_2 removal could be determined using the plant continuous monitors. Flue gas flow rates during this period were estimated by combustion calculation.

Slurry samples were also used to conduct settling rate and filtration tests so that potential effects of additives on solids dewatering properties could be evaluated. Scanning electron microscopy was used to compare the morphology of crystals formed with and without the presence of additives in the system.

2.4   <u>**Baseline Test Conditions and Results**</u>

2.4.1   **Baseline Test SO$_2$ Removal Efficiency**

Table 2-1 summarizes the average test conditions and SO$_2$ removal efficiency results for the baseline tests. The inlet SO$_2$ concentrations are reported on a dry flue gas basis, which is the basis of the SWEPCo inlet SO$_2$ analyzer data. More detailed test data for the individual Method 6 runs are included in Appendix A.

Baseline Test 1 began after two continuous days of Module C operation at SWEPCo's normal conditions. The Module C lower-loop slurry pH set point was maintained at 5.5 and the upper-loop slurry pH set point at 6.3 throughout this test. The actual pH levels during Test 1 were about 5.7 in the lower loop and 6.3 in the upper loop.

Results of the outlet Method 6 samples showed an average overall SO$_2$ removal efficiency of about 97% for the test module at normal operating conditions. The results for the duplicate lower-loop flue gas samples were in poor agreement during Test 1. The slurry droplets present at this sample location appeared to interfere with the Method 6 SO$_2$ measurement.

In Baseline Test 2, the pH set point was lowered to 6.0 in the upper loop and the lower-loop pH was allowed to stabilize without limestone feed. The actual upper-loop pH during Test 2 averaged about 5.9 and was relatively steady. The lower-loop pH ranged from about 5.1 to 5.4 and averaged 5.3. The overall SO$_2$ removal efficiency for Test 2 averaged about 92% at this lower pH set point. Poor reproducibility was again seen for Method 6 flue gas samples for the lower-loop location.

Baseline Test 3 was completed after increasing the lower-loop pH to the maximum obtainable with the upper-loop set point held at 6.0. The measured pH levels in this test averaged 6.0 in the upper loop and 5.7 in the lower loop. For Test 3, the lower-loop flue gas sample was obtained at a different sample port (just below the trap-out tray), and the probe end

Table 2-1

Average Baseline Test Conditions and Results

| Test No. | Slurry pH | | Flue Gas Velocity (ft/sec) | Inlet SO$_2$ (ppm dry) | SO$_2$ Removal % | |
	Upper	Lower			Lower Loop	Overall
1	6.3	5.7	8.3	1385	a	97.2
2	5.9	5.3	8.1	1400	a	91.7
3	6.0	5.7	8.1	1430	59	95.3
4	5.7	5.0	8.2	1430	27	85.0
5	6.1	5.2	8.6	1560	36	93.7
6	6.3	5.7	8.0	1590	a	96.7

Note: a - Lower-loop removal not measured due to sampling problems.

was left in the sample port rather than extended into the module itself. The new location and probe placement appeared to be successful, with reasonable agreement between duplicate test results for the lower-loop flue gas concentrations for Test 3. Increasing the lower-loop pH in Test 3 increased overall SO_2 removal to 95.3% compared with 91.7% in Test 2. The lower-loop flue gas Method 6 results indicated an average of 59% removal efficiency in that loop.

Baseline Test 4 was completed after decreasing the upper-loop pH set point to 5.7 and again allowing the lower-loop pH to stabilize without separate limestone feed. The lower-loop pH averaged 5.0 during this test. The overall SO_2 removal efficiency for this test decreased to an average of 85%. The lower-loop flue gas Method 6 results again appeared reasonable, averaging 27% removal efficiency for Test 4.

For Baseline Test 5, the upper-loop pH set point was returned to 6.0. The actual upper-loop pH was about 6.1. The lower-loop pH averaged 5.2, again with no separate limestone feed. This test was planned with a 33% increase in flue gas velocity, but the actual velocity increase obtained was less than 10% because of operational limits on the overall system pressure drop. The measured flue gas velocity for Test 5 was 8.6 ft/s compared to the baseline 8.0 ft/s. This increase was not considered significant, so no further high velocity tests were attempted. Overall SO_2 removal for this test averaged 93.7%, with about 36% removal in the lower loop.

Because Test 6 was also to have been a high-velocity test, which could not be completed as planned, the conditions for Test 6 were returned to those of Test 1. The actual measured pH levels were 6.3 in the upper loop and 5.7 in the lower loop. Under these conditions, overall SO_2 removal efficiency increased to an average of 96.7%, which was close to that observed for Test 1. No lower-loop exit flue gas samples were obtained during Test 6 due to a broken sampling nozzle.

2.4.2 Baseline Test SO₂ Removal Performance Correlation

Absorber performance can be approximately described by the following expression derived from "two-film" mass transfer theory:

$$\text{Number of Transfer Units (NTU)} = \ln (SO_{2in}/SO_{2out}) = K\,A/G \qquad (2\text{-}1)$$

where: SO_{2in} and SO_{2out} = inlet and outlet SO₂ concentrations;

K (lb/hr-ft²)   = average overall gas-phase mass transfer coefficient;

A (ft²)   = total interfacial area for mass transfer; and

G (lb/hr)   = total gas flow rate.

It is assumed in the above expression that the equilibrium partial pressure of SO₂ above the FGD liquor is small compared to the inlet and outlet concentrations.

The overall coefficient K can be expressed as a function of two individual coefficients, k_g and k_l, which represent mass transfer rates across the gas and liquid films, respectively:

$$1/K = 1/k_g + H/k_l\phi \qquad (2\text{-}2)$$

where H is a Henry's law constant, and ϕ is the liquid-film "enhancement factor." For a given absorber operating at constant gas and liquid flow rates, NTU will be a function of slurry pH because of the effect of pH on the liquid-film enhancement factor and, hence, on the value of K. NTU will also be a function of additive concentration for the same reason.

The form of Equation 2-2 suggests that the effects of increasing pH and additive concentration on the overall mass transfer coefficient (and therefore on NTU or SO₂ removal efficiency) will diminish at some point when $H/k_l\phi$ becomes small compared to $1/k_g$. This is referred to as "gas-film-limited" mass transfer. When this point is reached for a given absorber,

2-13

there is no benefit to increasing the additive concentration. Equation 2-1 shows that NTU should be inversely proportional to gas flow rate (if the product of K and A is independent of gas velocity) and proportional to liquid flow rate (if A is proportional to liquid flow rate).

Figure 2-2 is a plot of NTU versus pH for the lower loop of the test module during the baseline tests. In this figure, only data for Tests 3, 4, and 5 are shown because of the sampling difficulties in Tests 1, 2, and 6. The individual data points from Appendix A are shown, rather than the test averages from Table 2-1. Calculated values for NTU have been normalized to a flue gas velocity of 8.0 ft/s using Equation 2-1. For convenience, SO_2 removal efficiency is also indicated on the graph. The lower-loop removal efficiency ranged from about 20% to 60% during the baseline tests as the pH changed from 4.9 to 5.7.

Figure 2-3 is a plot of overall module NTU versus upper-loop slurry pH for the baseline tests. The overall efficiency ranged from about 85% to 96.7% as the upper-loop pH increased from 5.7 to 6.3.

2.4.3   Results of Baseline Test Slurry Sample Chemical Analyses

Solids Analyses

Results of solid-phase analyses for the baseline test slurry samples are included in Appendix A. These results were used to calculate limestone utilization and sulfite oxidation, which are important process performance parameters. Results are briefly described here.

The calculated limestone utilization values from Table A-3 have been plotted as a function of slurry pH in Figures 2-4 and 2-5 for the upper and lower loops, respectively. In each of these plots, it can be seen that the results for Baseline Test 1 do not lie on the fitted curve because of pH measurement problem in this test.

2-14
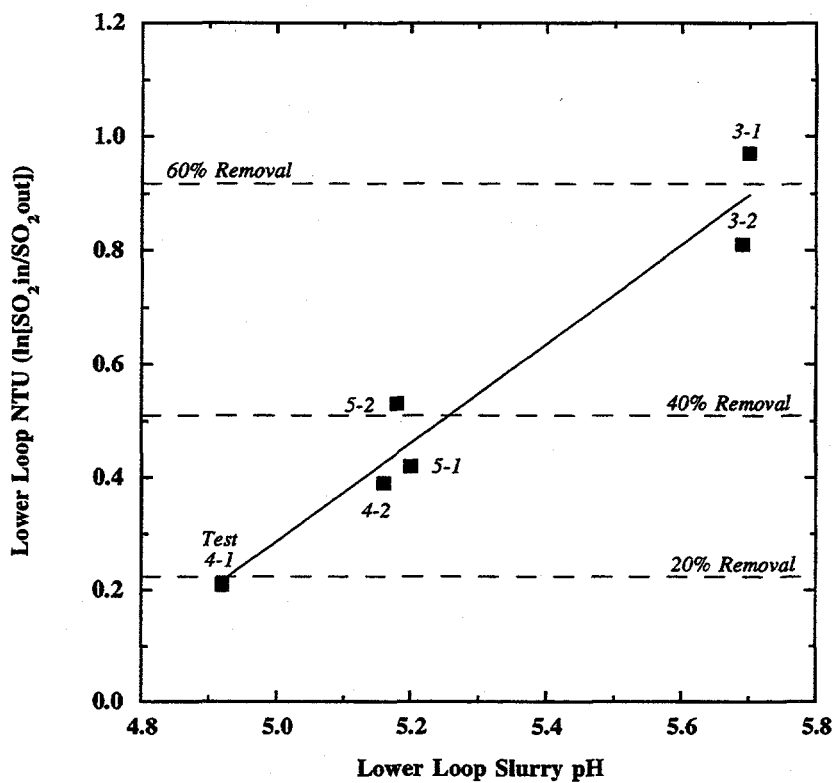
Figure 2-2. Pirkey Baseline Tests: Lower Loop NTU vs. Lower Loop pH
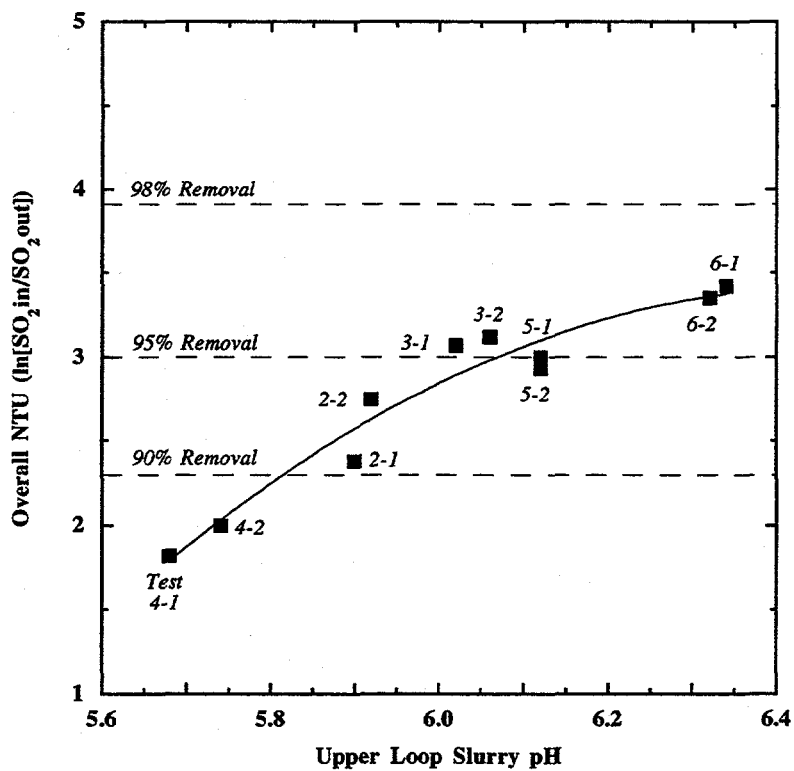
Figure 2-3. Pirkey Baseline Tests: Overall NTU vs. Upper Loop pH

2-15
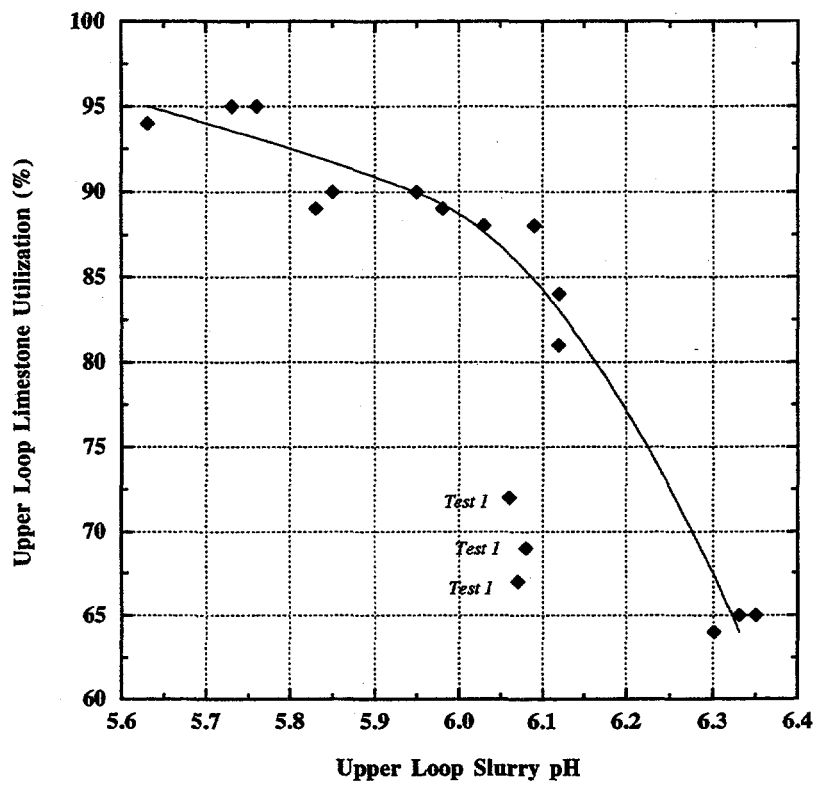
Figure 2-4. Pirkey Baseline Tests: Upper Loop Limestone Utilization vs. Upper Loop Slurry pH
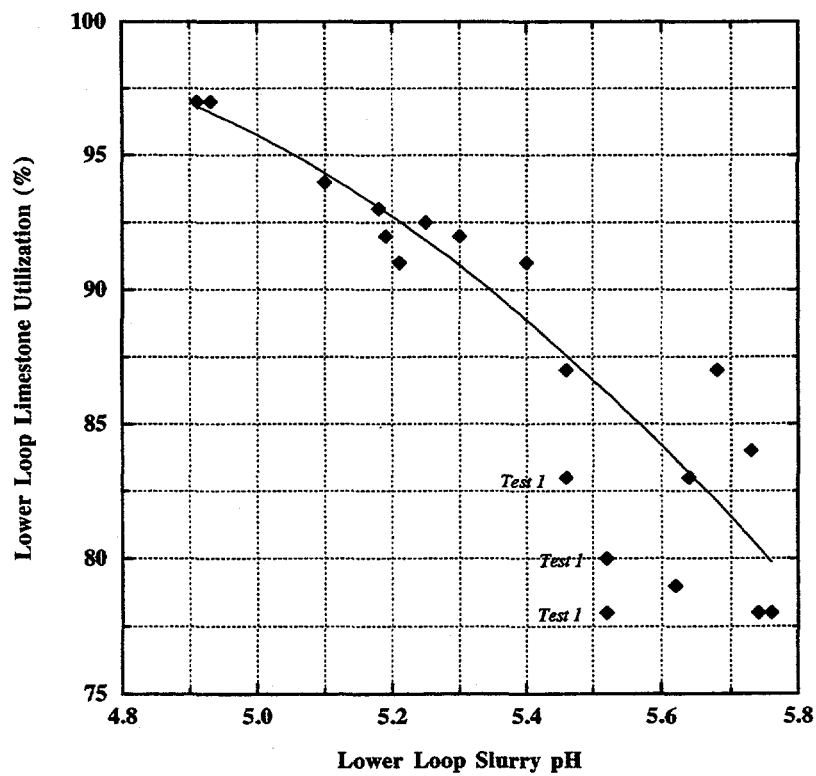
Figure 2-5. Pirkey Baseline Tests: Lower-Loop Limestone Utilization vs. Lower Loop Slurry pH

Oxidation percentages reported in Table A-2 are calculated as 100 x [1 - moles of sulfite/moles of total sulfite plus sulfate]. The calculated oxidation percentages for the baseline tests average about 17%, and there does not appear to be any trend among the different tests. However, only the solids from Test 1 would have been expected to reach a steady-state composition. Some of the solids samples are slightly above and some slightly below the 15% oxidation threshold below which gypsum scaling is generally avoided. Thus, the Pirkey FGD system was found to operate in a regime where intermittent gypsum scaling would be expected.

Liquid Analyses

Results of liquid-phase analyses for the baseline filtered slurry samples are reported in Appendix A in Table A-4. Liquid-phase analyses were used to calculate relative saturations for the limited solubility species (i.e., calcium sulfite, calcium sulfate, and calcium carbonate). Relative saturation for a specific compound is defined as the activity product for the ionic components in solution divided by the solubility product. These values were obtained using Radian's Aqueous Chemical And Physical Properties (ACAPP) computer routine, which calculates the equilibrium distribution of chemical species using the analytical results as inputs.

Of greatest interest in an inhibited-oxidation FGD system such as this is the gypsum relative saturation. The objective of inhibiting oxidation with sulfur (which reacts to produce thiosulfate in solution) is to prevent scaling by maintaining the gypsum relative saturation below 1.0. Previous research has shown that all of the sulfate produced by oxidation of absorbed SO_2 will precipitate as a solid solution with calcium sulfite, up to the point where the system oxidation percentage reaches about 15%. Above 15% oxidation, the balance of the sulfate (beyond 15% of the SO_2 absorbed) will precipitate as gypsum. The results in Table A-4 show that the baseline liquor samples all had gypsum relative saturations close to 1.0, with some samples slightly supersaturated and some slightly subsaturated. These results are consistent with the solids analyses, which showed that the baseline test oxidation percentage was close to 15%. Again, these results show that the Pirkey FGD system was found to be operating in a regime where intermittent gypsum scaling would be expected.

Selected liquid samples from the baseline tests were also analyzed for 26 different metal species. These results are also included in Appendix A (Table A-5).

2.4.4   Other Process Data for the Baseline Tests

Other process data for the Baseline Tests, including module pressure drops, system pressure drop, unit load, flue gas inlet temperature and pressure and CO_2 content, and inlet and outlet SO_2 concentrations recorded by CEM are included in Appendix B. Also in Appendix B are the results of slurry flow rate measurements. These data are discussed in Section 2.5.5.

2.5   <u>DBA and Sodium Formate Parametric Test Conditions and Results</u>

2.5.1   DBA Parametric Test SO_2 Removal Efficiency

Table 2-2 summarizes the average test conditions and SO_2 removal efficiency results for the DBA parametric tests. More detailed results of the individual Method 6 runs are included in Appendix A.

Parametric Test 1 started one day after DBA was initially added to the Module C upper-loop reaction tank. The upper loop was operated at the normal pH set point of 6.3 throughout this test. The actual upper-loop pH ranged from 6.17 to 6.24 and the lower-loop pH ranged from 5.54 to 5.69. Test 1 was concluded the following day after a total of eight Method 6 sample sets had been obtained. The upper-loop DBA concentration averaged 440 ppm and the lower-loop DBA concentration averaged 400 ppm during Test 1.

The overall SO_2 removal efficiency for Module C averaged 98.4% during DBA Test 1. The lower-loop removal efficiency averaged about 61%. The results from the lower-loop flue gas sample location were much more reproducible than those obtained during the baseline tests due to an improved sample nozzle configuration that was developed to prevent interference from slurry droplets.

Table 2-2

Average DBA Parametric Test Conditions and Results

Test No.	Slurry pH		DBA Conc. (mg/L)		Flue Gas Velocity (ft/sec)	Inlet SO₂ (ppm dry)	SO₂ Removal (%)	
	Upper Loop	Lower Loop	Upper Loop	Lower Loop			Lower Loop	Overall
1	6.2	5.6	440	400	8.1	1280	61	98.4
2	5.7	5.0	430	475	8.0	1415	36	92.7
3	5.7	4.8	640	710	7.8	1630	31	93.9
4a	6.2	5.3	630	710	8.0	1630	57	98.3
4b	6.3	5.6	710	700	7.9	1475	67	99.0
5	6.3	5.6	1450	1460	8.0	1640	72	99.2
6a	5.7	4.8	1460	1540	8.0	1470	36	96.0
6b	5.7	5.0	1490	1710	8.0	1515	46	97.2
7	6.3	5.6	2320	2510	7.9	1310	76	99.5

Parametric Test 2 was completed after lowering the upper-loop pH set point to 5.7. The measured slurry pH values for this test averaged 5.7 in the upper loop and 5.0 in the lower loop. The upper-loop DBA concentration averaged 430 ppm and the lower-loop concentration averaged 475 ppm. With the lower pH set points but similar DBA concentrations as in Test 1, the average overall SO_2 removal efficiency decreased to 92.7%. The lower-loop removal efficiency decreased to 36%.

Following Test 2, the DBA concentrations in the test module were increased and the pH set points were maintained at the low level. DBA Parametric Test 3 was completed after a one-day break. The average DBA concentrations during Test 3 were 640 ppm in the upper loop and 710 ppm in the lower loop. At this DBA concentration and the low pH set points, the overall SO_2 removal efficiency increased to 93.9%. The lower-loop removal averaged 31%, which was slightly lower than seen in Test 2 at the lower DBA level. The lower-loop pH was 4.8 during Test 3, however, compared to 5.0 during Test 2.

DBA Parametric Test 4 was completed the following day after returning the upper-loop pH set point to the normal (high) level of 6.3. During the first two runs of Test 4 (Test 4a in Table 2-2), the lower-loop pH was 5.3. This was increased to 5.6 during the second two runs of Test 4 (Test 4b in Table 2-2) so that a better comparison with earlier tests could be made. The DBA concentration increased slightly from 630 to 710 ppm in the upper loop and remained steady at 700 ppm in the lower loop during this test. At this DBA level, the overall SO_2 removal efficiency was 98.4% for Test 4a and increased to 99.0% for Test 4b. The lower-loop efficiency was 57% in Test 4a at pH 5.3 and 67% in Test 4b at pH 5.6.

The DBA concentration was increased again for Tests 5 and 6. Test 5 was a two-day test during which slurry samples for settling and filtration tests were obtained in addition to the normal slurry samples for chemical analyses. The upper-loop DBA concentration averaged 1450 ppm during Test 5. The corresponding lower-loop concentration was 1460 ppm. During Test 5, the pH values averaged 6.3 for the upper loop and 5.6 for the lower loop. The overall SO_2 removal averaged 99.2% and the lower loop removal was 72%.

During Test 6, the upper-loop pH set point was lowered to 5.7, and the lower-loop pH was allowed to stabilize without limestone feed. The lower-loop pH was 4.8 during the first two Method 6 sample sets for this test (Test 6a in Table 2-2) and 5.0 during the second two sample sets (Test 6b in Table 2-2). The overall SO_2 removal efficiency averaged 96.0% for Test 6a and increased to 97.2% for Test 6b. The lower-loop removal efficiency was 36% during Test 6a and 46% during Test 6b with the slightly higher pH of 5.0.

The final DBA Test was conducted at the high pH set points in both loops (6.3 upper, 5.7 lower) and with an average DBA concentration of 2320 ppm in the upper loop and 2510 ppm in the lower loop. Under these conditions, the overall removal efficiency was 99.5% and the lower-loop efficiency was 76%.

2.5.2   Sodium Formate Parametric Test SO_2 Removal Efficiency

The sodium formate parametric tests began about one week after a system outage. During the outage, the system reaction tanks were drained into the FGD surge pond. As a result, it was expected that nearly all of the residual DBA would be either purged from the system or consumed prior to the formate tests. Background buffer capacity samples taken prior to the formate tests indicated a residual DBA concentration of about 100 ppm.

Table 2-3 summarizes the average operating conditions and SO_2 removal results for the formate tests. The formate parametric test plan was similar to the DBA test plan; three sets of two tests each at high- and low-pH set points were completed increasing levels of formate concentration. More detailed results of the individual data sets are included in Appendix A, Table A-9.

Formate Parametric Tests 1 and 2 were conducted at an average formate concentration of 485 ppm in the upper loop and 490 ppm in the lower loop. Test 1 was a two-day test at the normal upper-loop pH set point of 6.3. The actual upper-loop pH ranged from

Table 2-3

Average Formate Parametric Test Conditions and Results

Test No.	Slurry pH		Formate Conc. (mg/L)		Flue Gas Velocity (ft/sec)	Inlet SO$_2$ (ppm dry)	SO$_2$ Removal (%)	
	Upper Loop	Lower Loop	Upper Loop	Lower Loop			Lower Loop	Overall
1a	6.2	5.5	480	445	8.1	980	52	98.0
1b	6.3	5.5	480	515	8.6	1110	49	61.0(a)
2	5.7	4.8	500	540	8.1	1010	24	93.5
3	5.7	4.8	870	890	7.8	1110	27	94.1
4	6.2	5.5	1270	1220	7.8	880	53	98.6
5	6.2	5.5	2300	2350	8.0	970(b)	59	99.0
6	5.7	4.8	2560	2790	7.9	940(b)	43	96.9

Notes: a - Upper-loop recycle pumps not operating.
         b - Inlet monitor not operating. Inlet SO$_2$ by Method 6.

6.12 to 6.33 and averaged 6.2 during Test 1. The lower-loop pH ranged from 5.38 to 5.53 and averaged 5.5.

Overall SO_2 removal for the first 6 runs of Test 1 (Test 1a in Table 2-3) averaged 98.0% and the corresponding lower-loop efficiency was 52%. During the last 2 runs of Test 1 (Test 1b in Table 2-3), the upper-loop recycle pumps were turned off so that the lower-loop efficiency indicated by the single-point flue gas sample from the lower-loop exit location could be compared to that indicated by the multi-point traverse at the module outlet location. This was done to confirm that the relatively high removal efficiencies seen in the lower loop were not due to slurry accumulation in the Method 6 sample probe and filter. The results for Test 1b showed an average removal efficiency of 49% based on the lower-loop exit SO_2 concentration and 61% based on the module outlet concentration. Considering that 300 gpm of mist eliminator wash water was still flowing to the upper loop and likely removed some SO_2, these results were considered to be in reasonable agreement and confirmed that the single-point SO_2 concentration measured at the lower-loop sample location was representative of the lower-loop performance.

Formate parametric Test 2 was completed after lowering the upper-loop pH set point to 5.7. The corresponding lower-loop pH was 4.8. At the lower pH values, the overall SO_2 removal efficiency decreased to 93.5% compared to 98% for Test 1. The lower-loop efficiency for Test 2 averaged 24% compared to 52% for Test 1.

Formate Tests 3 and 4 were conducted at the next highest formate concentration. The target concentration was 1000 ppm for these two tests, but the actual concentration increased from about 800 to 1300 ppm over the course of these tests. Because the rate of increase in formate concentration was low compared to the elapsed time for each flue gas and slurry sampling event, the performance data were not adversely affected by the changing conditions. Overall SO_2 removal averaged 94.1% during Test 3 at the low-pH condition and 98.6% during Test 4 at the normal-pH condition. Corresponding lower-loop efficiencies were 27% and 53%.

2-23

Formate Tests 5 and 6 were conducted at the highest formate concentration. Test 5 was a two-day test at the normal pH set point, during which slurry samples for settling and filtration tests were obtained. Test 6 was a one-day test at the low pH set point. The upper-loop formate averaged 2300 ppm during Test 5 and 2560 ppm during Test 6. The corresponding lower-loop concentrations were 2350 and 2790 ppm. The SWEPCo inlet flue gas analyzer failed just prior to Test 5. Therefore, the inlet, lower-loop exit, and outlet flue gas locations were sampled simultaneously using Method 6.

Overall SO_2 removal efficiency averaged 99% during Test 5 at the high-pH conditions. Overall efficiency decreased to 97% during Test 6 at the low-pH conditions. Corresponding average lower-loop efficiencies were 59% and 43%, respectively. During the final run of Test 5, the lower-loop pH was increased from 5.5 to 5.74 to evaluate the lower-loop efficiency at a pH that was closer to those during the DBA tests. This increase in lower-loop pH increased the efficiency there from 64% to 71%.

2.5.3   DBA and Formate Parametric Test SO_2 Removal Performance Correlation

Figure 2-6 shows the lower-loop SO_2 removal data for both the DBA and formate parametric tests. Two curves are plotted for each additive; a low-pH curve and a high-pH curve. Also shown on this figure are baseline results (at zero additive concentration) interpolated from Figure 2-2. Note that in Figure 2-6 and subsequent figures, the formate concentration is shown as ppm of formate ion, not as sodium formate.

The relative performance of DBA and formate on an equal mass basis can be compared using Figure 2-6. The average molecular weight of DBA, a dicarboxilic acid, is about 130. The molecular weight of formate ion, a monocarboxilic acid, is only 45. If the full buffering capacity of DBA and formate were used as the FGD slurry absorbs SO_2, the milliequivalents of buffer capacity provided per unit mass of formate would, therefore, be expected to be nearly 50% higher than that for DBA. In practice, however, because these two additives buffer over different
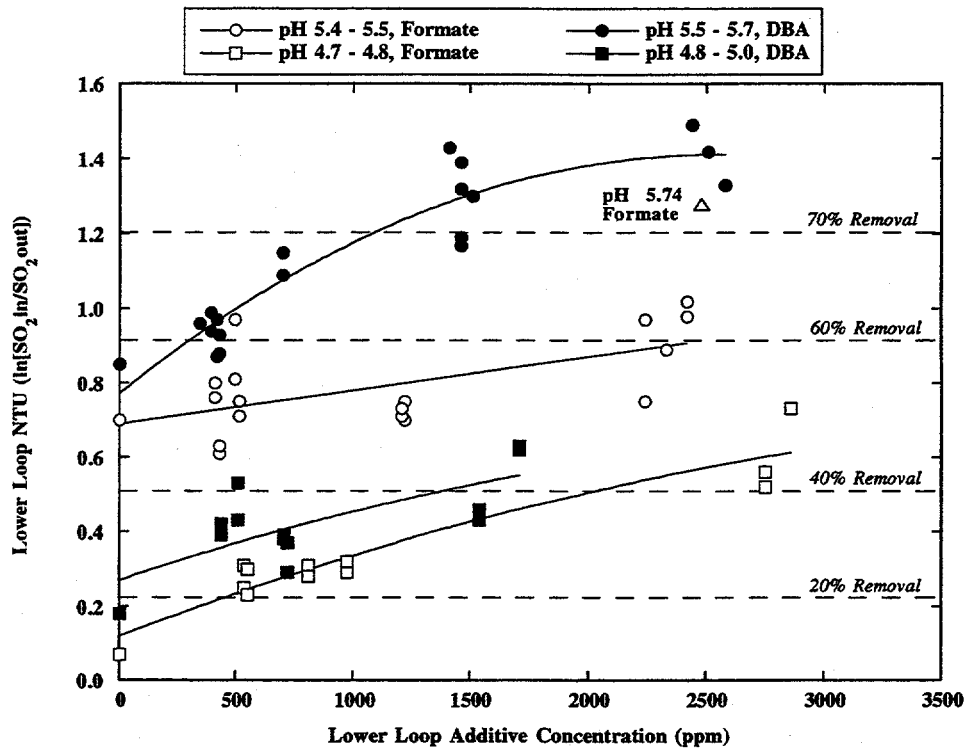
Figure 2-6. Pirkey Parametric Tests: Lower Loop NTU vs. Additive Concentration

2-25

pH ranges, the relative effectiveness of DBA and formate is a complex function of the absorber configuration and the operating pH.

The results in Figure 2-6 suggest that formate may be slightly less effective than DBA in the lower loop at the higher pH level; however, most of this difference can be accounted for by the difference in lower-loop pH between the DBA and formate parametric tests. The high-pH formate tests were conducted with a lower-loop pH range from 5.4 to 5.5, while the DBA test pH range was 5.5 to 5.7. A single data point from the end of formate Test 5, in which the lower-loop pH was increased from 5.5 to 5.74, is also shown in Figure 2-6. Formate performance for this test was more comparable to DBA performance. At the lower-pH level, DBA and formate performance were also comparable.

Figure 2-7 shows the overall SO_2 removal efficiency for the module plotted versus the upper-loop additive concentration for the DBA and formate parametric tests. High-pH and low-pH curves are again shown separately. The results in this figure show that formate is comparable to DBA at the lower pH level, but may be slightly less effective than DBA at the higher pH level. The difference is not large, however, and can probably be accounted for by other differences between these two test series. For example, results of slurry analyses presented later in this report show that the limestone utilization was higher and the slurry solids content was lower during Formate Test 5, compared to the corresponding DBA Test 7. Thus, the lower limestone loading in the recirculating slurry during Formate Test 5 may have contributed to the slightly lower overall SO_2 removal performance than in the equivalent DBA test.

2.5.4   Results of DBA and Formate Parametric Test Slurry Sample Analyses

Solids Analyses

Results of solids analyses for the DBA and formate parametric tests are included in Appendix A, Tables A-7 and A-10. The results have been used to calculate limestone utilization and sulfite oxidation which are also shown in the tables.
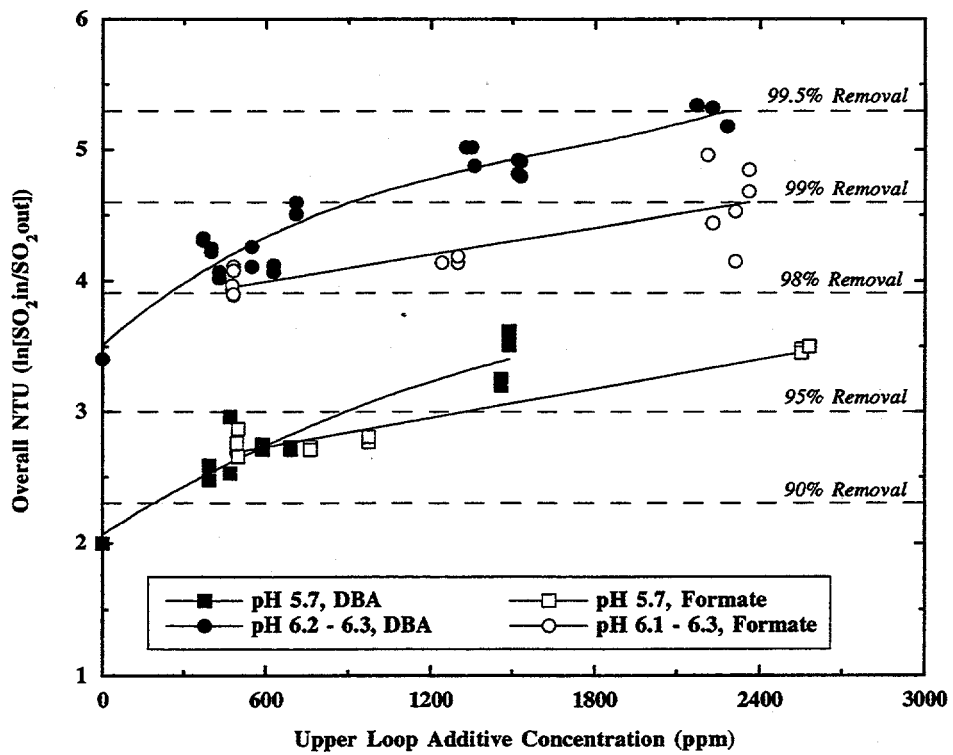
Figure 2-7. Pirkey Parametric Tests: Overall NTU vs. Additive Concentration

Limestone utilization results from the DBA and sodium formate parametric tests are plotted versus slurry pH in Figures 2-8 and 2-9 for the upper- and lower-loop slurry samples, respectively. Utilization results for the baseline tests are also shown, as curves fit to the data plotted in Figures 2-4 and 2-5. This comparison shows that limestone utilization at a given pH increased significantly from baseline values during both the DBA and formate parametric test series. In general, this appears to be a result of the lower oxidation percentages observed when these additives were used in the Pirkey FGD system, as discussed below. At lower oxidation percentages, the liquid-phase calcium concentration is correspondingly reduced, lowering the calcium carbonate relative saturation and increasing limestone dissolution at a given pH level.

Figures 2-10 and 2-11 show the effects of DBA and formate on sulfite oxidation percentages in the upper- and lower-loop slurry solids. Each of these additives had a significant effect -- lowering oxidation from the normal 15-20% range at Pirkey to about 10%. This is an important result for the Pirkey site because low oxidation has been difficult to maintain using the conventional approach of adding elemental sulfur to generate thiosulfate an oxidation inhibitor. Low oxidation permits operation in a sub-saturated mode with respect to gypsum, preventing gypsum scale formation and even allowing existing scale to dissolve into the recirculating liquor. In fact, during the DBA parametric tests, existing scale deposits in the system appeared to dissolve, as indicated by decreasing module pressure drop over time (see Appendix B), while operating the module at a constant gas velocity.

Liquid Analyses

Analytical results for the DBA and formate parametric filtered liquor samples are included in Appendix A, Tables A-8 and A-11. Also shown in these tables are estimated relative saturations (RS) for gypsum, calcium sulfite, and calcium carbonate. These can be compared to the baseline values to illustrate the effects of the additives on process chemistry.

Estimated gypsum relative saturations from Tables A-8 and A-11 for the DBA and formate parametric tests are plotted versus additive concentration in Figures 2-12 and 2-13 for
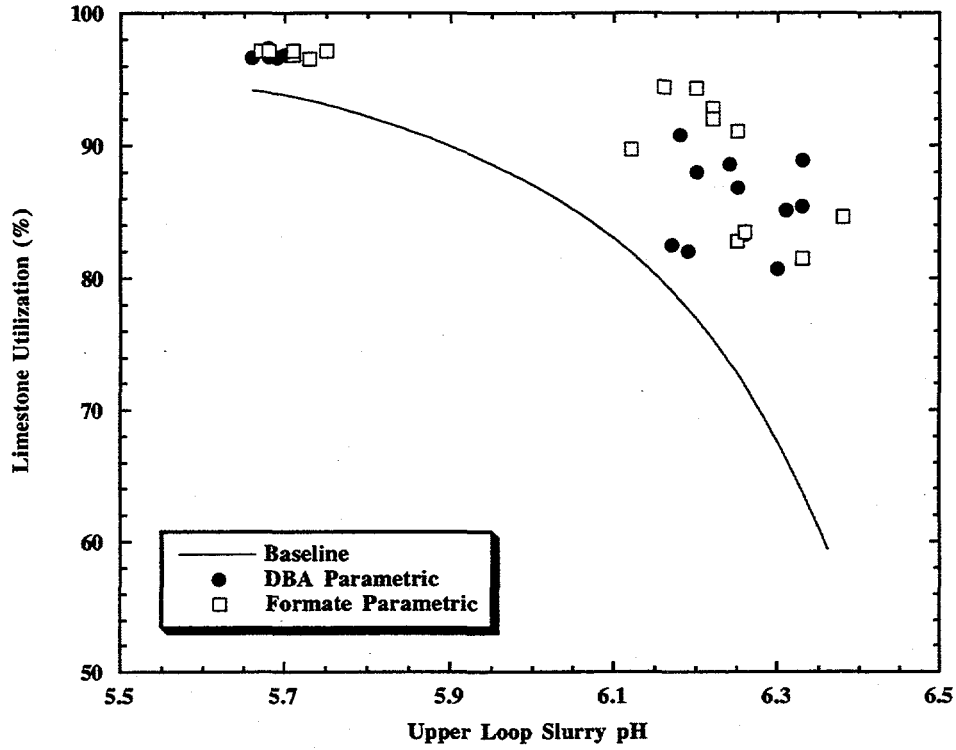
**Figure 2-8. Upper Loop Limestone Utilization vs. pH Baseline
Compared to Parametric Tests**
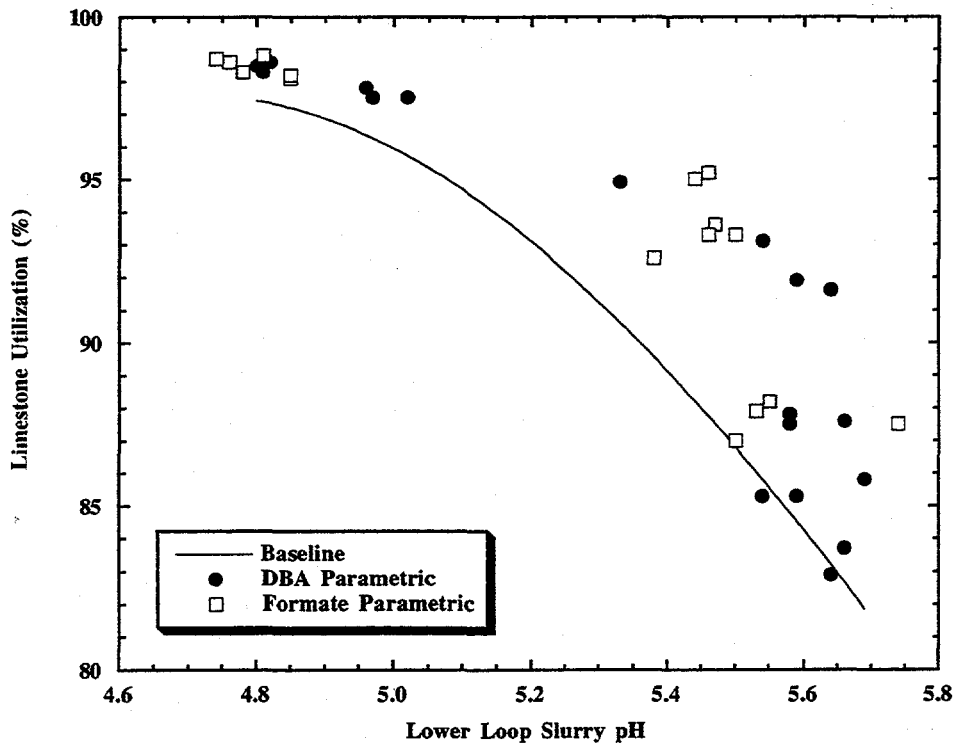
**Figure 2-9. Lower Loop Limestone Utilization vs. pH Baseline
Compared to Parametric Tests**
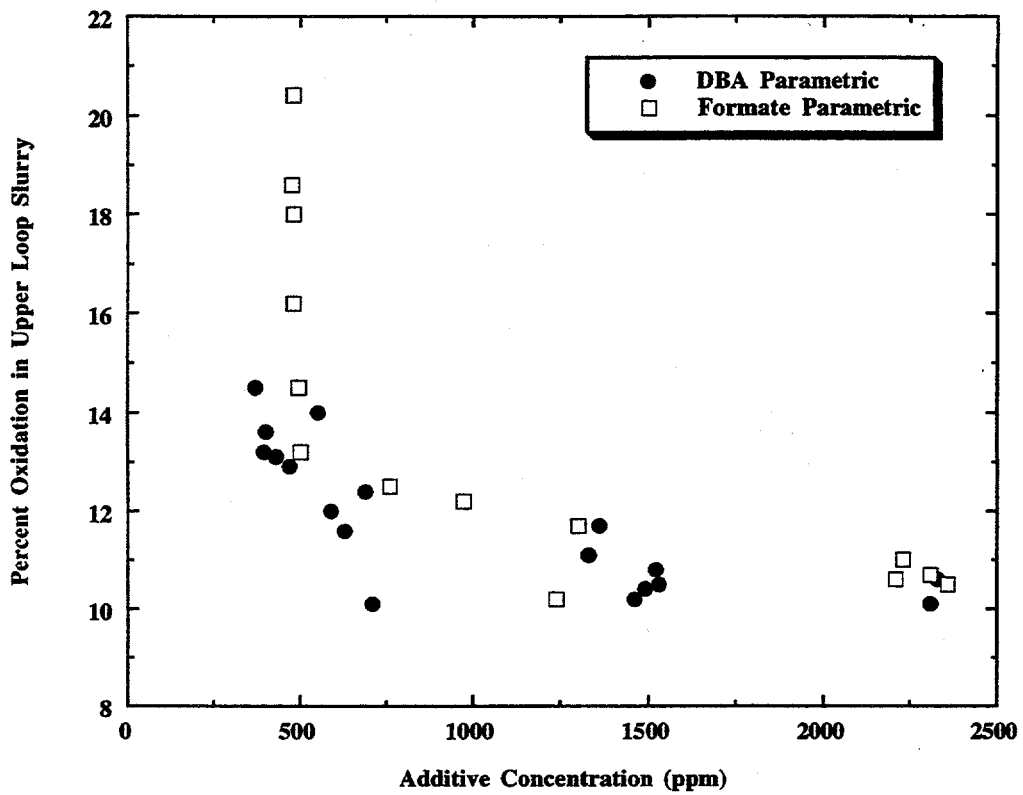
Figure 2-10. Upper Loop Oxidation vs. Additive Concentration
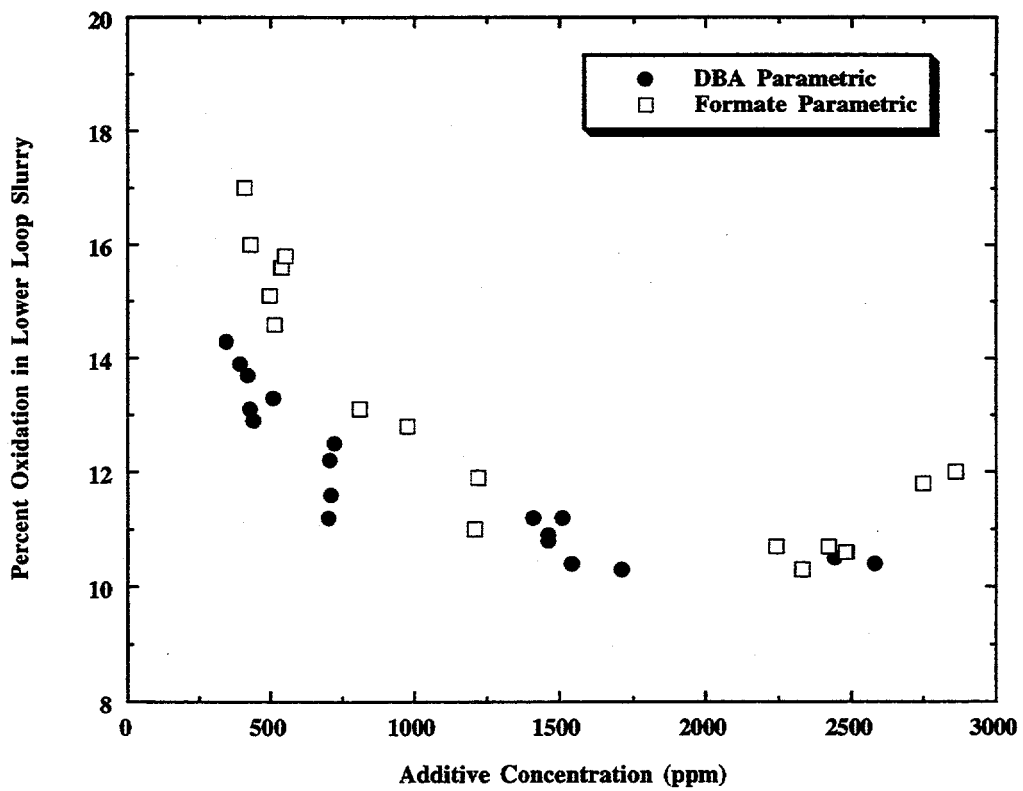
Figure 2-11. Lower Loop Oxidation vs. Additive Concentration
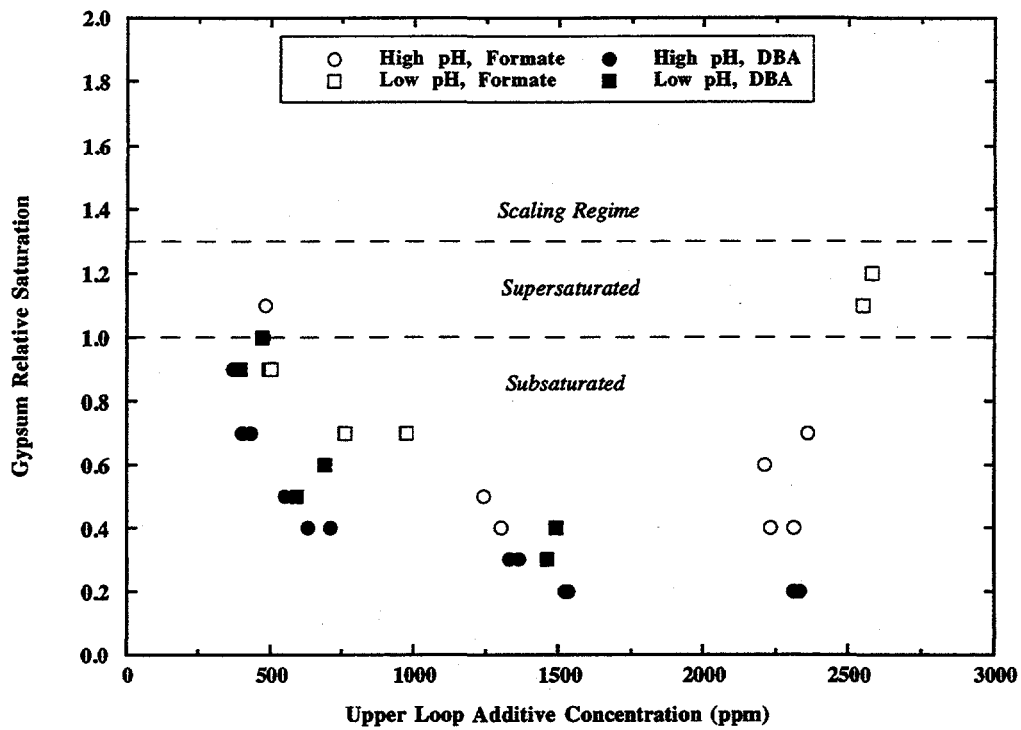
Figure 2-12. Pirkey Parametric Tests: Upper Loop Gypsum Relative Saturation vs. Additive Concentration
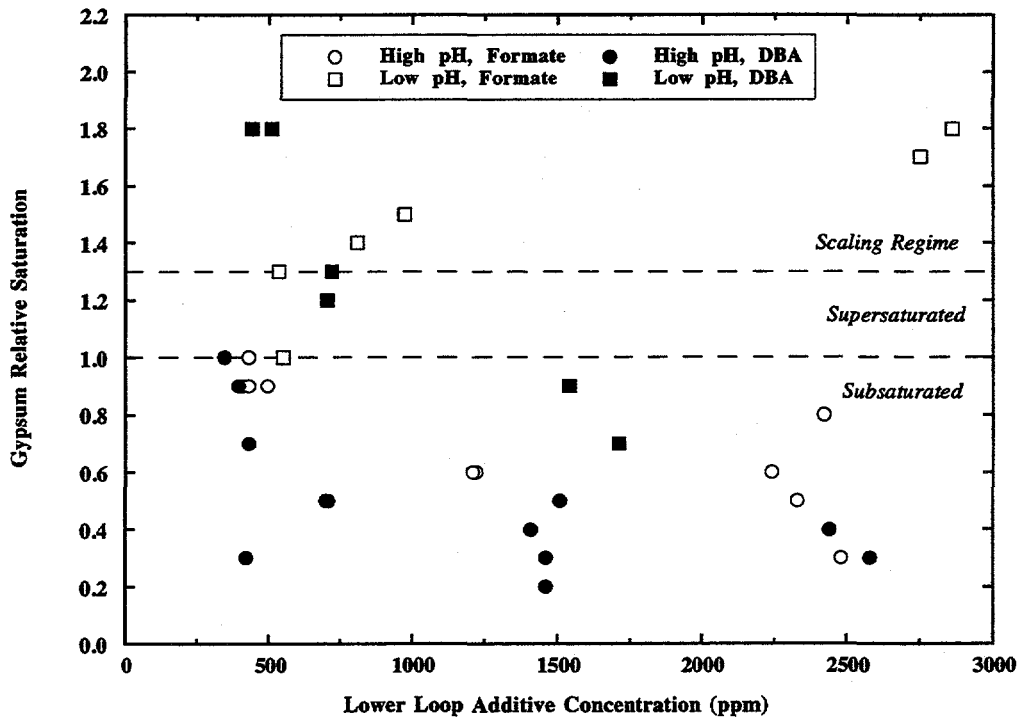
Figure 2-13. Pirkey Parametric Tests: Lower Loop Gypsum Relative Saturation vs. Additive Concentration

2-31

the upper- and lower-loop slurry samples, respectively. The plots show separate data point symbols for each additive and for each pH set point (high and low) used during the tests. The subsaturated and supersaturated regions are separated on the figures by a dashed line. A second dashed line at a relative saturation of 1.3 is used to indicate the onset of nucleation above which rapid scale formation typically occurs.

Referring to Figure 2-12 for the upper loop, the results for gypsum RS during the DBA parametric tests are all in the subsaturated region and show a steady decrease as the concentration of DBA in the system increased. During Test 1, the gypsum RS averaged 0.7, or slightly subsaturated. This result is in good agreement with the solids analyses, which indicated an average oxidation of about 14%. Recall that the average oxidation percentage for the baseline tests was 17% and the average gypsum RS was 1.0. Therefore, DBA began to inhibit oxidation at the lowest level used in the tests (400-500 ppm). As the DBA tests proceeded, gypsum relative saturation fell to 0.2 in the upper loop. The corresponding solids oxidation percentage was about 10% by the end of the DBA parametric tests.

The gypsum RS results for the upper loop during the formate parametric tests are generally higher than those for the DBA tests. During formate Test 1, the gypsum RS was still greater than 1.0, which is in agreement with the oxidation results from the solids analyses (Figure 2-10). The results in Figure 2-12 also show a definite pH effect. The lowest gypsum saturations for both DBA and formate are seen in the high-pH tests. A somewhat surprising result is the increase in gypsum RS to 1.1 to 1.2 during the final formate test, which was a low-pH test. The solids analyses for that test did not indicate that oxidation was greater than 15% in this test, as would be expected with a liquid-phase gypsum RS greater than 1.0. However, liquid-phase gypsum saturation results tend to be a more sensitive indicator of oxidation rate over a relatively short time period than solids analyses. This is because the solid-phase residence time in the module was much longer than the elapsed time for the one-day tests, especially at the low inlet SO_2 concentrations seen during the formate tests. The change in liquid-phase chemistry with pH and formate concentration changes is much faster.

In Figure 2-13, for the lower loop, similar trends were observed, but the gypsum RS levels during the low-pH tests were much higher than those seen in the upper-loop slurry. This is not unexpected because the lower-loop reaction tank is much smaller, while the amount of SO_2 removed in the lower loop was comparable to that removed in the upper loop (or even greater at high additive concentrations). The oxidation indicated by the solids analyses again lagged the liquid-phase conditions. For example, the estimated lower-loop gypsum RS was greater than 1 in Tests 2 and 3 (at low pH) for both the DBA and formate tests even though the solids analyses for these tests showed less than 15% oxidation.

The results for DBA and formate low-pH tests with higher additive levels show that subsaturated conditions were maintained with DBA at a concentration of about 1500 ppm, but the RS was much greater than 1 with formate, even at 2800 ppm. At first glance, the gypsum RS data seem to indicate that DBA was a more effective oxidation inhibitor than formate in the Pirkey FGD system. However, there were differences in both average unit load and inlet SO_2 content that could have affected this comparison. During the DBA tests, the inlet SO_2 ranged from 1200 to 1700 ppm compared to 800-1200 ppm during the formate tests. The unit load ranged from 460 to 690 MW during the DBA tests compared to 290-610 MW during the formate tests. Lower oxidation percentage is favored by both higher inlet SO_2 concentration and higher unit load, both of which were the case for the DBA tests, relative to conditions for the formate tests. Therefore, the difference in gypsum saturation between the DBA and formate tests cannot be attributed solely to the difference in the additive.

Concentrations of 26 elements were also determined in selected samples using inductively coupled argon plasma emissions spectroscopy. These data are summarized in Appendix A, Table A-5. Some differences in a few of the trace species concentrations can be seen among the different test series. Iron was present at 3 mg/L in the upper-loop and 6 mg/L in the lower-loop baseline liquor. At the beginning of the DBA parametric tests, the iron concentrations were only 0.4 and 2 mg/L and by the end of the DBA tests, iron was <0.24 mg/L in the upper-loop and 0.6 mg/L in the lower-loop liquor. The iron concentration also decreased throughout the formate parametric tests from 1 and 3 mg/L to <0.2 and 0.8 mg/L in the upper and

2-33

lower loops, respectively. Manganese concentrations also decreased significantly during the course of the DBA parametric tests. The decrease in manganese was less during the formate tests. Because there were relatively few measurements of trace metal concentrations made during these test series, it is not clear whether these changes in iron and manganese concentrations were related to the use of the additives, or merely reflect coincidental, normal variations.

2.5.5 Other Process Data for the DBA and Formate Parametric Tests

Control Room Data

Control room data for the Baseline Tests and DBA and Formate Parametric Tests are included in Appendix B. Data were recorded manually during the tests from the control room indicators. Several aspects of the process data are important to interpreting the performance data discussed previously. Of greatest interest are the system inlet pressure and overall Module C pressure drop.

The Module C gas velocity was essentially constant throughout the baseline and parametric tests (except for Baseline Test 5). The Module C pressure drop during the baseline tests averaged 5.4 in. H_2O. The Module C pressure drop at the same gas flow rate decreased throughout the DBA parametric tests from about 5.7 in. H_2O to 4.2 in. H_2O. The slurry liquid and solids analytical data presented above suggest that this decrease resulted from scale dissolution as the system chemistry shifted from supersaturated to subsaturated gypsum operation. The lower pressure drop was maintained throughout the formate parametric tests, indicating that no new scale had formed. The total system inlet pressure required to maintain the constant gas flow through the test module decreased from about 10.5 in. H_2O during the baseline tests to about 8 in. H_2O during the formate parametric tests. This decrease in operating pressure could represent a substantial cost savings if scaling conditions are generally encountered at Pirkey without additives, but can be avoided with additives.

Other changes in process conditions occurred that are known to affect sulfite oxidation in the system. The boiler load was quite high during the baseline and DBA parametric tests compared to the formate parametric tests. The system inlet flue gas sulfur content was about 50% higher during the baseline and DBA parametric tests compared to the formate parametric tests. As mentioned previously, both of these differences would tend to promote higher sulfite oxidation percentages during the formate tests so that the differences in gypsum relative saturations seen when comparing the DBA and formate tests cannot be entirely attributed to differences in the effects of the two additives.

Slurry Flow Rate Measurements

Results of slurry flow rate measurements are also included in Appendix B. Slurry flow rate measurements were repeated at various locations throughout the baseline and DBA parametric tests using an ultrasonic Doppler-effect flow meter. Flow measurements for the same process stream were made at various locations. The locations varied with respect to accessibility and distance from upstream and downstream flow disturbances. Slurry flow to the upper loop was first measured at the individual slurry pump discharges. These locations had convenient access but proved to be too close to the expansion between the pump discharge and slurry piping. The measured flow at these locations varied widely from 19,000 gpm to more than 25,000 gpm for a single pump. One of the upper-loop pump suction lines had a straight run suitable for flow measurement. At this location, the flow was 12,900 gpm for a single pump.

After limited success at the individual upper-loop pumps, the flow meter was installed on a long straight run of the main slurry header before it splits to the individual upper-loop spray headers. This location was difficult to reach, but was the best location from the standpoint of flow disturbances. The combined flow at this location for two operating recycle pumps was 25,700 gpm. This was in good agreement with the suction line measurement for a single pump (12,900 gpm). The main slurry header flow measurement at this location was repeated during the baseline and DBA parametric tests. The average total upper-loop slurry flow

was about 25,000 gpm. At the measured Module C flue gas flow, this corresponds to an upper-loop L/G of 48 gallons per thousand actual cubic feet of gas.

The lower-loop slurry flow was measured during the baseline and DBA parametric tests at the horizontal run downstream of both pumps (one pump operating) and upstream of the side streams to the presaturator and upper-loop reaction tank. The total lower-loop slurry flow averaged 10,800 gpm. Of this flow, approximately 600 gpm is diverted to the upper-loop reaction tank. The balance, about 10,000 gpm, corresponds to a lower-loop L/G of about 19 gal/kacf.

2.6 Effect of DBA and Sodium Formate on Other Solids Properties

Laboratory tests were performed to examine the effect of DBA and sodium formate additives on other solids properties. If DBA or sodium formate is used as a performance-enhancing additive, changes in solids properties caused directly or indirectly by additives could affect the operation of dewatering equipment.

Three methods were used to examine slurry samples from Module C as part of this test program: settling tests, filter leaf tests, and scanning electron microscopy (SEM). Settling tests were performed on site using lower-loop slurry samples to ascertain the effect of DBA and formate on sedimentation properties. Filter leaf tests were performed to assess changes in the solids filtration rate and solids water retention under vacuum filtration. Finally, SEM was used qualitatively to examine changes in crystal structure.

2.6.1 Settling Tests

Detailed results of settling tests are included in Appendix C. Batch settling tests were performed on slurry from the Module C lower loop to determine both settling rates and final solids underflow concentrations. Settling rates are reported as the unit area (UA, ft^2-day/ton) required to reach a 30 wt.% underflow concentration.

The calculated unit areas shown in Appendix C cannot be used for a direct comparison of settling rates among the various tests because the unit area is a strong function of initial slurry solids content, which varied by a factor of more than two among the tests   A more straightforward comparison can be made using the settling rate data that are plotted in Figure 2-14. The settling rate is less sensitive to small changes in initial slurry solids content than the calculated unit area.

Figure 2-14 shows the settling rate data for six of the settling tests plotted as the interface level in the test cylinder versus time. In this figure, the settling rate of the slurry from DBA Test 5 is obviously much faster than that for Baseline Test 1. Therefore, the DBA additive appears to have increased the settling rate, and the results would still show a significant reduction in calculated unit area had the initial slurry solids content been the same as for the baseline tests.

The results for the formate tests show very little change in settling rate due to the formate additive. The pre-formate test sample yielded a settling rate very close to that of the baseline test sample. The sample from Formate Test 5 showed a slight reduction in settling rate compared to the pre-formate sample, but this small change could be due to the effect of increased slurry density on settling rate.

The pre-DBA consumption test sample shows a settling rate that was slightly less than that for all of the other settling test samples. This decrease in settling rate relative to the baseline test may be due to the increased solids oxidation fraction (22.7% versus 18.6%). The sample taken during the DBA consumption test showed a marked increase in settling rate relative to the sample taken before that test. This result confirms that the DBA additive significantlly increased the slurry settling rate as seen during the DBA parametric tests.

2.6.2   Filter Leaf Tests

Detailed results for the filter leaf tests are also included in Appendix C. Filter leaf tests simulate the performance of a rotary drum vacuum filter. Two separate tests were
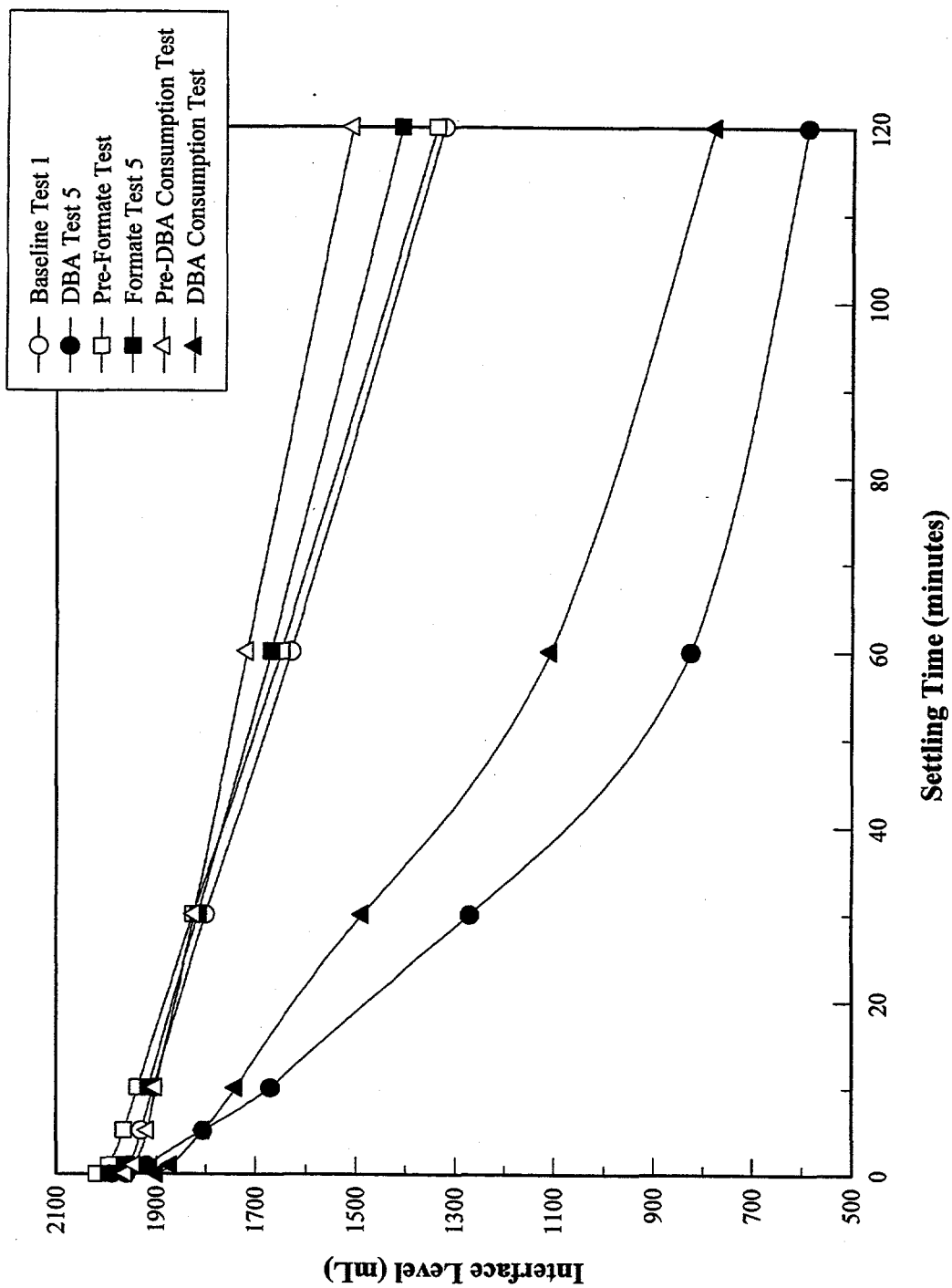
Figure 2-14. Settling Rate Comparison

performed: form filtration and cake moisture. The form filtration test was performed on lower-loop slurry samples to determine the effective solids filtration rates (lb/hr/ft^2 filter area). The test results give an indication of the required filtration surface and indicate the ease with which water is drawn from the solids. The cake moisture test measures the residual moisture after a constant cake drying time. This test measures the tendency for the filtered solids to retain water.

Filter leaf test samples were taken concurrently with settling test samples. In general, the scatter in the filtration rate results makes it difficult to draw conclusions regarding the effect of the additives.

2.6.3   SEM Photographs

Figures 2-15, 2-16, and 2-17 are scanning electron microscope photos of solids samples from the baseline, DBA, and formate tests. The differences in crystal morphology are readily apparent. In the baseline tests, the crystals are thin platelets with a length-to-width ratio (L/W) of about 2:1. The DBA test solids have an L/W of 3:1 or 4:1 and are much thicker. The formate test solids are nearly square (L/W = 1:1) and do not show the increased thickness of the DBA solids. The observed change in crystal morphology is consistent with the results of the settling tests, which indicated that DBA addition increased the slurry settling rate to a much greater extent than did formate addition.

2.7   <u>DBA Consumption Test Conditions and Results</u>

The cost effectiveness of using additives to enhance SO$_2$ removal in a given FGD system depends primarily upon the consumption rate of the additive in that system. For this reason, a long-term DBA consumption test was performed on the entire FGD system. DBA was selected over sodium formate based on a preliminary economic comparison following the parametric tests. The consumption test approach and results are described below.
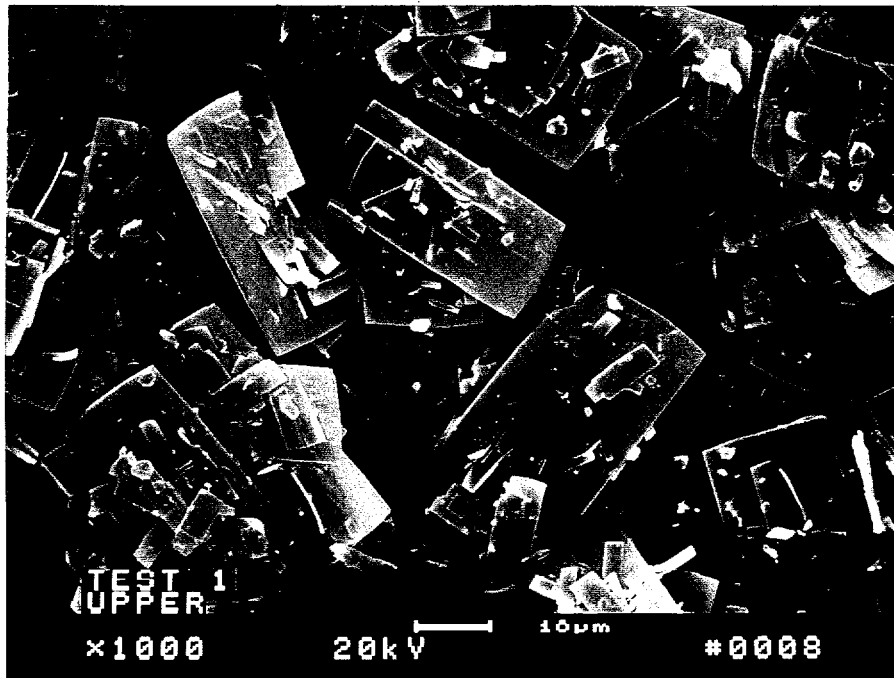
Figure 2-15. Baseline Solids
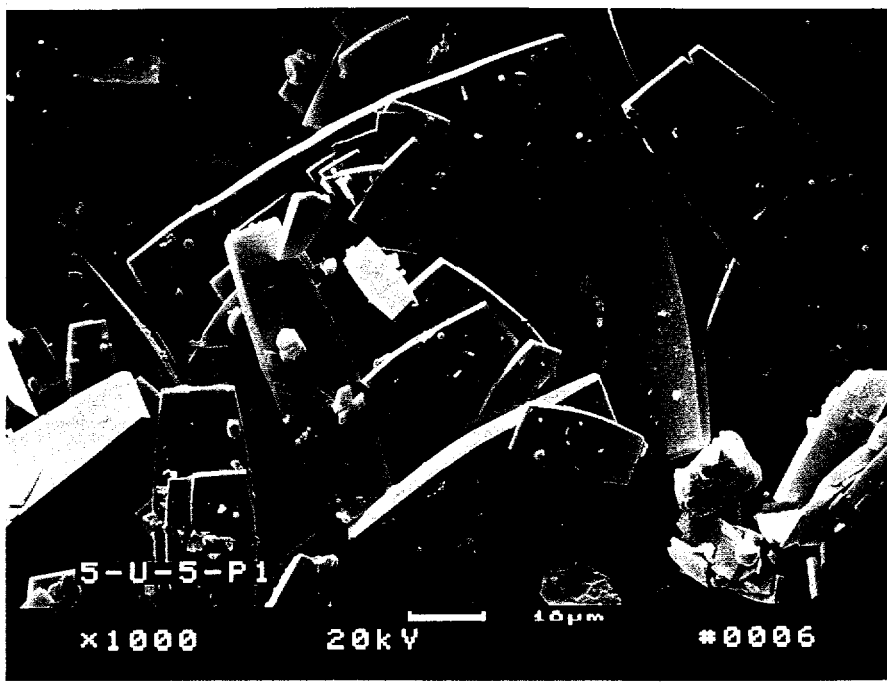
Figure 2-16. DBA Parametric Solids

2-40
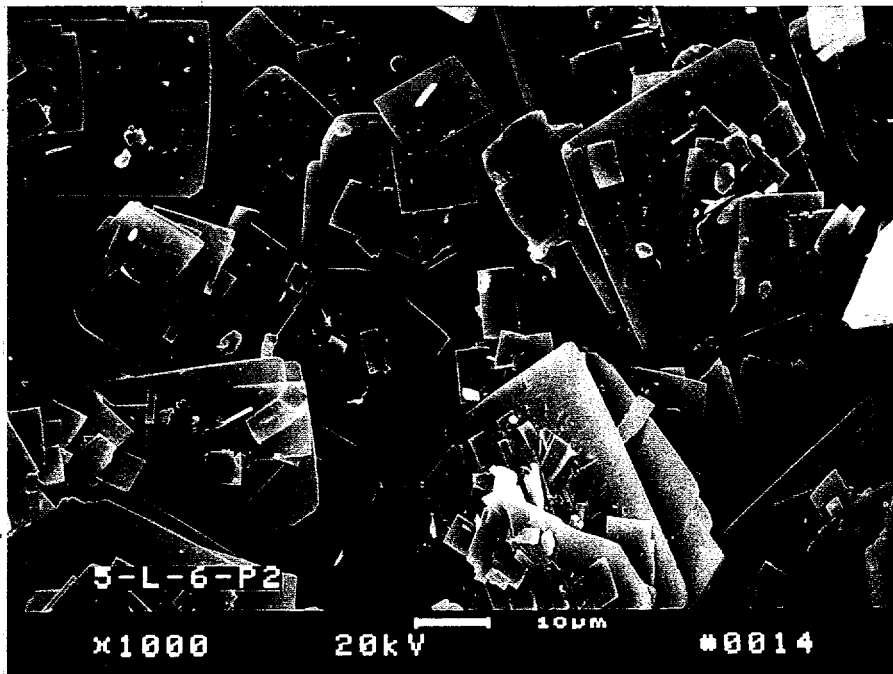
Figure 3-17. Formate Parametric Solids

2.7.1   Consumption Rate Calculation

The summation of the following terms represents the total loss of DBA from the Pirkey FGD system during the consumption test:

1)   Solution loss--DBA lost in liquor adhering to the filter cake. There is no separate liquor blowdown stream from the FGD system. Minor incidental blowdown losses, such as overflow splashed from the absorber feed tanks, were neglected.

2)   Degradation loss--loss which resulted from DBA components participating in chemical reactions where the reaction products are not DBA components.

3)   Coprecipitation loss--DBA lost from the incorporation of DBA into the calcium sulfite crystal structure as SO_2 removed in the FGD system precipitates.

The solution loss (loss 1) can be calculated for a given system based on the SO_2 removal rate, DBA concentration, and filter cake moisture content. The sum of losses 2 and 3 is normally termed "nonsolution losses." The nonsolution loss is a more complex function of system chemistry. The degradation loss cannot be measured directly without knowledge of the degradation reaction products. The coprecipitation loss could in principle be measured by analyzing the filter cake solids for DBA components. However, the current analytical method is not sensitive enough to make an accurate solid-phase DBA determination at the DBA level used in this test.

Using the terms defined above, the following form of the system mass balance gives the average nonsolution loss rate for a given test period:

DBA nonsolution loss (lb) =

DBA added (lb) - DBA inventory change (lb) - DBA solution loss (lb)

This material balance equation was applied to each DBA component (adipic, glutaric, and succinic acids) as well as to the sum of the components.

The DBA nonsolution loss rate is normally reported on a SO_2 removal basis (lb of DBA per ton of SO_2 removed). SO_2 removal in the FGD system for a given test period was calculated using the total limestone consumption and average limestone utilization for a given test period. As a check on this estimate, SO_2 removal was also calculated from the amount of coal burned, coal heating value, and the SO_2 content of the inlet and outlet flue gas in lb per million Btu.

2.7.2   Results

DBA Consumption

The DBA consumption test was completed during the period from 5/12/93 to 5/18/93. DBA was first added to the system on 5/11 by spiking the upper-loop reaction tanks and thickeners. The first DBA inventory was completed during the morning of 5/12. Continuous addition to both upper-loop reaction tanks was then used to maintain the DBA concentration at the desired steady-state level. Additional DBA inventories were completed on the 4th, 5th, and final (7th) day of testing.

The DBA consumption material balance was based on the test interval between the second inventory (5/15/93) and the final inventory (5/18/93). This interval was selected so that the solids in the system were at steady state. Table 2-4 summarizes results of the material balance computations described above. Each term in the overall system material balance for the test period is shown for each DBA component and for total DBA. The total consumption rate and nonsolution loss rate are also reported on the basis of lb/ton of SO_2 removed. Detailed material balance data including individual DBA component concentrations in all system vessels are included in Appendix D. Average concentrations for DBA components in the FGD system scrubber modules are included in Table 2-4.

2-43

Table 2-4

DBA Consumption Test Results[a]
(Total Test Duration = 143 Hours, Calculation Interval = 70 Hours)

	Adipic	Glutaric	Succinic	DBA
Total Added (lb)	1,370	3,970	1,875	7,210
Total Inventory Change (lb)	250	350	-960	-350
Total Consumption (lb)	1,120	3,620	2,835	7,560
Total Loss with Filter Cake (lb)	440	770	120	1,320
Total Non-solution Loss (NSL) (lb)	680	2,850	2,715	6,240
Total NSL/Total Consumption (%)	61	79	96	83
Total SO_2 Removed (tons)[b]	690	690	690	690
Total SO_2 Removed (tons)[c]	630	630	630	630
Total Non-solution Loss Rate (lb/ton SO_2)	1.0	4.1	3.9	9 ± 4
Total Consumption Rate (lb/ton SO_2)	1.6	5.2	4.1	11 ± 4
Average Feed Rate (lb/hr)	20	57	27	103 ± 4
Initial Average Module Concentrations (ppm)	370	800	90	1,260
Final Average Module Concentrations	340	700	30	1,070
Overall Average Module Concentrations	360	750	50	1,170

[a] Results based on the total material balance between the second and final inventories.

[b] Based on limestone consumption.

[c] Based on coal consumption and CEM data.

A total of 7210 lb of DBA (28,840 lb of 25% DBA solution) was added to the system during the 70-hour test duration between the second and last inventories. The average composition of the DBA additive was 19% adipic acid, 55% glutaric acid, and 26% succinic acid. The total DBA inventory change during this period was only 350 lb, which is less than 5% of the total added. The total DBA consumed was 7560 lb, which is the amount added plus the decrease in inventory. Of the total consumed, 1320 lb (about 17%) was accounted for by DBA lost with liquor adhering to the filter cake. The remaining consumption, 6240 lb, is the nonsolution loss due to oxidative degradation plus coprecipitation.

The total estimated SO_2 removed during the material balance interval was 690 tons, based on limestone consumption. For comparison, the total estimated SO_2 removed based on coal consumption, heating value, and CEM data was 630 tons, which agrees well with the limestone estimate. On an SO_2 removal basis, the overall DBA consumption was 7560/690 or 10.9 lb DBA/ton SO_2 removed. Of this total, 1.9 lb/ton SO_2 was lost with the filter cake liquor, and the remaining 9 lb/ton SO_2 was the nonsolution loss. During the interval, an average DBA feed rate of 103 lb/hr was required to maintain an average concentration of 1170 ppm in the FGD system modules.

The results show how the individual components were consumed at different rates. The average composition of the DBA fed to the system was 19% adipic, 55% glutaric, and 26% succinic acid. The final proportions of adipic, glutaric, and succinic acids in the scrubber module reaction tanks were 32%, 65%, and 3%, respectively. The ratio of nonsolution losses to the amounts fed increased in the order adipic < glutaric <succinic.

The amount of each DBA component leaving the system with the filter cake solids can also be estimated from solid-phase DBA analyses. The average concentrations of the three components in the waste slurry solids were <0.2 mg/g adipic acid, 1.3 mg/g glutaric acid, and 0.9 mg/g succinic acid. The waste solids production rate is 2.2 lb solid/lb of SO_2 removed (4400 lb/ton). The measured concentrations of the solid-phase DBA components correspond to coprecipitation loss rates of <0.9, 5.7, and 4.0 lb/ton for adipic, glutaric, and succinic acids,

respectively. These values are close to the estimated total nonsolution loss rates, indicating that nearly all of the losses can be accounted for by coprecipitation, rather than by degradation.

An error propagation analysis was done to estimate the uncertainty in the DBA consumption results using the procedure outlined in ANSI/ASME Power Test Code 19.1-1985, "Measurement Uncertainty." Table 2-5 lists the parameters that were used in the DBA material balance calculations along with the bias and precision errors assumed or calculated for each.

The largest errors are those associated with the inventory of solids in the system and with the DBA content of the solids in the system. The solids content of the thickeners could only be estimated. A bias error of 25% was assumed for the estimated solids inventory in the thickeners. A standard deviation of 25% was assumed for the total DBA content of the solids. Fortunately, the solid-phase DBA is only about 20% of the total DBA inventory, so that these uncertainties do not dominate the uncertainty of the results. The uncertainty analysis indicates that the total calculated DBA consumption (11 lb/ton SO_2 removed) is accurate to about ±35% at the 95% confidence level.

Results of Consumption Test Slurry Sample Chemical Analyses

A number of solids samples obtained during the consumption test were analyzed to determine limestone utilization and sulfite oxidation. Results of solid-phase analyses for the consumption test slurry samples are included in Appendix A, Table A-12. These results were used to verify that the process chemistry effects seen during the DBA parametric tests -- increased limestone utilization and decreased sulfite oxidation -- were repeated during the consumption test. The limestone utilization results were also used to estimate the amount of SO_2 removed during the consumption test.

Four sets of slurry samples were collected during the consumption test. The first sample set was taken just prior to introducing DBA to the system so the effects of DBA could be

2-46

Table 2-5

DBA Consumption Error Propagation Terms

Parameter	Bias Error	Precision Error (Standard Deviation)
Delivered DBA in Tanker	2%	-
Measured DBA in Tanker	-	300 lb
DBA in Liquid	-	5%
Liquid in System	2%	-
DBA in Solids	-	25%
Solids in Thickener	25%	-
Solids in Other Tanks	-	10%
Limestone Belt Scale	5%	-
Filter Cake Belt Scale	5%	-
Limestone Utilization	-	3% [a]
Filter Cake Moisture	-	5% [a]

[a] Calculated sample standard deviation.

verified. The limestone utilization in the lower-loop samples averaged only 72% prior to the test. The average lower-loop pH was about 5.8, which is considerably higher than the "normal" set point of 5.5. The utilization was higher in the A/C modules which share one upper-loop reaction tank (83%) than the B/D modules which share the other (62%). A comparison of utilization versus pH results for these samples with previous results shown in Figure 2-5 shows that the limestone utilization in Module C lower loop is very close to that expected at the measured pH of 5.72. The results for the other modules cannot be directly compared because the pH levels are well above those previously tested. At these high pH levels, the utilization versus pH curve becomes very steep.

Limestone utilization was 73% in the A/C module upper loop at a pH of 6.35. This result is also very close to the baseline results. Utilization in the B/D upper loop was only 38% at a pH of 6.41. Again, this pH is higher than tested before and is on the steep portion of the curve in Figure 2-4, but this result also appears to be consistent with the baseline tests. It should be noted that Radian's pH measurements for the upper-loop tanks were consistently about 0.2 pH units higher than indicated by the local on-line pH indicators throughout the consumption test. Therefore, the low utilizations seen in the pre-test samples could be a result of calibration errors in the on-line pH meters.

Sulfite oxidation ranged from 18 to 25% in the lower-loop and 26 to 29% in the upper-loop samples taken before DBA was added to the system. These levels are higher than those seen in the baseline tests, but comparable to those seen prior to the formate parametric tests.

The remaining three sets of samples were collected during the final three days of the consumption test. The results for these samples should represent the steady-state composition for operation with DBA additive. Limestone utilization for lower-loop samples averaged 91.4% at an average pH of 5.35. This is slightly higher than the baseline test results, but slightly lower than expected considering the parametric test results (see Figure 2-8). Utilization averaged 85% in the upper-loop samples at an average pH of 6.17. This is higher

2-48

than the baseline results and is in good agreement with the enhanced utilization seen during the DBA parametric tests.

The oxidation-inhibiting effect seen during the DBA parametric tests was confirmed by the long-term consumption test. Even though the pre-test oxidation percentages were much higher than those seen during the baseline tests, the oxidation was reduced to 10 to 12% in all of the modules by the end of the consumption test. This is the same oxidation percentage seen at the end of both the DBA and formate parametric tests.

Corresponding liquid-phase analytical results are summarized in Table A-13. Liquid-phase samples were obtained only from the C module. As in the previous test series, the liquid-phase results were used to estimate relative saturations for calcium sulfate (gypsum), sulfite, and carbonate. These results are included in the table. Gypsum relative saturations were slightly higher than 1.0 prior to the consumption test and were reduced to 0.7 in the lower loop and 0.5 in the upper loop by the end of the test. These results are comparable to those seen during the parametric tests at similar pH levels and additive concentrations.

Other Process Data for the Consumption Test

Appendix B, Table B-4 is a summary of other process data recorded during the consumption test. It was intended that no flue gas would be bypassed during the consumption test, but in practice, the system could not be operated continuously without bypass due to problems with the stack condensate drain. The stack drain was plugged, and operation without bypass caused condensation to collect in the base of the stack. With time, the condensation would overflow into the bypass duct, which was undesirable for a number of reasons. To avoid overflow of condensation, the bypass dampers were periodically opened to dry out the stack. The data averages shown in Table C-4 were computed only for periods of zero-bypass operation. The data for SO_2 removal efficiency in this table show that the target efficiency of 98% was met or exceeded throughout the test during periods when the bypass damper was closed.

2.8   Estimated Sodium Formate Consumption

The scope of testing at Pirkey did not include a steady-state formate consumption test, but sodium formate consumption can be estimated using data from the formate parametric test series. The major formate nonsolution loss mechanisms are believed to be coprecipitation and vaporization into the flue gas. Oxidative degradation is thought to be a less significant loss mechanism for inhibited-oxidation systems.

Solids samples from Formate Parametric Test 5 were analyzed and found to have an average formate content of 1.2 mg/g. The average Module C SO_2 removal rate was 2.2 tons/hour. Using these data, plus the assumption that 2.2 tons of solids were produced per ton of SO_2 removed (based on molecular weights and analytical results), the average loss of formate with the solids would be 5.3 lb/ton of SO_2 removed. The flue gas was also analyzed for formic acid during the formate parametric tests. During Test 5, the flue gas from Module C had an average formic acid content of 11 ppm (dry). The average liquid formate concentration during this test was 2300 ppm. The Module C flue gas flow rate was 390,000 scfm (dry). At this flow rate, the average loss with the flue gas would be about 30 lb/hr or 14 lb formate/ton of SO_2 removed. The total formate nonsolution loss due to coprecipitation plus vaporization under Test 5 conditions was therefore about 19 lb formate/ton of SO_2 removed.

To compare formate consumption with DBA consumption, the above formate consumption rate can be adjusted to the same basis as that for the long-term DBA consumption test. During that test, the average DBA concentration was 1130 ppm, the average SO_2 removal rate was 9.25 tons/hour, and the estimated average flue gas flow rate for the entire system (average load = 520 MW) was 1,300,000 scfm (dry).

The flue gas formic acid content during the formate parametric test is plotted as a function of liquid formate concentration in Figure 2-18. These data suggest that the flue gas formic acid concentration was roughly proportional to the liquid formate concentration. Therefore, under conditions similar to the DBA consumption test, the flue gas formate
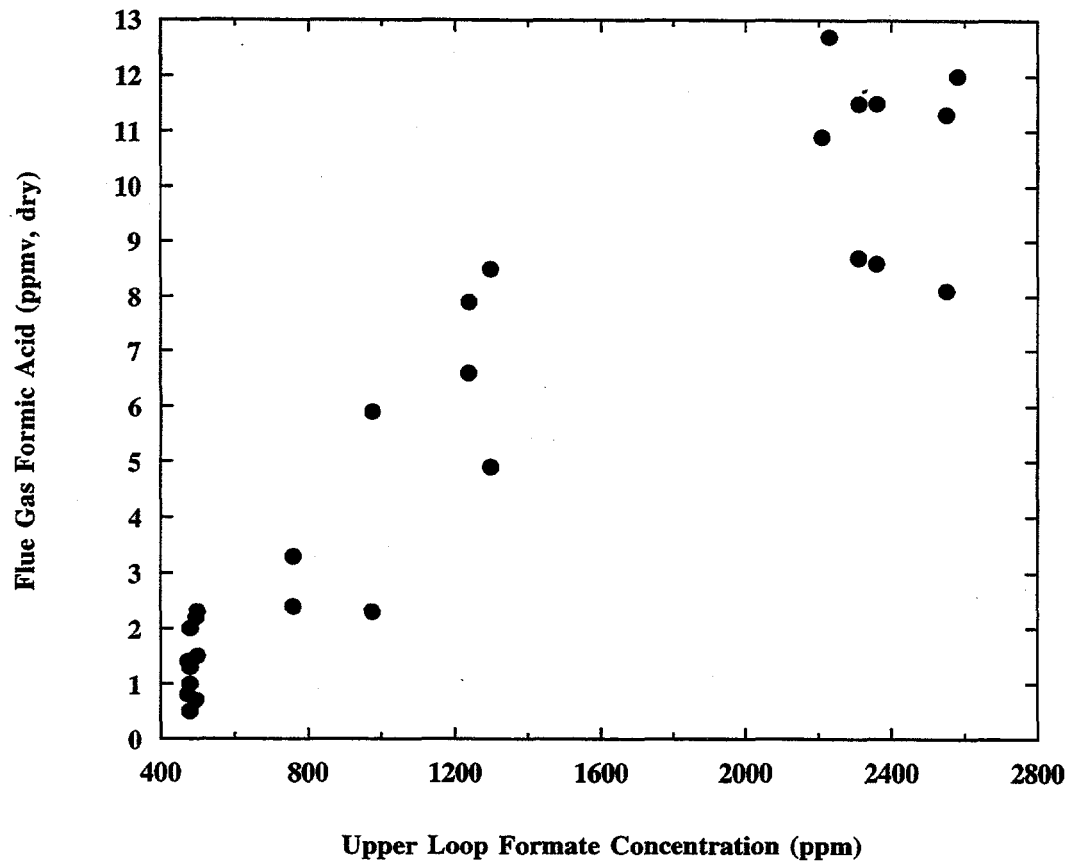
Figure 2-18. Pirkey Formate Parametric Tests: Flue Gas Formic Acid vs. Upper Loop Formate Concentration

concentration would be 1130/2300 x 11 ppm or 5.4 ppm, and the loss rate of formic acid in the flue gas for the entire system would be 1,300,000 scfm x 5.4 x 10^{-6} or 7 scfm. This is equivalent to 50 lb/hr of formate or 5.4 lb formate/ton of SO_2 removed.

The formate coprecipitation loss can be adjusted to a concentration of 1130 ppm from the actual 2300 ppm using a correlation developed for and incorporated into FGDPRISM. Using this model, the coprecipitation loss for formate at 1130 ppm would be about 70% of that at 2300 ppm or 3.7 lb formate/ton of SO_2 removed. Therefore, at 1130 ppm formate, the total estimated flue gas plus coprecipitation loss would be 5.4 + 3.7 or about 9 lb formate/ton of SO_2 removed. This is about the same as the measured result for DBA.

The formate consumption estimate does not include oxidative degradation, however. Previous test results from the ECTC suggest that the oxidative degradation loss could be as much as 20 to 30% of the vaporization plus coprecipitation loss. However, because the delivered price for formate (as sodium formate) is about 50% higher than that for DBA at Pirkey, formate is not an attractive alternative even if this additional loss mechanism is not considered.

3.0   FGDPRISM SIMULATIONS

The FGD PRocess Integration and Simulation Model (FGDPRISM) is a computer program that simulates the performance of FGD systems. The model was calibrated to SWEPCo's Pirkey Station with data collected during the baseline and parametric tests. After calibration, the model was used to predict performance at high inlet SO_2 concentrations and to investigate the option of operating the unit with only three of the four modules on-line. The results of the model calibration and the process simulations follow.

3.1   FGDPRISM Calibration Results

The latest version of the FGDPRISM model (Version 2.0) was used. The model is calibrated to test results by adjusting several parameters. For the Pirkey FGD system, the main parameters of the calibration are the reactivity of the limestone, the gas-/liquid-film thicknesses in the spray sections and on the tray, and the rate of precipitation of calcium sulfite and gypsum solids in the reactive slurry. Details of the calibration are included in Appendix E. The results of two baseline tests and two sodium formate tests were used to get a rough estimate of the calibration parameters. These parameters were then applied to a larger group of test data and adjusted to match the results. The objective was to achieve the best overall fit of limestone utilization, reaction tank pH, and SO_2 removal for these cases.

Eleven cases were used to refine the calibration parameters--four from the baseline tests, four from the DBA tests, and three from the sodium formate tests. The test cases were specifically chosen to represent system performance at high and low pH values for varying organic additive concentrations. The sodium formate test performed with no slurry flow to the upper loop was particularly useful in estimating the lower-loop mass transfer parameters.

Figure 3-1 compares the measured overall SO_2 removals with the predicted results for all calibration cases, except the sodium formate case where only the lower-loop SO_2 removal was measured. In general, the calibrated model slightly under-predicted the baseline test data,

3-1
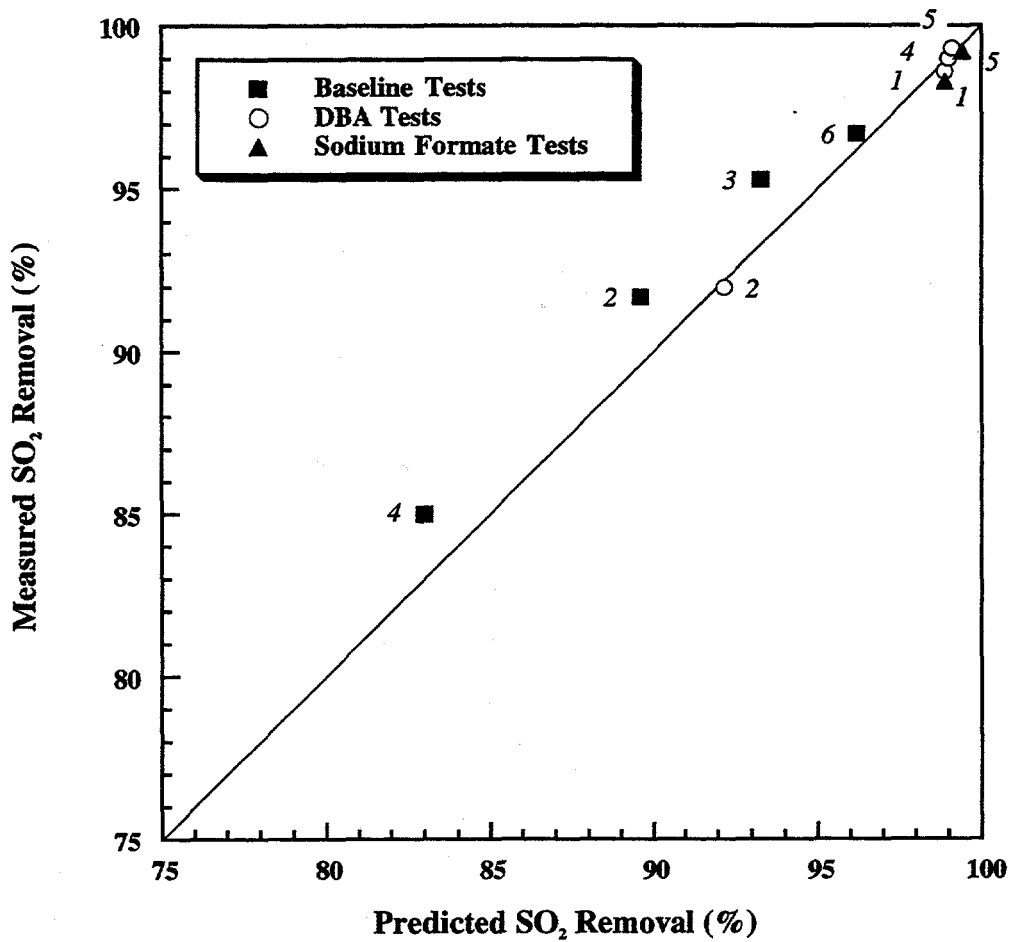
Figure 3-1. Predicted vs. Measured SO₂ Removals for Calibration Tests

slightly over-predicted the formate test data, and fit the DBA test data best. The upper-loop and lower-loop SO_2 removal for the predicted cases also matched the measured SO_2 removal values fairly well. With respect to limestone utilization and pH, the model was less accurate at the extremes of the pH range, but was not consistently high or low across the range. When the input limestone utilization was adjusted to match test results, the model calculated a higher pH for the low-pH cases and a lower pH for the high-pH cases.

Following the calibration, the remaining data from the baseline tests and parametric tests were simulated with the FGDPRISM model. A comparison of the predicted and observed overall SO_2 removal for these additional cases is shown in Figure 3-2. For several of the sodium formate and DBA additive cases, the predicted removal is greater than the observed value. The corresponding upper and lower pH values for the predictive cases are also higher than the observed values.

Although the calibrated model appears to over-predict the SO_2 removal performance for a number of the tests that were not used in the calibration, this does not significantly impact the upgrade economics discussed in Section 4 for those cases. This is because the most attractive economic cases were within the range of full-scale test results, so the SO_2 removal performance was based on interpolations of test data rather than on model predictions. If the modeled cases considered in the economic evaluation were based on over-predicted SO_2 removal performance, correcting this anticipated bias would only make those cases less economically attractive.

3.2   Predictive Simulations

When the FGDPRISM calibration was completed, several simulations were performed to determine if the unit could operate at full-load conditions (with no flue gas bypass) with only three modules. A general system case was constructed to approximate the values of the test cases. The general system case was run at two sulfur loadings ($3.6 \text{ lb}/10^6$ Btu and $8.0 \text{ lb}/10^6$ Btu), representing the average and high levels of sulfur present in the lignite fired at the Pirkey station. Predictions were done at each sulfur level with:

3-3
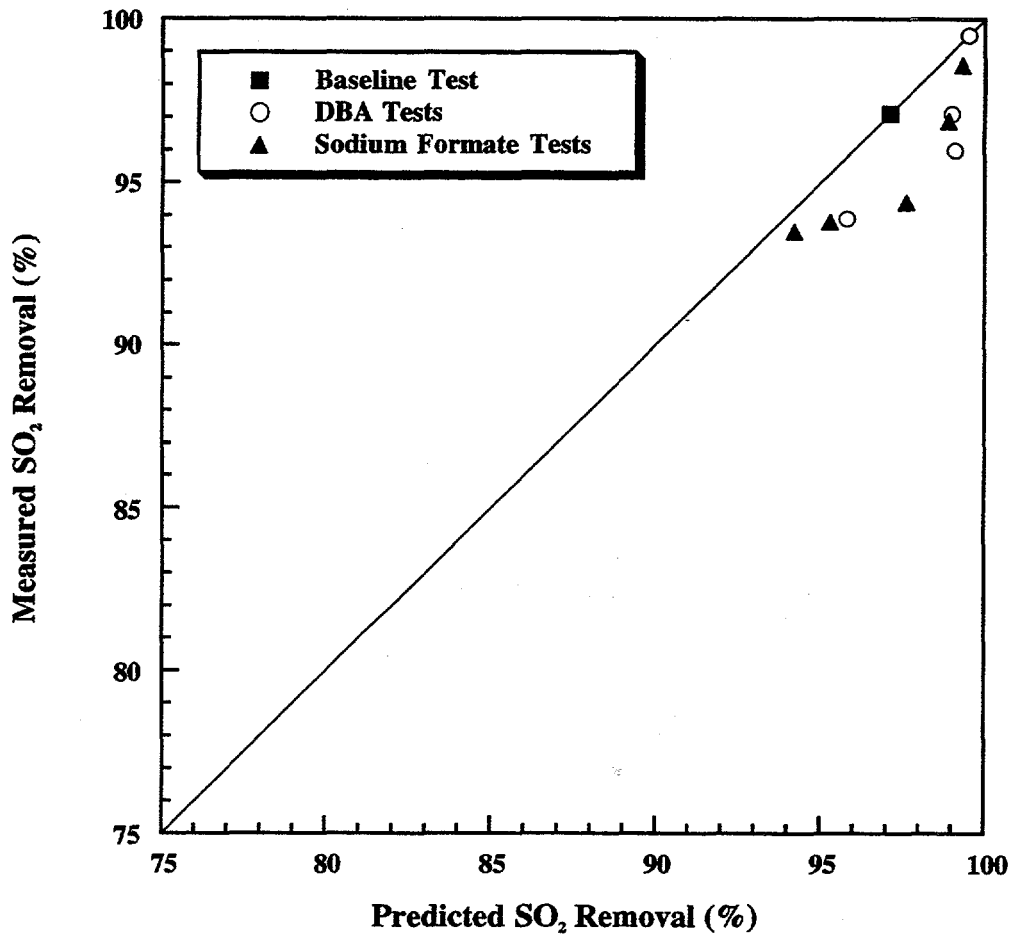
**Figure 3-2. Predicted vs. Measured SO₂ Removals for Test Data
Not Used in the Calibration**

- No DBA additive and four modules in operation;
- No DBA and three modules in operation; and
- With DBA and three modules in operation.

A limestone utilization of 87% for the lower loop and 85% for the upper loop was maintained for all of the cases.

The process conditions for the simulations are shown with the results in Table 3-1. At 3.6 lb/million Btu inlet SO_2 loading, the model predicted that Pirkey Station could operate in compliance with only three modules at full gas flow, with or without the use of DBA. Removing one module from service dropped the SO_2 removal from 97% to 87%.

With 8 lb/million Btu inlet SO_2, FGDPRISM predicted that the SO_2 removal efficiency would decrease to 69% with four modules in service at high load. This is less than the 85% efficiency that would be required for compliance. Current operating practice requires much lower limestone utilization to maintain compliance at high inlet SO_2 loadings. The next case, with 1000 ppm DBA added to the system, shows that, with four modules in service, compliance should easily be maintained (88.7% SO_2 removal). With 8 lb/million Btu inlet SO_2 and three modules in service, the model predicts that compliance can be maintained with 2000 ppm DBA added to the system. These cases were considered as alternatives in the economic evaluations discussed in Section 4.

Table 3-1

**Results of the Pirkey Station Predictive Simulations
with 3 or 4 Modules in Service**

Modules	DBA Conc. (ppm)	SO$_2$ Removal (%)			Utilization (%)		pH	
		Overall	Lower Loop	Upper Loop	Lower Loop	Upper Loop	Lower Loop	Upper Loop
3.6 lb/10^6 Btu Inlet SO$_2$ Loading								
4	0	96.6	44.2	93.8	87	85	5.71	6.13
3	0	87.0	37.8	79.1	87	85	5.62	5.94
8.0 lb/10^6 Btu Inlet SO$_2$ Loading								
4	0	69.0	25.1	58.6	87	85	5.51	5.73
4	1000	88.7	38.1	81.7	87	85	5.17	5.59
3	0	57.7	23.3	44.9	87	85	5.41	5.68
3	2000	86.1	40.1	76.8	87	85	4.90	5.43

4.0   ECONOMIC EVALUATION

Performance data from the baseline, parametric, and long-term DBA consumption tests, as well as FGDPRISM model predictions, were used to evaluate the economics of upgrades to increase SO_2 removal efficiency with the Pirkey FGD system. Results of these economic evaluations are presented in this section.

4.1   Upgrade Options and Cost Basis

Options to upgrade the SO_2 removal performance at Pirkey include operating without flue gas bypass at otherwise current conditions, and operating without flue gas bypass plus adding DBA to the system. Each of these options was considered with either three or four modules in service. If DBA is added, the optimum pH set points must also be selected. Table 4-1 summarizes the system design basis, cost components, and other assumptions necessary for evaluating these options.

Based on 1992 annual data, a total of 3.08 million tons of lignite were burned at Pirkey. The average heating value of the lignite was 6760 Btu/lb. Using these figures and unit heat rate data, the average capacity factor was about 65%. The full-load (685 MW) flue gas flow rate estimated by combustion calculation is 8.5 million lb/hr (1.86 million scfm). This flow rate corresponds to an average velocity of 8.3 ft/s at scrubber conditions through four modules. For the economic evaluation, it was assumed that the unit operates 8000 hours per year with an average load of 490 MW. The average flue gas flow rate at 490 MW was assumed to be 85% of the full-load flow or 7.2 million lb/hr (1.6 million scfm, 6.7 ft/s).

Also in 1992, the average equivalent SO_2 content of the fuel was 3.6 lb/million Btu, and the system outlet SO_2 was typically maintained at 1.05 lb/million Btu. Based on these figures, the baseline annual amount of SO_2 removed is about 53,100 tons, and the baseline emissions are

Table 4-1

Economic Basis for Pirkey SO_2 Removal Upgrade Options

Maximum Continuous Rating	685 MW net
Capacity Factor	65% (8000 hours at 490 MW avg.)
Average Flue Gas Flow	7.2 million lb/hr
Average Fuel Sulfur Content	3.6 lb/million Btu
Average Fuel Heating Value	6760 Btu/lb
Current Average Outlet SO_2	1.05 lb/million Btu
Current SO_2 Removal	53,100 tons/yr
Additional SO_2 Available for Removal	21,800 tons/yr
Capital Cost of DBA System	$300,000 for 100 lb/hr
Annualization Factor	0.17
Delivered Cost of DBA	$0.26/lb
Cost of Power	$0.05/kWhr
DBA Consumption Rate	10.9 lb/ton SO_2 at 1130 ppm
Cost of Prepared Limestone	$14/ton
Cost of Additional Sludge	$2/ton
Increase in System ΔP to Treat all Flue Gas	1.4 in. H_2O
Increase in System ΔP with 3 Modules	2.6 in. H_2O
Change in System ΔP Due to Improved Oxidation Control with DBA	- 1 in. H_2O
Fan Efficiency	80%
Current Average Limestone Utilization	75%, 87%

about 21,800 tons/year. These baseline emissions represent the additional amount of SO_2 available for removal by operating the FGD system at higher efficiency.

The capital cost of a DBA additive system sized for 100 lb/hr to be installed at Tampa Big Bend Unit 4 was previously estimated by Stone & Webster to be $550,000. Based on previous cost estimates by SWEPCo and comparison with EPRI's FGDCOST computer model, a lower value of $300,000 was used for this study. For feed rates higher or lower than 100 lb/hr, this cost was adjusted as a function of capacity ratio using an exponent of 0.15. An annual capital recovery factor of 0.17 was used. The delivered cost of DBA was assumed to be $0.26/lb, based on quotes from DuPont. The results of the DBA consumption test indicated that the total DBA consumption at a 1130 ppm concentration in the reaction tanks was 11 lb/ton of SO_2 removed. Based on results from pilot-scale tests at EPRI's ECTC, DBA consumption should be directly proportional to concentration. A linear relationship between DBA concentration and consumption was assumed for these calculations.

Increases in system SO_2 removal will increase some system operating costs, such as requiring additional limestone reagent and increasing the amount of FGD sludge to be dewatered and landfilled. Additional limestone reagent (prepared) was valued at $14/ton. The cost of dewatering and disposing of additional filter cake was estimated by SWEPCo to be $2/ton. Also, if all of the flue gas is treated in the FGD system, rather than bypassing a portion directly to the stack, the FGD system pressure drop will increase. The average increase in overall system pressure drop due to treating all of the flue gas with four modules was estimated to be 1.6 in. H_2O. A further 2.6 in. H_2O pressure drop increase was estimated for three-module operation without bypass. An average credit of 1 in. H_2O pressure drop was assumed for the DBA cases, based on the observed oxidation-inhibiting effect of DBA addition and the anticipated benefits of operating the modules free of any gypsum scale. To convert these pressure drop values to power costs, a fan efficiency of 80% was assumed, and the fan power was valued at $0.05/kWhr.

The results of additive tests at Pirkey showed that limestone utilization increased as oxidation decreased. Based on parametric test results at the baseline pH set point of 5.5 in the

lower-loop reaction tanks, it was assumed that DBA addition at 1000 ppm would increase limestone utilization by 5 percentage points. For DBA addition at 500 ppm at these conditions, a utilization increase of 3 percentage points was assumed. Savings in limestone costs are expected to be an important benefit of DBA addition at Pirkey. The actual baseline utilization and therefore the potential savings are relatively uncertain, however. Based on the test results, limestone utilization at the normal lower-loop pH set point of 5.5 should be about 87%. An average of Pirkey laboratory determinations for 1992 showed a utilization of 92.6%. On the other hand, annual limestone consumption data for 1992 (117,000 tons) correspond to an average utilization of only 75%. Because of this uncertainty, two different baseline utilization levels (75% and 87%) were used in the evaluation.

4.2   Results

The economic factors described above were included in a spreadsheet calculation that estimates the cost of additional tons of SO_2 removed at increasing levels of removal efficiency. Tables 4-2a and 4-2b summarize the results of these calculations. Table 4-2a assumes that the baseline limestone utilization is 75%, and Table 4-2b assumes 87%. Only the optimum cases are shown for DBA addition in either table. The marginal cost of additional tons of SO_2 removed was greater than the projected value of allowances at higher removal efficiencies than those shown in the tables. Additional details are shown in Appendix F.

The first series of entries in each table is based on the option of closing the system bypass dampers while maintaining FGD system operation at the current baseline conditions. To estimate the amount of additional SO_2 removal obtained by closing the bypass dampers, an average annual SO_2 removal efficiency was estimated using the baseline test data.

The test data were obtained at a flue gas velocity of 8 ft/s at scrubber conditions. This velocity is close to full load conditions (8.3 ft/sec), but the average annual operating load is only about 65% of full load (490 MW for 8000 hours versus 685 MW for 8760 hours). Therefore, the annual average SO_2 removal without flue gas bypass should be higher than the baseline

Table 4-2a

Economic Comparison of SO$_2$ Removal Upgrade Options
Assuming 75% Baseline Limestone Utilization

Option	SO$_2$ Removal, %	Additional SO$_2$ Removed (tons)	Limestone Utilization, %	Total Additional Costs ($ Thousand/yr)	Average Cost $/ton SO$_2$	Net Annual Value ($ Thousand)	
						@ $250/ ton SO$_2$	@ $150/ ton SO$_2$
Current Operation	70.8 [a]	-	75	-	-	-	-
Close Bypass Only							
4 Module 3 Module	97.9 90.2	20,200 14,500	75 75	939 880	46 61	4110 2700	2090 1300
Close Bypass Add 500 ppm DBA with Current pH Set Points	99.3	21,200	78	879	41	4420	2300
Close Bypass Add 1000 ppm DBA with Lower Set Points (6.0, 5.2)	98.7	20,800	95	561	27	4630	2560

[a] Includes the effect of partial fluegas bypass.

Table 4-2b

Economic Comparison of SO$_2$ Removal Upgrade Options
Assuming 87% Baseline Limestone Utilization

Option	SO$_2$ Removal, %	Additional SO$_2$ Removed (tons)	Limestone Utilization, %	Total Additional Costs ($ Thousand/yr)	Average Cost $/ton SO$_2$	Net Annual Value ($ Thousand) @ $250/ ton SO$_2$	@ $150/ ton SO$_2$
Current Operation	70.8 [a]	-	87	-	-	-	-
Close Bypass Only							
4 Module	97.9	20,200	87	841	42	4210	2190
3 Module	90.2	14,500	87	815	56	2810	1400
Close Bypass Add 500 ppm DBA with Current pH Set Points	99.3	21,200	90	822	39	4480	2360
Close Bypass Add 1000 ppm DBA with Lower Set Points (6.0, 5.2)	98.7	20,800	95	791	38	4400	2330

[a] Includes the efffect of partial fluegas bypass.

test results. The flue gas volume is not directly proportional to load because more excess air is used at low load than at high load. An approximate average annual SO_2 removal efficiency without bypass was estimated at 97.9% using Equation 2-1. This estimate assumes that the load-weighted average gas velocity is 85% of the full-load velocity. At this efficiency, operating with the bypass dampers closed should increase annual SO_2 removal by about 20,200 tons. With such a high efficiency, error introduced by this approximation should not have a significant effect on the estimated amount of additional SO_2 removal.

The total additional costs associated with additional SO_2 removal are also shown in the table. A detailed breakdown of these costs is given in Appendix F. The average cost of the additional tons of SO_2 removal obtained by closing the bypass dampers is $46/ton. If allowances are valued at $250, the annual value of increased removal for this option is slightly more than $4 million. If allowances are only valued at $150, the annual value is about $2 million. If the baseline reagent utilization is assumed to be 87% (Table 4-2b) rather than 75%, the cost is reduced to $42/ton and the corresponding annual values are higher by about $100,000.

Results of the FGDPRISM predictions from Section 3 were used to evaluate the next option shown in the tables, operation with three modules instead of four modules. Predictions show that SO_2 removal would be reduced significantly to about 90%, so the annual value of this option is much less attractive. Not only are fewer tons of SO_2 removed, but operating costs per ton of SO_2 removed are higher because the savings in pumping power obtained by running only three modules is more than offset by the increase in fan power due to increased system pressure drop. Adding DBA to this option would also not be economical, because more DBA would be needed than for any of the four-module cases discussed below.

The next option in the table is to add DBA to the four-module system while maintaining the current baseline pH set points. At Pirkey, the average baseline SO_2 removal without bypass is already high. However, some significant savings can be obtained with DBA addition due to its observed beneficial effect of lowering sulfite oxidation percentages and raising limestone utilization. The savings result from lower fan power costs (due to the elimination of

4-7

gypsum scale in the absorbers and reduced absorber pressure drop) and reduced limestone consumption. The parametric and consumption test results suggest that both of these savings will be fully realized at a DBA concentration of 1000 ppm or less. Therefore, there is little incentive for using higher concentrations. The marginal cost of additional tons of SO_2 removal using this option was examined as function of DBA concentration to estimate the optimum DBA concentration for this condition. Only the optimum case (500 ppm) is shown in the table for the current pH set points.

Closing the bypass and adding 500 ppm DBA (40 lb/hr) at the baseline pH set points is predicted to increase SO_2 removal to 99.3%. This corresponds to 21,200 tons/yr of additional SO_2 removed. If the baseline limestone utilization averages 75% (Table 4-2a), 500 ppm DBA is estimated to increase this utilization to 78%. If baseline utilization averages 87% (Table 4-2b), 500 ppm DBA should increase this to 90%. The effect of the assumed limestone utilization on the upgrade economics is relatively insignificant if the potential value of the additional SO_2 allowance is considered, though. In both tables, the value of allowances brings the net annual value of this option to approximately $4.4 million for an assumed SO_2 allowance value of $250/ton, or $2.3 million if the allowance value is $150/ton.

The next upgrade option shown in the table involves closing the bypass and using 1000 ppm DBA (80 lb/hr) with the lower-loop pH set point reduced to 5.2. The SO_2 removal efficiency is predicted to be slightly less than 99%, and 20,800 additional tons of SO_2 are removed. At this pH, the limestone utilization should be about 95%. For the case where baseline utilization is assumed to be only 75% (Table 4-2a), the total annual value of this option is either $4.6 million or $2.6 million, depending again on the value of the allowances. If the baseline limestone utilization is actually 87% (Table 4-2b), the total annual value of the option, including allowances, is either $4.4 million or $2.3 million.

Higher DBA concentrations and a lower pH set point are therefore slightly more economical than the 500 ppm DBA case if the lower, 75% baseline limestone utilization value is

assumed. The 1000 ppm and 500 ppm DBA concentration cases are equal in value at the higher, 87% baseline utilization, though.

4.3   Discussion

The economic evaluation described above shows that most of the additional tons of SO_2 that can be removed by the Pirkey FGD system could be realized merely by closing the bypass damper. With this observation, even the relatively minor additional expense and operating labor required to add DBA to the FGD system may not seem warranted. However, the anticipated benefits of DBA addition in reducing limestone requirements, gypsum scaling tendencies, and flue gas pressure drop through the absorber modules, more than offset these additional costs.

For example, for the case where the base limestone utilization is assumed to be at the higher value (87%), the results in Table 4-2b show that greater amounts of SO_2 can be removed at lower annual cost if DBA is added to the system. Merely closing the bypass damper with no DBA addition is estimated to allow the removal of an additional 20,200 tons of SO_2 per year, compared to the current mode of operation, at an incremental cost of about $840,000 per year. For the case where DBA is added to a concentration of 500 ppm and the current pH set points are maintained, an additional 1000 tons of SO_2 per year (21,200 total) would be removed at a lower annual incremental cost of about $820,000. This advantage of about $20,000 per year is after the capital and operating costs for DBA addition are accounted for. If the value of the additional SO_2 removed is considered, even at the lower $150/ton level, the advantage of the DBA case is much greater, showing a net annual value approximately $150,000 greater than the situation where the bypass is merely closed.

If the actual limestone utilization is lower than the 87% value used in Table 4-2b, the economics of DBA addition are even more attractive. Consider the case where DBA is added to a concentration of 1000 ppm and the pH set points are lowered to improve overall limestone utilization to 95%. An additional 600 tons/year of SO_2 can be removed relative to just closing

4-9

the bypass in the current operating mode (20,800 tons/yr vs. 20,200 tons/yr), and at a significantly lower annual cost of approximately $560,000 rather than $820,000. This reduced cost of about $260,000 per year does not even consider the potential market value of the additional 600 tons of SO_2 per year that could be removed in the DBA case. The value of this additional SO_2 removed amounts to $90,000 to $150,000 per year, depending on whether the SO_2 allowances are valued at $150/ton or $250/ton.

Furthermore, the ability to lower sulfite oxidation percentages and operate subsaturated with respect to gypsum scaling by using DBA may have other benefits. For example, absorber maintenance requirements may be reduced due to the reduced gypsum scaling tendencies. Such additional benefits of DBA addition were not considered in this economic analysis.

Additional economics cases were run to determine the cost-effectiveness of DBA addition in the current operating mode (flue gas bypass to maintain outlet emissions below 1.2 lb SO_2/million Btu). These cases are not included in Tables 4-2a or 4-2b, but, as in those tables, the economics were calculated for base limestone utilization values of 75% and 87%. For the 75% limestone utilization assumption, if DBA is added to a concentration of 1000 ppm and the lower-loop pH set point is lowered to achieve 95% limestone utilization, a net savings would result because of the reduced limestone consumption and lower absorber pressure drop, even after the costs of DBA addition are accounted for. The net savings would amount to nearly $200,000 annually. For the case where the higher, 87% limestone utilization was assumed, the DBA addition case would be slightly more expensive than the current mode of operation (by about $10,000 per year). However, even this slight cost increase may be offset by other savings that were not included in this evaluation, such as reduced absorber maintenance costs due to reduced scale formation.

DBA addition should also improve the operating flexibility of the FGD system, even when high-efficiency SO_2 removal operation is not required. DBA addition could be very useful to maintain compliance with the current SO_2 emission limit (1.2 lb SO_2/million Btu) when

4-10

the inlet SO_2 concentration is very high. For example, FGDPRISM predicts that full-load compliance cannot be maintained with acceptable limestone utilization when the inlet SO_2 loading reaches 8 lb SO_2/million Btu, even with all four modules in service and no flue gas bypass. However, the model predicts that 87% removal could be achieved at current limestone utilization levels with 1000 ppm DBA in the upper loop, while only 85% removal is required for compliance.

DBA addition could also be used to maintain compliance if one of the four modules must be taken out of service for maintenance. Again, for the case with an inlet SO_2 loading of 8 lb/million Btu, the FGDPRISM results indicate that 2000 ppm of DBA would allow compliance to be maintained using only three modules.

4.4   Recommended Upgrade Option

In summary, DBA addition appears to be an attractive upgrade option for the Pirkey Station FGD system. In the future, where high-efficiency operation of the FGD system is desired, using DBA additive rather than just closing the bypass damper in the current mode of operation is estimated to save $20,000 to $260,000 annually in operating expenses. Furthermore, if a dollar value is placed on the additional tons of SO_2 removed, DBA addition could increase net annual values by up to $400,000 compared to merely closing the bypass damper. The net annual values realized would depend on the actual limestone utilization being experienced without DBA additive, and on the dollar value placed on SO_2 credits. Depending on these factors, the optimum DBA concentration ranges from 500 to 1000 ppm and the optimum SO_2 removal efficiency is approximately 99%.

In the current mode of operating the FGD system, where an outlet emission rate of 1.2 lb SO_2/million Btu or lower must be maintained, DBA addition would also likely be cost-effective, due to the expected benefits of reduced limestone consumption, reduced flue gas pressure drop through the FGD absorbers, and perhaps reduced absorber maintenance costs. The cost-effectiveness of DBA addition in the current operating mode will depend on what limestone

utilization is actually being achieved in the FGD system, and on what DBA concentration is actually required to realize all of the expected benefits of improved limestone utilization and reduced gypsum scale formation. In the worst case, where 1000 ppm of DBA is required and where the base limestone utilization is 87%, these economics show that DBA addition is slightly more expensive than not using the additive. Even this extra expense might be offset by reduced absorber maintenance costs, though. If lower concentrations are sufficient to realize all of the benefits of DBA addition, and/or if the actual limestone utilization is lower than 87%, DBA additive is clearly cost-effective at the currently-required SO_2 removal levels.

APPENDIX A

Detailed Flue Gas Measurements

And Results of Slurry Chemical Analyses

Flue Gas Measurements

Tables A-1, A-6, and A-9 show details of individual Method 6 measurements made during the baseline and parametric tests.

Solids Analyses

Detailed results of solid-phase analyses for the baseline test slurry samples are summarized in Table A-2. The sample designation "1-U-1" refers to the first upper-loop sample from Test 1, and "1-U-2" would be the second upper-loop sample from that test. Similarly, "1-L-1" is the first lower-loop sample from Test 1. Each slurry sample indicated in the table was filtered, and the filter cake was dried and weighed to determine the slurry solids content in weight percent. A portion of the dried solids was then digested in HCl. The portion of solids that remained undissolved is reported as "inerts" in weight percent of the solids.

The digested solids solution was analyzed for Ca^{++} and Mg^{++} by atomic absorption and for $SO_4^=$ by ion chromatography (IC). A separate portion of the dried solids was analyzed for $SO_3^=$ (sulfite) by thiosulfate/iodine titration. A third portion of the dried solids was analyzed for $CO_3^=$ (carbonate) by coulometric measurement of CO_2 gas evolved from an acidified sample. These analytical methods are described in detail in EPRI's FGD Chemistry and Analytical Methods Handbook.

Two calculated values for limestone utilization are reported in Table A-2 following the analytical results. Utilization is defined as [1 - moles of carbonate/(moles of product solids + moles of carbonate)]. The "Ca-independent" value for utilization is calculated using the total S (sulfite plus sulfate) analysis as the total moles of product. The "SO_4-independent" value is calculated using the Ca analysis as the total moles of product + moles of carbonate. The calculated utilization values are also expressed as reagent ratio, which is the inverse of utilization.

Additional baseline slurry samples other than those shown in Table A-2 were analyzed for carbonate content to improve the accuracy of the limestone utilization data and to examine the extent to which the limestone content of the slurry varied during the tests. Table A-3 shows all of the slurry solids carbonate analyses, including those listed in Table A-2. Also shown in Table A-3 are calculated limestone utilizations in percent. For samples with only carbonate analyses, approximate utilizations were calculated by using the calcium analyses for the sample from the same test that was completely analyzed.

Oxidation percentages reported in Table A-2 are calculated as 100 x [1 - moles of sulfite/moles of total sulfite plus sulfate].

The remaining entries in Table A-2 include solids analyses calculated on a weight basis, followed by calculated "closures" for the analytical results. Closures are calculated as a quality assurance indicator. The molar closure in percent is calculated for a given set of solids analyses as the difference between the sums of positively and negatively charged ionic species in moles/gram divided by the total of the positively and negatively charged species in moles/gram. The calculated "acceptable" closure in percent is the expected error in the calculated molar closure at the 95% confidence level based on the assumptions that each of the individual analyses has a standard deviation of ±5% and that all significant species have been included in the analyses. The calculated closures in Table A-2 indicate good data quality for the baseline solids analyses. All of the molar closures are well below the acceptable limits.

Results of solids analyses for the DBA and formate parametric tests and the DBA consumption test are summarized in Tables A-7, A-10, and A-12. The format of these tables is the same as that described above for the baseline solids, except for the sample designation in Table A-12. In that table, the designation "1-D-L", for example, represents a sample taken from

the lower loop of the D module during the first inventory. The designation "3-A/C-U" represents a sample taken from the upper-loop tank serving modules A and C during the third inventory.

Liquid Analyses

Results of liquid-phase analyses for the baseline filtered slurry samples are shown in Table A-4. Calcium, magnesium, and sodium were determined by atomic absorption spectrophotometry. Chloride, sulfite, sulfate, and thiosulfate were determined by ion chromatography. The reported result for "total hydrolyzable sulfate" is the total sulfate measured in the liquid sample after digestion under acidic oxidizing conditions, which converts all sulfur species to sulfate. The final result reported as "sulfur/nitrogen" species (S/N in the table) represents the difference between the total hydrolyzable sulfate and the sum of the moles of sulfur in the other reported sulfur species.

Tables A-8, A-11, and A-13 summarize analytical results for the DBA and formate parametric filtered liquor samples and the DBA consumption test samples. The format for these tables is the same as that explained above for the baseline results.

Table A-1

Detailed Baseline Test Conditions and Results

Test No.	Run No.	Date	Time	Slurry pH Upper	Slurry pH Lower	Flue Gas Velocity (ft/s)	On-line Inlet SO₂ (ppm)	Lower Loop SO₂ (ppm) Onsite	Lower Loop SO₂ (ppm) Offsite	Outlet SO₂ (ppm) Onsite	Outlet SO₂ (ppm) Offsite	SO₂ Removal (%)[b] Lower Loop	SO₂ Removal (%)[b] Overall
1	1	2/23/93	1036-1129	6.06[a]	5.46[a]	8.3	1385	-	-	11	30	-	97.8
1	2	2/23/93	1212-1305	6.08[a]	5.49[a]	8.3	1390	-	-	27	39	-	97.2
1	3	2/23/93	1716-1807	6.07[a]	5.52[a]	8.1	1480	260	480	46	50	c	96.6
1	4	2/23/93	1830-1921	6.07[a]	5.52[a]	8.3	1480	41	100	52	45	c	97.0
2	1	2/24/93	1025-1116	5.90	5.17	8.1	1400	680	720	110	130	c	90.4
2	2	2/24/93	1230-1316	5.92	5.38	8.3	1470	360	470	85	105	c	92.9
3	1	2/24/93	1702-1748	6.02	5.70	8.1	1430	510	560	66	69	62	95.2
3	2	2/24/93	1815-1901	6.06	5.69	8.1	1400	580	630	44	65	55	95.3
4	1	2/25/93	1040-1124	5.68	4.92	8.2	1430	1110	1180	220	240	18	83.1
4	2	2/25/93	1204-1246	5.74	5.16	7.9	1470	1020	990	190	190	33	86.9
5	1	2/25/93	1617-1703	6.12	5.18	8.6	1560	960	950	75	95	39	93.9
5	2	2/25/93	1723-1809	6.12	5.20	8.6	1670	1080	1130	86	110	32	93.4
6	1	2/26/93	0827-0923	6.34	5.69	8.0	1590	-	-	27	51	-	96.8
6	2	2/26/93	0944-1028	6.32	5.75	8.0	1560	-	-	52	54	-	96.5

[a] Upper-loop pH measurements by Radian during Test 1 were low due to a meter malfunction. The actual pHs were approximately 6.3 in the upper loop and 5.7 in the lower loop.

[b] Based on off-site analyses.

[c] Lower-loop removal not reproducible due to sampling problems.

Table A-2

Baseline Solid-Phase Analytical Results

Radian Number	1.1.1	1.1.2	1.1.3	2.1.2	3.1.2	4.1.2	5.1.2	6.1.2	1.1.1	1.1.2	1.1.3	1.1.2
Date	02-23-93	02-23-93	02-23-93	02-24-93	02-24-93	02-25-93	02-25-93	02-26-93	02-23-93	02-23-93	02-23-93	02-24-93
Time	10:51	03:28	17:58	10:59	17:55	11:20	17:02	09:30	11:21	03:00	18:25	11:28
Ca, mM/g	7.74	8.21	7.76	7.53	7.45	7.50	7.76	7.91	7.56	7.64	7.55	7.42
Mg, mM/g	0.05	0.05	0.06	0.04	0.04	0.03	0.04	0.06	0.05	0.04	0.06	0.04
SO3, mM/g	4.35	4.27	4.21	5.48	5.50	5.84	5.44	4.49	5.15	5.01	4.94	5.60
SO4, mM/g	1.07	1.06	0.80	1.22	1.09	1.06	0.92	0.74	0.71	1.14	0.76	1.28
CO3, mM/g	2.32	2.55	2.70	0.72	0.87	0.42	1.27	2.79	1.32	1.52	1.66	0.45
Inerts, wt %	1.87	2.13	1.70	2.43	2.13	2.80	2.76	2.76	1.99	2.41	1.88	2.66
Solids, wt.%	12.27	12.85	13.65	12.56	12.43	13.24	13.81	13.37	12.60	12.94	12.94	12.65
pH	6.06 [a]	6.08 [a]	6.07 [a]	5.85	6.03		6.12	6.33	5.46 [b]	5.52 [b]	5.52 [b]	5.10
Temperature, °C	56.8	56.8	57.5	56.5	57.1		56.5	56.4	56.6	57.1	57.4	57.4
Reagent Utilization, %												
Ca-Independent	70.0	67.6	65.0	90.4	88.3	94.3	83.3	65.2	81.6	80.2	77.4	93.9
SO4-Independent	70.2	69.1	65.5	90.5	88.4	94.5	83.7	65.0	82.7	80.2	78.2	94.0
Reagent Ratio												
Ca-Independent	1.43	1.48	1.54	1.11	1.13	1.06	1.20	1.53	1.23	1.25	1.29	1.07
SO4-Independent	1.42	1.45	1.53	1.10	1.13	1.06	1.19	1.54	1.21	1.25	1.28	1.06
Oxidation, %	19.7	19.9	16.0	18.2	16.6	15.4	14.4	14.2	12.2	18.5	13.3	18.6
Solid Solution, wt.%	67.2	66.0	65.1	84.7	85.0	90.2	83.5	68.7	76.8	77.4	74.8	86.6
Gypsum, wt.%	5.1	5.3	1.0	4.4	2.1	0.6	0.0	0.0	0.0	4.4	0.0	5.0
CaCO3, wt.%	23.2	25.5	27.0	7.2	8.7	4.2	12.7	27.9	13.2	15.2	16.6	4.5
Inerts, wt.%	1.9	2.1	1.7	2.4	2.1	2.8	2.8	2.8	2.0	2.4	1.9	2.7
Ca, mg/g	310	328	310	301	298	300	311	316	302	306	302	297
Mg, mg/g	1	1	1	1	1	1	1	1	1	1	1	1
SO3, mg/g	348	341	337	438	440	467	435	359	412	401	395	448
SO4, mg/g	102	102	77	117	105	102	88	71	69	110	73	123
CO3, mg/g	139	153	162	43	52	25	76	167	79	91	100	27
Closures												
Weight, %	-2.4	0.4	-4.9	-0.7	-2.0	-1.5	-0.4	-1.0	-6.4	-0.5	-5.9	-0.9
Molar, %	0.3	2.4	0.7	1.0	0.2	1.5	1.1	-0.4	2.9	0.1	1.7	0.8
Acceptable, %	6.0	6.0	6.0	6.3	6.3	6.4	6.2	6.0	6.3	6.1	6.1	6.4

Table A-2

(Continued)

Run Number	#1.2.1	#1.2.2	#1.2.3	#1.2.4
Date	02-24-93	02-25-93	02-25-93	02-26-93
Time	18:18	11:46	17:11	09:54
Ca, mM/g	7.60	7.33	7.45	7.774
Mg, mM/g	0.04	0.03	0.04	0.048
SO_3, mM/g	5.26	5.87	5.85	5.257
SO_4, mM/g	1.10	1.44	1.06	0.859
CO_3, mM/g	1.19	0.24	0.60	1.76
Inerts, wt.%	2.68	2.54	2.20	1.76
Solids, wt.%	15.11	13.77	13.42	12.32
pH	5.73	4.93	5.19	5.76
Temperature, °C	56.6	58.1	57.3	57.0
Reagent Utilization, %				
Ca-Independent	84.2	96.9	92.0	77.7
SO_4-Independent	84.4	96.8	92.0	77.5
Reagent Ratio				
Ca-Independent	1.19	1.03	1.09	1.29
SO_4-Independent	1.18	1.03	1.09	1.29
Oxidation, %	17.3	19.7	15.3	14.0
Solid Solution, wt.%	81.2	90.8	90.5	80.3
Gypsum, wt.%	2.9	7.0	0.4	0.0
$CaCO_3$, wt.%	11.9	2.4	6.0	17.6
Inerts, wt.%	2.7	2.5	2.2	1.8
Ca, mg/g	304	293	298	311
Mg, mg/g	1	1	1	1
SO_3, mg/g	420	470	468	421
SO_4, mg/g	105	138	101	82
CO_3, mg/g	71	14	36	106
Closures				
Weight, %	-0.9	1.8	-1.1	-0.7
Molar, %	0.7	-1.3	-0.1	-0.3
Acceptable, %	6.2	6.4	6.4	6.1

[a] The pH meter was not accurate; pH was estimated to be 6.3.
[b] The pH meter was not accurate; pH was estimated to be 5.7.

Table A-3

Complete Baseline Slurry Carbonate Analyses
and Calculated Utilizations

Sample	mM/g CO$_3$	pH	Utilization
1-U-1	2.32	6.06	72
1-U-2	2.55	6.08	69
1-U-3	2.70	6.07	67
2-U-1	0.76	5.95	90
2-U-2	0.72	5.85	90
2-U-3	0.85	5.98	89
2-U-4	0.86	5.83	89
3-U-1	0.85	6.03	88
3-U-2	0.90	6.03	88
3-U-3	0.93	6.09	87
4-U-1	0.35	5.63	94
4-U-2	0.42	5.73	95
4-U-3	0.40	5.76	95
5-U-1	1.22	6.12	84
5-U-2	1.27	6.12	84
5-U-3	1.44	6.12	81
6-U-1	2.78	6.35	65
6-U-2	2.79	6.33	65
6-U-3	2.87	6.30	64
1-L-1	1.32	5.46	83
1-L-2	1.52	5.52	80
1-L-3	1.66	5.52	78
2-L-1	0.56	5.25	93
2-L-2	0.45	5.10	94
2-L-3	0.62	5.30	92
2-L-4	0.94	5.46	87
3-L-1	0.97	5.68	87
3-L-2	1.19	5.73	84
3-L-3	1.30	5.64	83
4-L-1	0.24	4.91	97
4-L-2	0.24	4.93	97
4-L-3	0.68	5.40	91
5-L-1	0.50	5.18	93
5-L-2	0.60	5.19	92
5-L-3	0.66	5.21	91
6-L-1	1.62	5.62	79
6-L-2	1.76	5.76	78
6-L-3	1.76	5.74	78

Table A-4

Baseline Liquid-Phase Analytical Results

Radian Number:	1-U-1	1-U-2	1-U-3	2-U-2	3-U-2	4-U-2	5-U-2	6-U-2
Date	02-23-93	02-23-93	02-23-93	02-24-93	02-24-93	02-25-93	02-25-93	02-26-93
Time	10:51	15:28	17:58	10:59	17:35	11:20	17:02	09:30
Ca, mM/L	20.4	21.3	21.2	20.1	18.0	20.8	20.2	18.8
Mg, mM/L	99.3	89.9	88.0	91.8	82.7	85.8	90.9	79.7
Na, mM/L	10.2	10.2	9.04	9.14	8.47	9.88	9.59	7.89
Cl, mM/L	22.4	22.4	23.0	23.2	22.7	24.9	23.7	20.8
CO_3, mM/L	4.95	4.87	4.96	3.69	3.97	3.76	4.83	4.56
SO_3, mM/L	6.03	5.78	5.43	8.15	7.96	10.9	7.67	5.85
SO_4, mM/L	62.0	57.0	57.6	53.6	57.9	57.7	57.0	50.4
S_2O_3, mM/L	23.4	24.2	27.8	16.3	22.2	15.6	18.3	15.2
Tot Hyd SO_4, mM/L	144	159	154	157	149	165	153	131
S/N, mM/L	28.9	48.2	35.2	62.6	38.4	65.1	52.1	44.7
pH	6.06	6.08	6.07	5.85	6.03	5.73	6.12	6.33
Temperature, °C	56.8	56.8	57.5	56.5	57.1	56.3	56.5	56.4
Ca, mg/L	819	855	848	804	721	833	809	752
Mg, mg/L	2430	2160	2140	2230	2010	2090	2210	1940
Na, mg/L	234	234	208	210	195	227	220	181
Cl, mg/L	794	795	814	821	805	882	842	736
CO_3, mg/L	297	292	298	221	238	226	290	274
SO_3, mg/L	483	463	434	652	638	871	614	468
SO_4, mg/L	5950	5480	5530	5140	5570	5540	5470	4840
S_2O_3, mg/L	2620	2710	3110	1820	2490	1740	2050	1700
Charge Imbalance								
Calculated, %	4.3	-2.2	-2.0	-0.4	-4.9	-5.4	-1.0	-0.1
Acceptable, %	5.9	5.8	5.8	5.8	5.8	5.7	5.8	5.8
Relative Saturation								
Gypsum	1.0	1.0	1.0	0.9	0.9	1.0	1.0	0.9
$CaSO_3 \cdot 0.5H_2O$	5.6	5.9	5.5	5.1	5.6	5.9	6.4	6.0
$CaCO_3$	0.4	0.5	0.5	0.008	0.13	0.05	0.25	0.5

Table A-4

(Continued)

Radian Number:	1-L-1	1-L-2	1-L-3	2-L-2	3-L-2	4-L-2	5-L-2	6-L-2
Date	02-23-93	02-23-93	02-23-93	02-24-93	02-24-93	02-25-93	02-25-93	02-26-93
Time	11:21	15:00	18:25	11:28	18:18	11:46	17:11	09:54
Ca, mM/L	22.0	21.0	22.1	25.2	20.4	29.9	23.4	16.7
Mg, mM/L	102	101	102	97.5	106	108	100	83.4
Na, mM/L	10.5	11.4	10.5	10.3	10.8	10.9	10.7	8.62
Cl, mM/L	26.4	26.8	27.0	24.5	24.9	27.8	25.3	21.3
CO_3, mM/L	5.82	7.57	6.54	2.95	4.40	1.77	3.12	5.18
SO_3, mM/L	12.1	13.0	8.76	28.3	10.3	38.6	30.0	4.33
SO_4, mM/L	50.9	58.9	63.9	56.8	60.2	57.5	58.2	47.9
S_2O_3, mM/L	24.9	26.1	17.6	19.8	22.7	16.1	19.8	18.6
Tot Hyd SO_4, mM/L	159	179	171	174	170	155	175	140
S/N, mM/L	46.5	54.7	62.9	49.5	54.3	26.9	46.8	51.0
pH	5.46	5.52	5.52	5.10	5.73	4.93	5.19	5.76
Temperature, °C	56.6	57.1	57.4	57.4	56.6	58.1	57.3	57.0
Ca, mg/L	883	841	884	1008	818	1200	937	670
Mg, mg/L	2480	2470	2490	2370	2570	2620	2430	2030
Na, mg/L	242	261	241	236	248	250	246	198
Cl, mg/L	937	950	956	867	883	984	897	755
CO_3, mg/L	349	454	392	177	264	106	187	311
SO_3, mg/L	965	1040	701	2270	822	3090	2400	346
SO_4, mg/L	4890	5660	6140	5450	5780	5520	5590	4600
S_2O_3, mg/L	2790	2920	1980	2220	2545	1810	2220	2090
Charge Imbalance								
Calculated, %	4.3	-1.8	-0.7	-0.1	1.3	8.6	-0.2	-0.5
Acceptable, %	5.9	5.8	5.8	5.6	5.9	5.8	5.7	5.9
Relative Saturation								
Gypsum	0.9	0.9	1.1	1.1	0.9	1.3	1.0	0.8
$CaSO_3 \cdot 0.5H_2O$	6.3	6.2	4.5	5.7	5.1	1.5	6.6	2.2
$CaCO_3$	0.07	0.09	0.08	0.004	0.06	0.001	0.005	0.07

Table A-5

Trace Species
Analytical Data Summary
(Results are in mg/L.)

	Baseline				DBA Parametric			
Description:	1-U-3		1-L-3		1-U-6		1-L-6	
Element	Result	Detect Limit	Result	Detect Limit	Result	Detect Limit	Result	Detect Limit
Aluminum	ND	0.94	ND	1.0	ND	1.2	ND	1.9
Antimony	ND	0.47	ND	0.52	ND	0.58	ND	0.94
Arsenic	ND	1.4	ND	1.6	ND	1.7	ND	2.8
Barium	0.24	0.047	0.30	0.052	0.30	0.058	0.33	0.094
Beryllium	ND	0.0094	ND	0.010	ND	0.012	ND	0.019
Boron	200	2.8	230	3.1	220	3.5	240	5.6
Cadmium	ND	0.023	ND	0.026	ND	0.029	ND	0.047
Calcium	910	4.7	890	5.2	590	5.8	690	9.4
Chromium	ND	0.047	ND	0.052	ND	0.058	ND	0.094
Cobalt	ND	0.047	ND	0.052	ND	0.058	ND	0.094
Copper	0.17	0.094	0.21	0.10	0.32	0.12	0.37	0.19
Iron	2.8	0.23	6.0	0.26	0.39	0.29	2.0	0.47
Lead	ND	0.23	ND	0.26	ND	0.29	ND	0.47
Magnesium	2300	4.7	2600	5.2	2800	5.8	2900	9.4
Manganese	2.5	0.047	2.2	0.052	1.6	0.058	1.6	0.094
Molybdenum	ND	0.23	0.27	0.26	0.32	0.29	ND	0.47
Nickel	0.85	0.094	0.95	0.10	1.1	0.12	1.2	0.19
Potassium	65	14	75	16	76	17	76	28
Selenium	7.1	1.4	10	1.6	17	1.7	34	2.8
Silicon	45	4.7	57	5.2	50	5.8	56	9.4
Silver	ND	0.047	ND	0.052	ND	0.58	ND	0.094
Sodium	240	4.7	270	5.2	260	5.8	270	9.4
Strontium	7.1	0.014	6.6	0.016	5.4	0.17	6.1	0.028
Thallium	ND	0.47	ND	0.52	ND	0.58	ND	0.94
Vanadium	ND	0.094	ND	0.10	ND	0.12	ND	0.19
Zinc	ND	0.094	ND	0.10	ND	0.12	ND	0.19

Table A-5

(Continued)

| Description: | DBA Parametric | | | | Formate Parametric | | | |
| | 5-U-5 | | 5-L-5 | | 1-U-6 | | 1-L-6 | |
Element	Result	Detect Limit	Result	Detect Limit	Result	Detect Limit	Result	Detect Limit
Aluminum	ND	0.98	1.7	0.86	ND	0.83	ND	0.86
Antimony	ND	0.49	ND	0.43	ND	0.41	ND	0.43
Arsenic	ND	1.5	ND	1.3	ND	1.2	ND	1.3
Barium	0.22	0.049	0.23	0.043	0.22	0.041	0.24	0.043
Beryllium	ND	0.0098	0.011	0.0086	ND	0.0083	0.014	0.0086
Boron	220	2.9	230	2.6	190	2.5	230	2.6
Cadmium	ND	0.024	ND	0.022	ND	0.021	ND	0.022
Calcium	270	4.9	330	4.3	980	4.1	930	4.3
Chromium	ND	0.049	ND	0.043	ND	0.041	ND	0.043
Cobalt	ND	0.049	ND	0.043	ND	0.041	ND	0.043
Copper	0.47	0.098	0.54	0.086	ND	0.083	ND	0.086
Iron	ND	0.24	0.58	0.22	1.0	0.21	3.0	0.22
Lead	ND	0.24	ND	0.22	ND	0.21	ND	0.22
Magnesium	2500	4.9	2600	4.3	1800	4.1	2100	4.3
Manganese	0.43	0.049	0.44	0.043	2.6	0.041	2.3	0.043
Molybdenum	0.28	0.24	0.37	0.22	ND	0.21	ND	0.22
Nickel	0.99	0.098	1.0	0.086	0.71	0.083	0.78	0.086
Potassium	70	15	75	13	50	12	58	13
Selenium	34	1.5	58	1.3	8.1	1.2	19	1.3
Silicon	53	4.9	58	4.3	43	4.1	53	4.3
Silver	ND	0.049	ND	0.043	ND	0.041	ND	0.043
Sodium	230	4.9	240	4.3	400	4.1	430	4.3
Strontium	2.5	0.015	2.8	0.013	7.6	0.012	7.0	0.013
Thallium	ND	0.49	ND	0.43	ND	0.41	ND	0.43
Vanadium	0.18	0.098	0.19	0.086	ND	0.083	ND	0.086
Zinc	ND	0.098	ND	0.086	ND	0.083	ND	0.086

Table A-5

(Continued)

| Element | Formate Parametric | | | |
| | 5-U-6 | | 5-L-6 | |
Description:	Result	Detect Limit	Result	Detect Limit
Aluminum	ND	0.73	ND	1.1
Antimony	ND	0.36	ND	0.55
Arsenic	ND	1.1	ND	1.6
Barium	0.24	0.036	0.26	0.055
Beryllium	0.011	0.0073	0.013	0.011
Boron	220	2.2	270	3.3
Cadmium	ND	0.018	ND	0.027
Calcium	580	3.6	550	5.5
Chromium	ND	0.036	ND	0.055
Cobalt	ND	0.036	ND	0.055
Copper	0.16	0.073	0.16	0.11
Iron	ND	0.18	0.76	0.27
Lead	ND	0.18	ND	0.27
Magnesium	2200	3.6	2700	5.5
Manganese	1.9	0.036	1.7	0.055
Molybdenum	ND	0.18	ND	0.27
Nickel	0.81	0.073	1.0	0.11
Potassium	62	11	74	16
Selenium	18	1.1	34	1.6
Silicon	51	3.6	65	5.5
Silver	ND	0.036	ND	0.055
Sodium	1300	3.6	1500	5.5
Strontium	5.4	0.011	4.8	0.016
Thallium	ND	0.36	ND	0.55
Vanadium	ND	0.073	ND	0.11
Zinc	ND	0.073	ND	0.11

ND = Not detected at the specified detection limit.

Table A-6

Detailed DBA Parametric Test Conditions and Results

Test No.	Run No.	Date	Time	Slurry pH Upper Loop	Slurry pH Lower Loop	DBA Conc. (ppm)[a] Upper Loop	DBA Conc. (ppm)[a] Lower Loop	Flue Gas Velocity (ft/s)	Online Inlet SO₂ (ppm)	Lower Loop SO₂ (ppm) Onsite	Lower Loop SO₂ (ppm) Offsite	Outlet SO₂ (ppm) Onsite	Outlet SO₂ (ppm) Offsite	SO₂ Removal (%)[a] Lower Loop	SO₂ Removal (%)[a] Overall
1	1	3/09/93	0930-1034	6.19	5.54	550	345	8.0	1230	200	430	19	20	65	98.3
1	2	3/09/93	1100-1201	6.19	5.60	550	345	8.1	1240	450	490	18	19	61	98.5
1	3	3/09/93	1414-1513	6.17	5.65	370	390	7.9	1260	440	460	15	16	63	98.7
1	4	3/09/93	1607-1707	6.17	5.69	370	390	8.2	1220	480	490	18	18	60	98.5
1	5	3/10/93	0830-0929	6.20	5.59	400	420	8.2	1330	500	515	20	20	61	98.5
1	6	3/10/93	1015-1114	6.20	5.59	400	420	8.2	1300	540	550	20	21	57	98.4
1	7	3/10/93	1420-1519	6.24	5.54	430	430	7.9	1310	520	510	13	22	61	98.3
1	8	3/10/93	1545-1644	6.24	5.54	430	430	8.1	1330	540	550	23	24	58	98.2
2	1	3/11/93	0915-0956	5.66	4.97	470	510	8.0	1360	770	780	67	70.	41	94.8
2	2	3/11/93	1045-1126	5.66	4.97	470	510	8.0	1420	910	920	111	114	35	92.0
2	3	3/11/93	1145-1226	5.68	4.96	395	440	8.0	1390	890	900	99	103	34	92.6
2	4	3/11/93	1245-1326	5.68	4.96	395	440	8.1	1490	1010	1005	120	128	32	91.4
3	1	3/13/93	1030-1111	5.70	4.80	690	720	7.9	1690	1130	1150	104	107	32	93.7
3	2	3/13/93	1130-1211	5.70	4.80	690	720	7.9	1700	1170	1270	106	108	26	93.6
3	3	3/13/93	1504-1545	5.68	4.82	590	705	7.8	1570	1040	1050	88	93	33	94.1
3	4	3/13/93	1605-1646	5.68	4.82	590	705	7.6	1550	1010	1030	83	88	33	94.3
4	1	3/14/93	0850-0949	6.18	5.33	630	710	8.0	1620	720	700	26	27	57	98.3
4	2	3/14/93	1015-1114	6.18	5.33	630	710	8.0	1640	700	685	25	26	58	98.4
4	3	3/14/93	1400-1459	6.31	5.64	710	700	7.9	1520	610	520	15	16	67	99.0
4	4	3/14/93	1515-1614	6.31	5.64	710	700	7.9	1430	440	450	13	14	68	99.0

A-14

Table A-6

(Continued)

Test No.	Run No.	Date	Time	Slurry pH Upper Loop	Slurry pH Lower Loop	DBA Conc. (ppm)[a] Upper Loop	DBA Conc. (ppm)[a] Lower Loop	Flue Gas Velocity (ft/s)	Online Inlet SO₂ (ppm)	Lower Loop SO₂ (ppm) Onsite	Lower Loop SO₂ (ppm) Offsite	Outlet SO₂ (ppm) Onsite	Outlet SO₂ (ppm) Offsite	SO₂ Removal (%)[a] Lower Loop	SO₂ Removal (%)[a] Overall
5	1	3/15/93	0958-1057	6.30	5.58	1330	1510	7.9	1580	410	430	6	10	73	99.4
5	2	3/15/93	1311-1410	6.36	5.66	1350	1460	8.0	1610	370	400	9	11	75	99.3
5	3	3/15/93	1500-1549	6.33	5.58	1360	1410	7.9	1620	430	380	10	12	76	99.3
5	4	3/16/93	1115-1214	6.33	5.59	1520	1460	8.1	1650	430	445	11	12	73	99.2
5	5	3/16/93	1240-1339	6.33	5.59	1520	1460	8.0	1710	480	520	13	14	69	99.2
5	6	3/16/93	1359-1458	6.25	5.58	1530	1460	8.2	1680	-	-	14	14	-	99.2
5	7	3/16/93	1528-1627	6.25	5.58	1530	1460	8.1	1660	490	525	14	15	68	99.1
6	1	3/17/93	0835-0934	5.69	4.81	1460	1540	8.0	1480	950	940	54	59	36	96.0
6	2	3/17/93	0950-1049	5.67	4.72	1460	1540	8.0	1460	940	935	56	59	35	95.9
6	3	3/17/93	1450-1549	5.68	5.02	1490	1710	7.9	1530	840	810	40	44	47	97.1
6	4	3/17/93	1605-1704	5.68	5.02	1490	1710	8.1	1500	810	810	38	42	46	97.2
7	1	3/18/93	1010-1109	6.26	5.66	2310	2580	7.9	1370	350	360	5	7	74	99.5
7	2	3/18/93	1125-1224	6.28	5.65	2320	2510	7.9	1300	310	310	5	6	76	99.5
7	3	3/18/93	-	6.30	5.64	2330	2440	7.9	1260	280	280	5	6	78	99.6

[a] Based on off-site analyses.

A-15

Table A-7

DBA Parametric Test Solids Analyses

Radian Number	1.U.1	1.U.3	1.U.4	1.U.6	2.U.1	2.U.2	3.U.1	3.U.3	4.U.1
Date	3/9/93	3/9/93	3/10/93	3/10/93	3/11/93	3/11/93	3/13/93	3/13/93	3/14/93
Time	1040	1530	1000	1500	1030	1250	1111	1530	1007
Ca, mM/g	7.35	7.38	7.36	7.60	7.45	7.44	7.55	7.50	7.68
Mg, mM/g	0.05	0.08	0.05	0.04	0.05	0.05	0.05	0.03	0.05
SO$_3$, mM/g	5.31	5.31	5.79	5.91	6.25	6.13	6.23	6.40	6.02
SO$_4$, mM/g	0.87	0.90	0.92	0.89	0.92	0.93	0.88	0.87	0.79
CO$_3$, mM/g	1.34	1.31	0.90	0.87	0.25	0.24	0.23	0.21	0.70
Inerts, wt.%	1.84	1.60	1.36	1.56	1.84	1.54	1.87	1.84	1.42
Solids, wt.%	16.3	16.7	16.7	16.9	17.4	16.0	16.6	16.7	17.0
pH	6.19	6.17	6.20	6.24	5.66	5.68	5.70	5.68	6.18
Temperature, °C	57.4	58.0	57.5	57.0	57.6	56.9	56.9	56.6	56.3
Reagent Utilization, %									
Ca-Independent	82.2	82.6	88.2	88.6	96.6	96.7	96.8	97.3	90.7
SO$_4$-Independent	81.9	82.5	87.9	88.6	96.6	96.8	96.9	97.3	90.9
Reagent Ratio									
Ca-Independent	1.22	1.21	1.13	1.13	1.04	1.03	1.03	1.03	1.10
SO$_4$-Independent	1.22	1.21	1.14	1.13	1.03	1.03	1.03	1.03	1.10
Oxidation, %	14.0	14.5	13.6	13.1	12.9	13.2	12.4	12.0	11.6
Solid Solution, wt.%	81.1	81.6	88.0	89.2	94.0	92.6	93.1	95.2	89.1
Gypsum, wt.%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CaCO$_3$, wt.%	13.4	13.1	9.0	8.7	2.5	2.4	2.3	2.1	7.0
Inerts, wt.%	1.8	1.6	1.4	1.6	1.8	1.5	1.9	1.8	1.4
Ca, mg/g	294	295	294	304	298	298	302	300	307
Mg, mg/g	1	2	1	1	1	1	1	1	1
SO$_3$, mg/g	425	425	463	473	500	490	498	512	482
SO$_4$, mg/g	83	87	88	86	89	89	84	84	76
CO$_3$, mg/g	80	78	54	52	15	15	14	12	42
Closures									
Weight, %	-4.3	-4.1	-2.6	-0.7	-1.4	-2.8	-1.7	-0.7	-1.7
Molar, %	-0.8	-0.4	-1.3	-0.2	0.5	1.3	1.7	0.3	1.4
Acceptable, %	6.2	6.2	6.3	6.3	6.5	6.5	6.6	6.6	6.4

Table A-7
(Continued)

Radian Number	4-U-3	5-U-1	5-U-2	5-U-4	5-U-5	6-U-1	6-U-4	7-U-1	7-U-2
Date	3/14/93	3/15/93	3/15/93	3/16/93	3/16/93	3/17/93	3/17/93	3/18/93	3/18/93
Time	1513	1059	1345	1224	1516	0944	1542	1108	1305
Ca, mM/g	7.68	7.63	7.63	7.68	7.59	7.40	7.42	7.60	7.71
Mg, mM/g	0.04	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06
SO_3, mM/g	5.79	5.67	5.75	5.86	5.87	6.37	6.42	5.64	5.53
SO_4, mM/g	0.65	0.71	0.76	0.71	0.69	0.72	0.74	0.63	0.65
CO_3, mM/g	1.15	0.82	1.32	1.12	1.00	0.25	0.24	1.27	1.49
Inerts, wt.%	1.64	1.73	1.64	1.68	1.64	1.71	1.83	1.69	1.79
Solids, wt.%	17.2	16.9	7.0	17.6	17.7	18.7	18.8	18.3	18.4
pH	6.31	6.33	6.36	6.33	6.25	5.69	5.68	6.26	6.30
Temperature, °C	53.9	54.6	58.0	58.0	58.4	58.2	57.9	57.5	57.0
Reagent Utilization, %									
Ca-Independent	84.9	88.6	83.1	85.4	86.7	96.6	96.8	83.2	80.6
SO_4-Independent	85.2	89.3	82.8	85.5	86.9	96.6	96.8	83.5	80.8
Reagent Ratio									
Ca-Independent	1.18	1.13	1.20	1.17	1.15	1.04	1.03	1.20	1.24
SO_4-Independent	1.17	1.12	1.21	1.17	1.15	1.03	1.03	1.20	1.24
Oxidation, %	10.1	11.1	11.7	10.8	10.5	10.2	10.4	10.1	10.6
Solid Solution, wt.%	84.1	83.4	85.2	85.9	85.7	92.7	93.6	81.9	80.8
Gypsum, wt.%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$CaCO_3$, wt.%	11.5	8.2	13.2	11.2	10.0	2.5	2.4	12.7	14.9
Inerts, wt.%	1.6	1.7	1.6	1.7	1.6	1.7	1.8	1.7	1.8
Ca, mg/g	307	305	305	307	304	296	297	304	308
Mg, mg/g	1	1	1	1	1	1	1	1	1
SO_3, mg/g	463	454	460	469	470	510	514	451	442
SO_4, mg/g	63	68	73	68	66	69	71	61	63
CO_3, mg/g	69	49	79	67	60	15	14	76	89
Closures									
Weight, %	-2.3	-4.8	-0.6	-1.2	-2.4	-2.8	-2.0	-3.3	-2.2
Molar, %	0.9	3.2	-0.9	0.3	0.6	0.7	0.4	0.7	0.6
Acceptable, %	6.3	6.4	6.2	6.3	6.4	6.6	6.6	6.3	6.2

Table A-7

(Continued)

Radian Number:	1.1.1	1.1.3	1.1.4	1.1.5	2.1.1	2.1.2	3.1.1	3.1.3	4.1.1
Date	3/9/93	3/9/93	3/10/93	3/10/93	3/11/93	3/11/93	3/13/93	3/13/93	3/14/93
Time	1015	1500	0930	1530	1000	1230	1128	1350	1023
Ca, mM/g	7.44	7.46	7.43	7.11	7.23	7.15	7.42	7.38	7.43
Mg, mM/g	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.03	0.05
SO_3, mM/g	5.49	5.67	5.92	5.95	6.14	6.30	6.48	6.34	6.13
SO_4, mM/g	0.91	0.91	0.94	0.90	0.94	0.94	0.93	0.88	0.80
CO_3, mM/g	1.09	1.07	0.60	0.50	0.18	0.16	0.11	0.10	0.38
Inerts, wt.%	1.64	1.49	1.82	1.62	1.73	1.52	1.96	1.61	1.67
Solids, wt.%	17.3	17.5	17.4	17.7	17.8	16.9	17.1	17.1	17.9
pH	5.54	5.69	5.59	5.54	4.92	4.96	4.80		5.33
Temperature, °C	57.9	58.0	57.5	57.0	56.8	57.4	56.8		57.0
Reagent Utilization, %									
Ca-Independent	85.4	86.0	91.9	93.2	97.5	97.9	98.6	98.6	94.9
SO_4-Independent	85.4	85.7	91.9	93.0	97.5	97.8	98.6	98.6	95.0
Reagent Ratio									
Ca-Independent	1.17	1.16	1.09	1.07	1.03	1.02	1.01	1.01	1.05
SO_4-Independent	1.17	1.17	1.09	1.08	1.03	1.02	1.01	1.01	1.05
Oxidation, %	14.3	13.9	13.7	13.1	13.3	12.9	12.5	12.2	11.6
Solid Solution, wt.%	84.1	86.4	90.0	89.8	92.8	94.8	97.0	94.6	90.7
Gypsum, wt.%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$CaCO_3$, wt.%	10.9	10.7	6.0	5.0	1.8	1.6	1.1	1.0	3.8
Inerts, wt.%	1.6	1.5	1.8	1.6	1.7	1.5	2.0	1.6	1.7
Ca, mg/g	298	298	297	284	289	286	297	295	297
Mg, mg/g	1	1	1	1	1	1	1	1	1
SO_3, mg/g	439	454	474	476	491	504	518	507	490
SO_4, mg/g	88	88	91	86	90	90	89	85	77
CO_3, mg/g	66	64	36	30	11	9	6	6	23
Closures									
Weight, %	-3.5	-2.0	-2.1	-4.4	-3.6	-3.0	-0.2	-2.5	-3.2
Molar, %	0.0	-1.0	0.1	-1.4	0.1	-1.4	-0.3	0.6	1.1
Acceptable, %	6.2	6.2	6.4	6.4	6.6	6.6	6.6	6.6	6.5

Table A-7

(Continued)

Radian Number:	4.1.3	5.1.1	5.1.2	5.1.4	5.1.5	6.1.1	6.1.4	7.1.1	7.1.2
Date	3/14/93	3/15/93	3/15/93	3/16/93	3/16/93	3/17/93	3/18/93	3/18/93	3/18/93
Time	1509	1114	1332	1211	1502	0931	1527	1055	1251
Ca, mM/g	7.39	7.55	7.49	7.63	7.50	7.25	7.25	7.52	7.68
Mg, mM/g	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
SO_4, mM/g	6.04	5.88	5.90	5.77	5.88	6.48	6.42	5.75	5.60
SO_3, mM/g	0.76	0.74	0.74	0.70	0.72	0.75	0.73	0.67	0.66
CO_3, mM/g	0.62	0.92	0.93	1.11	0.94	0.12	0.19	1.23	1.31
Inerts, wt.%	1.69	1.52	1.60	1.84	2.01	1.84	1.88	1.98	1.90
Solids, wt.%	17.9	17.7	17.8	18.8	18.9	18.6	19.8	19.2	19.1
pH	5.64	5.58	5.66	5.59	5.58	4.81	5.02	5.66	5.64
Temperature, °C	54.3	57.0	57.6	57.9	57.7	55.5	57.6	57.4	57.4
Reagent Utilization, %									
Ca-Independent	91.6	87.8	87.7	85.3	87.5	98.3	97.5	83.9	82.7
SO_4-Independent	91.6	87.9	87.6	85.5	87.6	98.3	97.5	83.7	83.0
Reagent Ratio									
Ca-Independent	1.09	1.14	1.14	1.17	1.14	1.02	1.03	1.19	1.21
SO_4-Independent	1.09	1.14	1.14	1.17	1.14	1.02	1.03	1.19	1.20
Oxidation, %	11.2	11.2	11.2	10.8	10.9	10.4	10.3	10.4	10.5
Solid Solution, wt.%	88.9	86.6	86.9	84.6	86.2	94.5	93.5	83.9	81.8
Gypsum, wt.%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$CaCO_3$, wt.%	6.2	9.2	9.3	11.1	9.4	1.2	1.9	12.3	13.1
Inerts, wt.%	1.7	1.5	1.6	1.8	2.0	1.8	1.9	2.0	1.9
Ca, mg/g	295	302	300	305	300	290	290	301	307
Mg, mg/g	1	1	1	1	1	1	1	1	1
SO_4, mg/g	483	470	472	462	470	518	514	460	448
SO_4, mg/g	73	71	71	67	69	72	70	64	63
CO_3, mg/g	37	55	56	67	56	7	11	74	79
Closures									
Weight, %	-3.2	-2.5	-2.4	-2.1	-2.4	-2.7	-3.1	-2.2	-2.6
Molar, %	0.0	0.4	-0.2	0.6	0.1	-0.4	-0.3	-0.5	1.1
Acceptable, %	6.5	6.4	6.4	6.3	6.4	6.7	6.6	6.3	6.3

Table A-8

DBA Parametric Test Liquid Analyses

Radian Number	1.U.1	1.U.3	1.U.4	1.U.6	2.U.1	2.U.2	3.U.1	3.U.3	4.U.1
Date	3-09-93	3-09-93	03-10-93	03-10-93	3-11-93	3-11-93	3-13-93	3-13-93	3-14-93
Time	10:40	15:30	10:00	15:00	10:30	12:50	11:11	15:40	10:07
Ca, mM/L	11.4	20.4	15.0	13.8	19.1	18.4	12.7	11.7	9.2
Mg, mM/L	99	98.8	100	102	109	109	108	108	103
Na, mM/L	10.0	9.6	10.5	10.5	11.1	10.0	10.3	10.5	9.9
K, mM/L									
Cl, mM/L	27	27.2	29	29.7	29	29.4	29	28.6	26
F, mM/L									
CO_3, mM/L	4.2	4.2	3.7	3.4	2.0	2.0	4.1	4.1	5.2
NO_3, mM/L									
SO_3, mM/L	6.9	7.3	9.1	8.7	10.3	13.6	12.1	17.2	11.1
SO_4, mM/L	53.0	57.1	61.7	59.7	66.2	66.5	55.6	52.8	50.0
S_2O_3, mM/L	18.0	18.2	18.6	16.9	16.5	15.6	15.4	16.6	17.2
Tot Hyd SO_4, mM/L	155	156	150	168	164	179	163	172	154
S/N, mM/L	59.0	55.2	41.8	65.6	54.9	67.6	64.2	68.9	58.2
DBA, mM/L	4.2	2.8	3.1	3.3	3.6	3.0	5.3	4.5	4.8
pH	6.19	6.17	6.20	6.24	5.66	5.68	5.70	5.68	6.18
Temperature, °C	57.4	58.0	57.5	57.0	57.6	56.9	56.9	56.6	56.3
Ca, mg/L	456	817	602	554	765	735	511	469	370
Mg, mg/L	2410	2400	2430	2470	2650	2660	2630	2620	2500
Na, mg/L	229	220	241	241	254	230	236	240	227
K, mg/L	0	0	0	0	0	0	0	0	0
Cl, mg/L	957	965	1030	1050	1030	1040	1030	1010	922
F, mg/L	0	0	0	0	0	0	0	0	0
CO_3, mg/L	253	253	223	205	120	122	246	248	314
NO_3, mg/L	0	0	0	0	0	0	0	0	0
SO_3, mg/L	550	580	730	690	820	1090	968	1380	890
SO_4, mg/L	5090	5480	5930	5730	6360	6390	5340	5070	4800
S_2O_3, mg/L	2010	2040	2080	1890	1850	1750	1720	1860	1920
DBA, mg/L	550	370	400	430	470	395	690	590	630
Charge Imbalance									
Calculated, %	-3.1	-0.1	-1.8	-4.9	-0.0	-2.9	-1.5	-2.9	-1.7
Acceptable, %	6.0	5.8	5.8	5.9	5.8	5.8	6.0	5.9	6.0
Relative Saturation									
Gypsum	0.5	0.9	0.7	0.7	1.0	0.9	0.6	0.5	0.4
$CaSO_3 * 0.5H_2O$	3.7	6.3	6.0	5.5	4.3	5.6	3.8	4.8	4.7
$CaCO_3$	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02

Table A-8

(Continued)

Radian Number	4-U-3	5-U-1	5-U-2	5-U-4	5-U-5	6-U-3	6-U-4	7-U-1	7-U-2
Date	3-14-93	3-15-93	3-15-93	3-16-93	3-16-93	3-17-93	3-17-93	3-18-93	3-18-93
Time	15:13	10:59	13:45	12:24	15:16	09:44	15:42	11:08	13:05
Ca, mM/L	8.7	8.6	8.0	7.0	6.7	9.5	10.2	5.3	7.1
Mg, mM/L	103	96	95.7	96.3	96	100	103	95	92.2
Na, mM/L	9.5	9.1	9.4	9.6	9.3	9.9	10.7	9.4	8.7
K, mM/L									
Cl, mM/L	26.0	26	25.5	25.2	25	26	26.7	26	25.1
F, mM/L									
CO$_3$, mM/L	5.0	5.1	5.4	5.3	4.7	4.2	4.0	5.5	5.5
NO$_3$, mM/L									
SO$_3$, mM/L	10.4	12.1	11.3	12.2	12.8	21.1	18.6	12.0	12.0
SO$_4$, mM/L	50.6	41.5	35.6	39.6	39.9	41.8	40.7	40.5	36.9
S$_2$O$_3$, mM/L	16.4	14.9	14.5	15.1	15.0	15.2	15.3	16.3	16.5
Tot Hyd SO, mM/L	144	128	136	122	127	151	148	140	133
S/N, mM/L	50.3	45.1	60.4	40.0	44.4	57.5	58.4	54.7	51.4
DBA, mM/L	5.5	10.2	10.4	11.7	11.8	11.2	11.5	17.8	17.8
pH	6.31	6.33	6.36	6.33	6.25	5.69	5.68	6.26	6.30
Temperature, °C	53.9	54.6	58.0	58.0	58.4	58.2	57.9	57.5	57.0
Ca, mg/L	347	346	319	281	269	382	410	213	283
Mg, mg/L	2510	2330	2330	2340	2330	2430	2520	2310	2240
Na, mg/L	218	209	216	220	213	227	245	215	200
K, mg/L									
Cl, mg/L	921	922	903	892	886	922	948	922	891
F, mg/L	0	0	0	0	0	0	0	0	0
CO$_3$, mg/L	299	308	324	320	280	250	238	329	328
NO$_3$, mg/L	0	0	0	0	0	0	0	0	0
SO$_3$, mg/L	834	965	902	976	1020	1690	1490	960	964
SO$_4$, mg/L	4860	3980	3420	3810	3830	4020	3910	3890	3550
S$_2$O$_3$, mg/L	1830	1670	1620	1690	1680	1700	1710	1820	1850
DBA, mg/L	710	1330	1350	1520	1530	1460	1490	2310	2320
Charge Imbalance									
Calculated, %	-0.4	-0.5	-1.3	0.4	-1.0	-2.9	-0.4	-7.8	-6.3
Acceptable, %	6.0	5.9	6.0	5.9	5.9	5.8	5.9	5.8	5.7
Relative Saturation									
Gypsum	0.4	0.3	0.3	0.2	0.2	0.3	0.4	0.2	0.2
CaSO$_4$*0.5H$_2$O	4.7	5.7	5.2	4.8	4.5	5.2	4.8	3.5	4.8
CaCO$_3$	0.02	0.02	0.03	0.02	0.01	0.02	0.02	0.13	0.19

Table A-8

(Continued)

Radian Number	1.1.1	1.1.3	1.1.4	1.1.6	2.1.1	2.1.2	3.1.1	3.1.3	4.1.1
Date	3-09-93	3-09-93	3-10-93	3-10-93	3-11-93	3-11-93	3-13-93	3-13-93	3-14-93
Time	10:15	15:00	09:30	15:30	10:00	12:30	11:28	15:45	10:23
Ca, mM/L	21.2	18.6	7.7	15.9	32.6	31.2	27.3	27.0	13.6
Mg, mM/L	115	115	114	114	117	117	100	106	110
Na, mM/L	10.4	9.4	11.2	10.7	12.2	11.5	11.2	10.8	10.6
K, mM/L	28	27.5	28	28.8	29	29.7	31	31.4	27
F, mM/L	6.2	5.7	4.6	3.7	1.6	2.0	2.7	3.2	2.2
CO₃, mM/L									
NO₃, mM/L									
SO₃, mM/L	16.6	13.9	18.0	18.4	28.6	20.5	23.8	27.0	22.1
SO₄, mM/L	66.0	65.1	55.7	60.7	79.9	76.0	63.5	62.3	50.4
S₂O₃, mM/L	24.8	21.1	18.0	18.0	19.9	17.5	16.9	19.3	17.1
Tot Hyd SO₄, mM/L	159	172	184	191	225	214	191	210	171
S/N, mM/L	27.2	50.9	74.0	75.6	77.0	82.6	69.8	82.0	64.6
DBA, mM/L	2.7	3.0	3.2	3.3	3.9	3.4	5.5	5.4	5.5
pH	5.54	5.69	5.59	5.54	4.92	4.96	4.80	4.82	5.33
Temperature, °C	57.9	58.0	57.5	57.0	56.8	57.4	56.8	56.0	57.0
Ca, mg/L	848	746	307	635	1310	1250	1093	1080	544
Mg, mg/L	2800	2800	2770	2760	2840	2840	2430	2580	2674
Na, mg/L	239	215	257	246	281	264	258	248	243
K, mg/L	0	0	0	0	0	0	0	0	0
Cl, mg/L	993	976	993	1020	1030	1050	1100	1110	957
F, mg/L	0	0	0	0	0	0	0	0	0
CO₃, mg/L	374	343	276	222	95	122	162	192	130
NO₃, mg/L	0	0	0	0	0	0	0	0	0
SO₃, mg/L	1330	1110	1440	1470	2290	1640	1900	2160	1770
SO₄, mg/L	6340	6250	5350	5830	7670	7300	6100	5990	4840
S₂O₃, mg/L	2780	2360	2020	2020	2230	1960	1890	2170	1910
DBA, mg/L	345	390	420	430	510	440	720	705	710
Charge Imbalance									
Calculated, %	4.2	0.8	-3.9	-3.2	-4.7	-3.0	-5.5	-6.4	-0.4
Acceptable, %	5.8	5.9	6.1	5.9	5.5	5.6	5.4	5.5	5.9
Relative Saturation									
Gypsum	1.0	0.9	0.3	0.7	1.8	1.8	1.3	1.2	0.5
CaSO₃*0.5H₂O	6.0	5.7	2.8	5.2	4.6	3.6	2.8	3.2	4.0
CaCO₃	0.04	0.05	0.01	0.02	0.00	0.00	0.00	0.00	0.00

Table A-8

(Continued)

Radian Number:	4-L-3	5-L-1	5-L-2	5-L-4	5-L-5	6-L-1	5-L-4	7-L-1	7-L-2
Date	3-14-93	3-15-93	3-15-93	3-16-93	3-16-93	3-17-93	3-17-93	3-18-93	3-18-93
Time	015:09	11:14	13:32	12:11	15:02	09:31	15:27	10:55	12:51
Ca, mM/L	11.4	12.5	11.3	8.7	8.0	23.9	20.3	14.3	14.4
Mg, mM/L	111	85	85.5	98.2	99	110	118	110	107
Na, mM/L	10.5	9.4	9.7	10.1	10.1	11.0	10.7	10.2	10.2
K, mM/L									
Cl, mM/L	26.7	26	25.9	27.5	27	28	28.2	27	26.3
F, mM/L	2.3	5.8	5.1	5.2	5.6	1.3	1.7	6.6	7.0
CO₃, mM/L									
NO₃, mM/L									
SO₃, mM/L	16.9	25.3	25.4	27.5	25.2	49.0	35.1	23.6	18.0
SO₄, mM/L	52.8	38.9	35.2	34.3	35.4	49.5	45.8	29.6	35.7
S₂O₃, mM/L	17.9	16.1	15.6	15.9	15.4	16.2	16.2	13.9	18.5
Tot Hyd SO₄, mM/L	165	147	155	153	151	200	190	150	147
S/N, mM/L	59.6	51.2	62.8	59.0	59.1	68.8	77.0	68.7	55.9
DBA, mM/L	5.4	11.6	11.2	11.2	11.2	11.8	13.2	19.8	19.3
pH	5.64	5.58	5.66	5.59	5.58	4.81	5.02	5.66	5.64
Temperature, °C	54.3	57.0	57.6	57.9	57.7	55.5	57.6	57.4	57.4
Ca, mg/L	460	500	450	350	319	958	814	572	576
Mg, mg/L	2700	2070	2080	2390	2410	2670	2870	2670	2600
Na, mg/L	240	215	222	233	232	252	246	234	234
K, mg/L	0	0	0	0	0	0	0	0	0
Cl, mg/L	947	922	917	974	957	993	998	957	933
F, mg/L	0	0	0	0	0	0	0	0	0
CO₃, mg/L	139	347	307	314	335	77	102	398	417
NO₃, mg/L	0	0	0	0	0	0	0	0	0
SO₃, mg/L	1360	2020	2030	2200	2010	3920	2810	1890	1440
SO₄, mg/L	5070	3740	3380	3290	3400	4750	4400	2840	3430
S₂O₃, mg/L	2010	1800	1750	1780	1730	1820	1810	1560	2070
DBA, mg/L	700	1510	1460	1460	1460	1540	1710	2580	2510
Charge Imbalance									
Calculated, %	-0.2	-7.4	-8.3	-3.1	-2.8	-3.8	-0.5	2.1	0.7
Acceptable, %	6.0	5.5	5.5	5.8	5.9	5.4	5.7	5.8	5.8
Relative Saturation									
Gypsum	0.5	0.5	0.4	0.3	0.2	0.9	0.7	0.3	0.4
CaSO₃*0.5H₂O	4.3	7.0	7.4	5.4	4.5	5.2	5.0	8.2	6.1
CaCO₃	0.01	0.03	0.03	0.02	0.02	0.00	0.00	0.05	0.05

A-23

Table A-9

Detailed Formate Parametric Test Conditions and Results

Test No.	Run No.	Date	Time	Slurry pH Upper Loop	Slurry pH Lower Loop	Formate Conc.[a] (ppm) Upper Loop	Formate Conc.[a] (ppm) Lower Loop	True Gas Velocity (ft/s)	Online Inlet SO₂ (ppm)	Lower Loop SO₂[a] (ppm) Offsite	Lower Loop SO₂[a] (ppm) Onsite	Outlet SO₂[a] (ppm) Offsite	Outlet SO₂[a] (ppm) Onsite	SO₂ Removal[a] (%) Lower Loop	SO₂ Removal[a] (%) Overall
1	1	4/13/93	1005-1108	6.12	5.55	475	410	8.0	902	420	440	18	18	53	98.0
1	2	4/13/93	1232-1332	6.11	5.45	475	410	8.2	964	440	480	20	12	54	97.9
1	3	4/13/93	1530-1629	6.25	5.38	480	430	8.1	974	540	550	21	20	45	97.8
1	4	4/13/93	1700-1759	6.25	5.44	480	430	8.1	1005	540	510	21	21	46	97.9
1	5	4/14/93	0910-1012	6.26	5.53	480	495	8.1	994	390	450	17	8	61	98.3
1	6	4/14/93	1125-1225	6.25	5.53	480	495	8.2	1068	490	490	20	19	55	98.2
1	7	4/14/93	1500-1541	6.33	5.50	480	515	8.7	1144	600	610	447[b]	430	48	61.0[b]
1	8	4/14/93	1649-1730	6.33	5.50	480	515	8.5	1074	530	410	420[b]	380	51	61.0[b]
2	1	4/15/93	0835-0916	5.73	4.85	495	535	8.0	938	680	540	61	71	27	93.6
2	2	4/15/93	1115-1156	5.72	4.82	495	535	8.0	1032	810	780	64	65	22	93.8
2	3	4/15/93	1445-1526	5.71	4.78	500	550	8.3	984	740	740	61	60	25	93.8
2	4	4/15/93	1547-1628	5.71	4.78	500	550	8.0	1069	850	780	76	71	21	92.9
3	1	4/16/93	0940-1021	5.71	4.81	760	810	7.9	1208	890	890	75	74	27	93.7
3	2	4/16/93	1040-1121	5.71	4.81	760	810	7.7	1134	860	850	68	68	25	93.9
3	3	4/16/93	1350-1437	5.67	4.74	975	975	7.7	1064	780	820	60	59	26	94.4
3	4	4/16/93	1455-1536	5.67	4.74	975	975	7.8	1042	750	780	58	60	28	94.4

Table A-9

(Continued)

Test No.	Run No.	Date	Time	Slurry pH		Permeate Conc.[a] (ppm)		Flue Gas Velocity (ft/s)	Online Inlet SO₂ (ppm)	Lower Loop SO₂[a] (ppm)		Outlet SO₂[a] (ppm)			SO₂ Removal[a] (%)	
				Upper Loop	Lower Loop	Upper Loop	Lower Loop			Offsite	Offsite	Onsite	Onsite	Onsite	Lower Loop	Overall
4	1	4/17/93	0912-1011	6.22	5.47	1240	1220	7.8	867	400	410	12	12	12	54	98.6
4	2	4/17/93	1035-1134	6.22	5.47	1240	1220	7.8	834	410	410	12	12	11	51	98.6
4	3	4/17/93	1405-1504	6.22	5.46	1300	1210	7.7	912	440	450	12	12	12	52	98.6
4	4	4/17/93	1600-1659	6.22	5.46	1300	1210	7.8	904	430	430	12	12	12	53	98.7
5	1	4/19/93	1013-1113	6.20	5.46	2310	2240	7.9	769ᶜ	360	360	11	11	10	53	98.5
5	2	4/19/93	1255-1354	6.16	5.47	2310	2240	8.0	1045ᶜ	400	405	11	11	11	62	98.9
5	3	4/19/93	1535-1634	6.16	5.44	2230	2330	8.0	1123ᶜ	460	430	13	12	12	59	98.8
5	4	4/20/93	0930-1030	6.25	5.5	2360	2420	8.1	957ᶜ	360	350	9	9	6	62	99.0
5	5	4/20/93	1343-1442	6.31	5.48	2360	2420	8.1	868ᶜ	320	300	7	7	7	64	99.2
5	6	4/20/93	1612-1711	6.38	5.74	2210	2480	8.2	924ᶜ	260	180	7	7	6	71	99.2
6	1	4/21/93	0915-0956	5.75	4.85	2550	2750	7.9	938ᶜ	600	600	30	30	22	37	96.8
6	2	4/21/93	1137-1218	5.72	4.81	2550	2750	7.8	962ᶜ	540	510	28	28	28	44	97.1
6	3	4/21/93	1348-1429	5.68	4.76	2580	2860	7.9	917ᶜ	470	530	28	28	29	48	96.9

[a] Based on off-site analyses.
[b] Without upper-loop recycle pumps operating.
[c] Meter off line. SO₂ determined by Method 6.

A-25

Table A-10

Formate Parametric Test Solids Analyses

Radian Number:	1.U.1	1.U.3	1.U.4	1.U.6	2.U.1	2.U.2	3.U.1	3.U.3
Date	4/13/93	4/13/93	4/14/93	4/14/93	4/15/93	4/15/93	4/16/93	4/16/93
Time	1058	1629	1012	1524	0933	1502	1019	1432
Ca, mM/g	7.54	7.94	7.72	7.28	7.40	7.60	7.35	7.44
Mg, mM/g	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
SO_3, mM/g	5.39	5.14	5.37	5.28	6.08	6.20	6.22	6.25
SO_4, mM/g	1.23	1.13	1.04	1.35	1.03	0.94	0.89	0.87
CO_3, mM/g	0.77	1.34	1.27	1.38	0.26	0.24	0.21	0.21
Inerts, wt.%	2.26	2.06	2.17	1.93	1.91	1.92	2.09	1.91
Solids, wt.%	9.7	9.8	10.2	10.7	8.6	8.3	7.9	7.9
pH	6.12	6.25	6.26	6.33	5.73	5.71	5.71	5.67
Temperature, °C	54.4	55.4	53.9	55.4	54.8	52.4	53.6	52.9
Reagent Utilization, %								
Ca-Independent	89.6	82.4	83.5	82.8	96.5	96.7	97.1	97.1
SO_4-Independent	89.8	83.2	83.6	81.1	96.5	96.9	97.2	97.2
Reagent Ratio								
Ca-Independent	1.12	1.21	1.20	1.21	1.04	1.03	1.03	1.03
SO_4-Independent	1.11	1.20	1.20	1.23	1.04	1.03	1.03	1.03
Oxidation, %	18.6	18.0	16.2	20.3	14.5	13.2	12.5	12.3
Solid Solution, wt.%	83.3	79.5	83.0	81.6	93.3	93.6	93.1	93.3
Gypsum, wt.%	4.9	3.9	1.5	7.2	0.0	0.0	0.0	0.0
$CaCO_3$, wt.%	7.7	13.4	12.7	13.8	2.6	2.4	2.1	2.1
Inerts, wt.%	2.3	2.1	2.2	1.9	1.9	1.9	2.1	1.9
Ca, mg/g	302	318	309	291	296	304	294	298
Mg, mg/g	1	1	1	1	1	1	1	1
SO_3, mg/g	431	411	430	422	486	496	498	500
SO_4, mg/g	118	109	100	129	99	90	85	84
CO_3, mg/g	46	80	76	83	16	14	13	13
Closures								
Weight, %	-1.2	0.2	-0.3	1.7	-2.0	-1.1	-2.5	-2.2
Molar, %	1.2	2.4	0.5	-4.5	0.4	1.7	0.4	0.9
Acceptable, %	6.3	6.2	6.2	6.0	6.5	6.6	6.6	6.6

Table A-10

(Continued)

Radian Number	4-U-1	4-U-3	5-U-1	5-U-3	5-U-4	5-U-6	6-U-1	6-U-3
Date	4/17/93	4/17/93	4/19/93	4/19/93	4/20/93	4/20/93	4/21/93	4/21/93
Time	1002	1444	1037	1630	1009	1659	1003	1436
Ca, mM/g	7.50	7.51	7.53	7.59	7.36	7.69	7.54	7.49
Mg, mM/g	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.03
SO$_3$, mM/g	7.06	6.11	6.18	6.17	6.02	5.74	6.32	6.22
SO$_4$, mM/g	0.80	0.81	0.74	0.76	0.71	0.68	0.78	0.83
CO$_3$, mM/g	0.57	0.60	0.42	0.42	0.66	1.18	0.22	0.22
Inerts, wt.%	1.79	1.91	2.09	2.16	2.05	2.04	2.10	2.18
Solids, wt.%	9.4	9.8	12.0	12.1	12.3	12.5	12.5	13.1
pH	6.22	6.22	6.2	6.16	6.25	6.38	5.75	5.68
Temperature, °C	52.9	54.6	54.5	56.2	55.8	55.6	55	54
Reagent Utilization, % Ca-Independent	93.2	92.0	94.3	94.3	91.1	84.5	97.0	97.0
SO$_4$-Independent	92.4	92.0	94.4	94.5	91.1	84.7	97.1	97.1
Reagent Ratio Ca-Independent	1.07	1.09	1.06	1.06	1.10	1.18	1.03	1.03
SO$_4$-Independent	1.08	1.09	1.06	1.06	1.10	1.18	1.03	1.03
Oxidation, %	10.2	11.7	10.7	10.9	10.6	10.7	18.4	11.8
Solid Solution, wt.%	102.6	90.6	90.5	90.6	88.0	84.0	92.8	92.3
Gypsum, wt.%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CaCO$_3$, wt.%	5.7	6.0	4.2	4.2	6.6	11.8	2.2	2.2
Inerts, wt.%	1.8	1.9	2.1	2.2	2.1	2.0	2.1	2.2
Ca, mg/g	300	300	301	303	295	308	301	300
Mg, mg/g	1	1	1	1	1	1	1	1
SO$_3$, mg/g	565	489	494	494	482	459	506	498
SO$_4$, mg/g	77	78	71	73	68	66	75	80
CO$_3$, mg/g	34	36	25	25	40	71	13	13
Closures Weight, %	6.5	-1.5	-2.4	-2.0	-3.4	-1.7	-1.9	-2.3
Molar, %	-5.6	0.1	1.5	1.8	0.1	0.8	1.7	1.7
Acceptable, %	6.5	6.5	6.6	6.6	6.5	6.3	6.4	6.6

Table A-10

(Continued)

Radian Number:	1-L-1	1-L-3	1-L-4	1-L-6	2-L-1	2-L-3	1-L-1	1-L-1
Date	4/13/93	4/13/93	4/14/93	4/14/93	4/15/93	4/15/93	4/16/93	4/16/93
Time	1055	1612	0958	1501	0913	1514	1008	1420
Ca, mM/g	7.36	7.36	7.50	7.57	7.37	7.18	7.37	7.45
Mg, mM/g	0.04	0.03	0.04	0.04	0.02	0.02	0.02	0.02
SO_3, mM/g	5.46	5.71	5.64	5.68	6.04	6.06	6.31	6.40
SO_4, mM/g	1.12	1.09	0.98	0.97	1.13	1.14	0.95	0.94
CO_3, mM/g	0.87	0.54	0.91	0.99	0.14	0.12	0.09	0.10
Inerts, wt.%	2.20	2.23	2.20	2.28	1.61	1.57	1.60	1.53
Solids, wt.%	9.9	9.5	11.9	13.2	10.0	9.5	9.0	8.3
pH	5.55	5.38	5.53	5.5	4.85	4.78	4.81	4.74
Temperature, °C	55	55.1	54.4	55	54.1	53.3	3.9	52.4
Reagent Utilization, % Ca-Independent	88.3	92.6	87.9	87.0	98.1	98.4	98.8	98.7
SO_2-Independent	88.2	92.7	87.9	87.0	98.1	98.3	98.8	98.7
Reagent Ratio Ca-Independent	1.13	1.08	1.14	1.15	1.02	1.02	1.01	1.01
SO_2-Independent	1.13	1.08	1.14	1.15	1.02	1.02	1.01	1.01
Oxidation, %	17.0	16.1	14.8	14.6	15.7	15.9	13.1	12.8
Solid Solution, wt.%	84.4	88.3	87.0	87.4	93.4	93.7	95.2	96.1
Gypsum, wt.%	2.7	1.5	0.0	0.0	1.0	1.3	0.0	0.0
$CaCO_3$, wt.%	8.7	5.4	9.1	9.9	1.4	1.2	0.9	1.0
Inerts, wt.%	2.2	2.2	2.2	2.3	1.6	1.6	1.6	1.5
Ca, mg/g	294	295	300	303	295	287	295	298
Mg, mg/g	1	1	1	1	1	1	0	0
SO_4, mg/g	437	457	451	454	483	485	505	512
CO_3, mg/g	108	105	94	93	108	110	91	90
	52	32	55	59	8	7	5	6
Closures Weight, %	-2.3	-2.5	-1.8	-0.6	-2.3	-2.8	-2.2	-1.2
Molar, %	-0.3	0.4	0.1	-0.2	0.6	-0.9	0.3	0.2
Acceptable, %	6.2	6.4	6.3	6.3	6.5	6.5	6.6	6.6

A-28

Table A-10

(Continued)

Radian Number	4.1.1	4.1.3	5.1.1	5.1.3	5.1.4	5.1.6	6.1.1	6.1.3
Date	4/17/93	4/17/93	4/19/93	4/19/93	4/20/93	4/20/93	4/21/93	4/21/93
Time	1015	1458	1049	1615	0956	1641	0946	1420
Ca, mM/g	7.33	7.56	7.49	7.50	7.58	7.67	7.40	7.34
Mg, mM/g	0.03	0.03	0.04	0.04	0.04	0.04	0.03	0.03
SO$_3$, mM/g	5.93	6.23	6.16	6.19	6.07	5.80	6.28	6.28
SO$_4$, mM/g	0.80	0.77	0.71	0.71	0.73	0.69	0.84	0.86
CO$_3$, mM/g	0.46	0.50	0.35	0.37	0.50	0.94	0.13	0.10
Inerts, wt.%	1.53	1.55	1.51	1.30	1.40	1.47	1.62	1.66
Solids, wt.%	10.0	10.7	12.7	13.0	13.1	14.5	14.2	13.9
pH	5.47	5.46	5.46	5.44	5.5	5.74	4.85	4.76
Temperature, °C	53.9	53.5	53.9	56.5	57.3	56.4	55.6	55
Reagent Utilization, %								
Ca-Independent	93.6	93.3	95.2	94.9	93.1	87.3	98.2	98.6
SO$_4$-Independent	93.7	93.4	95.3	95.1	93.4	87.8	98.2	98.6
Reagent Ratio								
Ca-Independent	1.07	1.07	1.05	1.05	1.07	1.14	1.02	1.01
SO$_4$-Independent	1.07	1.07	1.05	1.05	1.07	1.14	1.02	1.01
Oxidation, %	11.8	11.0	10.4	10.3	10.7	10.6	11.8	12.1
Solid Solution, wt.%	88.1	91.5	89.8	90.2	88.8	84.8	93.2	93.5
Gypsum, wt.%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CaCO$_3$, wt.%	4.6	5.0	3.5	3.7	5.0	9.4	1.3	1.0
Inerts, wt.%	1.5	1.6	1.5	1.3	1.4	1.5	1.6	1.7
Ca, mg/g	293	302	299	300	303	307	296	294
Mg, mg/g	1	1	1	1	1	1	1	1
SO$_3$, mg/g	474	498	493	495	486	464	502	502
SO$_4$, mg/g	77	74	68	68	70	66	81	83
CO$_3$, mg/g	28	30	21	22	30	56	8	6
Closures								
Weight, %	-5.2	-1.6	-4.1	-3.8	-3.6	-3.3	-3.2	-3.4
Molar, %	1.2	0.6	2.0	1.8	2.1	1.9	1.2	0.9
Acceptable, %	6.5	6.5	6.6	6.6	6.5	6.4	6.6	6.6

Table A-11

Formate Parametric Test Liquid Analyses

Radian Number:	1.0.1	1.0.3	1.0.4	1.0.6	2.0.1	2.0.3	3.0.1	3.0.3
Date	4/13/93	4/13/93	4/14/93	4/14/93	4/15/93	4/15/93	4/16/93	4/16/93
Time	1058	1629	1012	1524	0933	1502	1019	1432
Ca, mM/L	22.2	23.5	22.5	23.3	20.9	19.6	17.1	16.7
Mg, mM/L	73.0	69.7	67.5	74.2	72.3	65.3	70.6	66.8
Na, mM/L	15.6	14.8	15.0	16.5	15.9	14.8	21.7	24.4
K, mM/L								
Cl, mM/L	16.1	15.9	16.7	15.7	16.3	16.1	15.3	16.0
F, mM/L								
CO$_3$, mM/L	3.03	3.99	3.71	3.81	2.51	2.68	2.88	3.10
NO$_3$, mM/L								
SO$_3$, mM/L	8.69	7.59	7.70	7.27	13.0	14.2	15.9	16.8
SO$_4$, mM/L	47.9	47.3	50.6	52.2	42.9	47.1	41.5	43.5
S$_2$O$_3$, mM/L	16.7	15.8	17.1	16.5	14.9	16.7	17.6	18.0
Tot Hyd SO$_4$, mM/L	132	114	112	122	122	125	115	125
S/N, mM/L	42.5	27.7	19.1	29.9	36.2	30.2	22.8	28.6
Formate, mM/L	10.6	9.17	10.7	10.6	11.0	11.2	16.8	21.6
pH	6.12	6.25	6.26	6.33	5.73	5.71	5.71	5.67
Temperature, °C	54.4	55.4	53.9	55.4	54.8	52.4	53.6	52.9
Ca, mg/L	889	940	901	934	836	784	686	671
Mg, mg/L	1770	1690	1640	1800	1760	1590	1720	1620
Na, mg/L	359	340	345	378	366	340	499	560
K, mg/L	0	0	0	0	0	0	0	0
Cl, mg/L	570	563	591	557	577	569	541	565
F, mg/L	0	0	0	0	0	0	0	0
CO$_3$, mg/L	182	239	223	229	151	161	173	186
NO$_3$, mg/L	0	0	0	0	0	0	0	0
SO$_3$, mg/L	696	608	617	582	1040	1140	1270	1340
SO$_4$, mg/L	4600	4550	4870	5010	4120	4530	3980	4180
S$_2$O$_3$, mg/L	1870	1770	1920	1850	1670	1870	1970	2020
Formate, mg/L	470	410	480	480	500	500	760	970
Charge Imbalance								
Calculated, %	-0.7	3.0	0.7	1.9	2.3	-4.0	1.8	-3.9
Acceptable, %	5.5	5.5	5.5	5.5	5.5	5.4	5.4	5.3
Relative Saturation								
Gypsum	1.0	1.1	1.1	1.1	0.9	0.9	0.7	0.7
CaSO$_4$*0.5H$_2$O	8.4	8.7	8.6	8.6	7.5	7.4	7.4	7.1
CaCO$_3$	0.17	0.36	0.32	0.42	0.03	0.03	0.03	0.03

Table A-11

(Continued)

Radian Number	4.0.1	4.0.3	6.0.1	6.0.3	6.0.4	6.0.6	6.0.1	6.0.3
Date	4/17/93	4/17/93	4/19/93	4/19/93	4/20/93	4/20/93	4/21/93	4/21/93
Time	1002	1444	1037	1630	1009	1659	1003	1436
Ca, mM/L	12.0	11.5	11.1	10.9	16.5	13.5	24.2	25.4
Mg, mM/L	80.9	80.3	95.3	95.2	102	94.8	113	117
Na, mM/L	31.2	30.7	55.1	56.0	59.4	53.1	65.5	66.7
K, mM/L								
Cl, mM/L	16.3	18.7	19.9	21.5	23.1	23.0	24.8	25.5
F, mM/L								
CO$_3$, mM/L	3.86	4.02	3.56	4.10	4.34	4.68	2.68	2.80
NO$_3$, mM/L								
SO$_3$, mM/L	11.33	12.0	14.1	13.4	12.1	12.13	17.5	18.2
SO$_4$, mM/L	41.6	42.0	50.8	46.7	54.9	58.6	71.5	74.1
S$_2$O$_3$, mM/L	18.4	19.6	21.0	18.9	18.3	21.3	20.0	21.2
Tot Hyd SO$_4$, mM/L	115	127	134	144	156	147	172	185
S/N, mM/L	25.1	33.3	27.5	46.2	52.5	33.6	43.2	50.2
Formate, mM/L	27.6	28.8	51.4	49.6	52.5	49.0	56.6	57.4
pH	6.22	6.22	6.20	6.16	6.25	6.38	5.75	5.68
Temperature, °C	52.9	54.6	54.5	56.2	55.8	55.6	55.0	54.0
Ca, mg/L	481	462	444	436	663	543	968	1020
Mg, mg/L	1970	1950	2320	2310	2490	2300	2760	2840
Na, mg/L	718	706	1270	1290	1370	1220	1510	1530
K, mg/L	0	0	0	0	0	0	0	0
Cl, mg/L	578	663	707	764	819	815	879	905
F, mg/L	0	0	0	0	0	0	0	0
CO$_3$, mg/L	232	241	214	246	260	281	161	168
NO$_3$, mg/L	0	0	0	0	0	0	0	0
SO$_3$, mg/L	907	963	1130	1070	965	971	1400	1450
SO$_4$, mg/L	4000	4040	4880	4490	527	5630	6870	7110
S$_2$O$_3$, mg/L	2060	2190	2350	2110	2050	2390	2240	2370
Formate, mg/L	1240	1300	2310	2230	2360	2210	2550	2580
Charge Imbalance								
Calculated, %	3.3	-1.0	1.6	0.6	1.2	-2.1	2.2	1.2
Acceptable, %	5.7	5.6	5.5	5.6	5.5	5.5	5.3	5.3
Relative Saturation								
Gypsum	0.5	0.4	0.4	0.4	0.7	0.6	1.1	1.2
CaSO$_3$*0.5H$_2$O	6.7	6.8	6.6	6.1	8.1	7.7	8.7	8.4
CaCO$_3$	0.16	0.16	0.11	0.12	0.24	0.3	0.04	0.03

Table A-11

(Continued)

Radian Number:	1-L-3	1-L-3	1-L-4	1-L-6	2-L-1	2-L-3	3-L-1	3-L-3
Date	4/13/93	4/13/93	4/14/93	4/14/93	4/15/93	4/15/93	4/16/93	4/16/93
Time	1055	1612	0958	1501	0913	1514	1008	1420
Ca, mM/L	22.7	23.1	22.1	22.2	32.8	33.5	34.9	36.0
Mg, mM/L	77.5	74.5	87.9	90.0	89.5	77.8	80.7	79.1
Na, mM/L	13.5	13.7	16.9	18.0	18.2	16.9	23.9	28.1
K, mM/L								
Cl, mM/L	17.6	17.9	19.4	20.4	19.8	18.8	17.7	16.8
F, mM/L								
CO_3, mM/L	3.64	3.65	3.73	4.30	2.34	2.51	2.39	2.48
NO_3, mM/L								
SO_3, mM/L	19.7	23.5	16.1	15.5	41.6	42.3	48.2	43.7
SO_4, mM/L	45.0	45.8	50.6	50.6	50.3	32.8	50.6	51.2
S_2O_3, mM/L	17.9	18.9	20.2	21.7	18.1	19.3	20.9	20.0
Tot Hyd SO_4, mM/L	107	136	129	140	177	171	170	162
S/N, mM/L	6.3	28.9	22.1	30.8	49.0	57.0	28.9	27.3
Formate, mM/L	9.09	9.61	11.0	11.5	11.8	12.3	18.0	21.7
pH	5.55	5.38	5.53	5.50	4.85	4.78	4.81	4.74
Temperature, °C	55.0	55.1	54.4	55.0	54.1	53.3	53.9	52.4
Ca, mg/L	909	927	886	889	1320	1340	1400	1440
Mg, mg/L	1880	1810	2140	2190	2180	1890	1960	1920
Na, mg/L	311	316	389	413	419	389	550	646
K, mg/L	0	0	0	0	0	0	0	0
Cl, mg/L	623	635	688	721	702	666	629	597
F, mg/L	0	0	0	0	0	0	0	0
CO_3, mg/L	218	219	224	258	140	151	143	149
NO_3, mg/L	0	0	0	0	0	0	0	0
SO_3, mg/L	1580	1880	1290	1240	3330	3390	3860	3500
SO_4, mg/L	4320	4400	4870	4860	4840	3150	4860	4920
S_2O_3, mg/L	2000	2120	2270	2430	2030	2160	2340	2240
Formate, mg/L	410	430	490	520	530	550	810	980
Charge Imbalance								
Calculated, %	8.8	-0.2	5.7	4.0	0.7	1.0	-0.1	1.2
Acceptable, %	5.5	5.4	5.6	5.6	5.2	5.1	5.0	5.0
Relative Saturation								
Gypsum	0.9	1.0	0.9	0.9	1.3	1.0	1.4	1.5
$CaSO_3$*$0.5H_2O$	8.8	8.0	6.5	5.9	6.4	6.4	6.9	5.8
$CaCO_3$	0.03	0.01	0.02	0.02	0.001	0.001	0.001	0.001

Table A-11

(Continued)

Radian Number:	4-I-1	4-I-3	5-I-1	5-I-3	5-I-4	5-I-6	6-I-1	6-I-3
Date	4/17/93	4/17/93	4/19/93	4/19/93	4/20/93	4/20/93	4/21/93	4/21/93
Time	1015	1458	1049	1615	0956	1641	0946	1420
Ca, mM/L	16.1	16.0	16.8	14.4	21.2	12.8	38.0	38.2
Mg, mM/L	87.2	87.4	100	102	112	117	131	126
Na, mM/L	34.1	34.6	58.6	58.0	64.5	63.5	75.4	75.5
K, mM/L								
Cl, mM/L	19.6	19.9	22.5	22.3	25.0	25.8	30.3	29.7
F, mM/L								
CO$_3$, mM/L	4.59	5.39	4.09	3.56	3.05	4.61	2.20	2.14
NO$_3$, mM/L								
SO$_3$, mM/L	43.6	25.1	28.0	27.7	29.2	21.7	52.8	49.6
SO$_4$, mM/L	42.3	42.6	47.6	48.5	57.4	37.3	83.5	82.5
S$_2$O$_3$, mM/L	22.4	23.0	20.8	21.5	21.7	23.1	27.1	25.5
Tot Hyd SO$_4$, mM/L	142	148	154	151	174	162	237	243
S/N, mM/L	11.3	34.2	37.2	31.6	44.0	56.5	46.9	60.3
Formate, mM/L	27.1	26.8	49.8	51.7	53.9	55.0	61.2	63.5
pH	5.47	5.46	5.46	5.44	5.50	5.74	4.85	4.76
Temperature, °C	53.9	53.5	53.9	56.5	57.3	56.4	55.6	55.0
Ca, mg/L	645	641	674	575	849	511	1530	1530
Mg, mg/L	2120	2130	2430	2470	2730	2840	3180	3060
Na, mg/L	783	796	1350	1330	1480	1460	1730	1740
K, mg/L	0	0	0	0		0	0	0
Cl, mg/L	694	707	797	790	885	914	1080	1050
F, mg/L	0	0	0	0	0	0	0	0
CO$_3$, mg/L	275	323	245	214	183	277	132	128
NO$_3$, mg/L	0	0	0	0	0	0	0	0
SO$_3$, mg/L	3490	2010	2240	2220	2330	1730	4230	3970
SO$_4$, mg/L	4070	4100	4570	4660	5520	3590	8020	7920
S$_2$O$_3$, mg/L	2500	2580	2330	2410	2430	2590	3040	2850
Formate, mg/L	1220	1210	2240	2330	2430	2480	2750	2860
Charge Imbalance								
Calculated, %	1.8	0.6	3.0	2.8	3.1	6.8	0.1	-1.9
Acceptable, %	5.3	5.4	5.3	5.4	5.3	5.8	5.0	5.0
Relative Saturation								
Gypsum	0.6	0.6	0.6	0.5	0.8	0.3	1.7	1.8
CaSO$_3$*0.5H$_2$O	10.9	6.5	7.0	5.8	9.0	6.4	7.2	5.7
CaCO$_3$	0.015	0.018	0.013	0.01	0.014	0.035	0.001	0.001

Table A-12

Long-Term DBA Test Solid-Phase Analytical Results

Radian Number	1-A-1	2-A-1	3-A-1	4-A-1	1-E-1	2-B-1	3-B-1	4-B-1	1-C-1	2-C-1	3-C-1	4-C-1
Date	5/11/93	5/16/93	5/17/93	5/18/93	5/11/93	5/16/93	5/17/93	5/18/93	5/11/93	5/16/93	5/17/93	5/18/93
Time	1035	1015	0930	0810	NA	1025	0945	0815	0945	0945	0900	0720
Ca, mm/g	7.50	7.57	7.51	7.37	7.84	7.41	7.47	7.52	7.23	7.40	7.39	7.34
Mg, mm/g												
SO$_3$, mm/g	4.56	6.16	6.08	6.30	4.15	5.91	5.96	5.95	4.88	6.17	6.23	6.24
Total S (as SO$_4$), mm/g	6.05	6.99	6.80	7.03	5.07	6.84	6.75	6.73	6.32	6.99	6.96	6.97
SO$_4$, mm/g	1.49	0.83	0.72	0.73	0.92	0.93	0.79	0.78	1.44	0.82	0.73	0.73
CO$_3$, mm/g	1.46	0.64	0.73	0.41	2.90	0.63	0.85	0.88	1.14	0.40	0.46	0.43
Inerts, wt%	1.44	1.51	1.62	1.57	1.50	1.52	1.42	1.54	1.51	1.55	1.54	1.56
Solids, wt%	9.10	12.40	14.70	12.90	6.00	13.10	12.60	10.10	10.10	12.70	14.30	11.70
pH	5.82	5.4	5.49	5.4	5.85	5.25	5.5	5.43	5.72	5.05	5.19	5.32
Temp, °C	57.8	56.1	57.4	55.1	53.6	56.7	57.0	56.1	55.6	56.5	57.9	55.4
Reagent Util, %												
Ca-Independent	80.6	91.6	90.3	94.5	63.6	91.6	88.8	88.4	84.7	94.6	93.8	94.2
SO$_4$-Independent	80.5	91.5	90.3	94.4	63.0	91.5	88.6	88.3	84.2	94.6	93.8	94.1
Reagent Ratio												
Ca-Independent	1.24	1.09	1.11	1.06	1.57	1.09	1.13	1.13	1.18	1.06	1.07	1.06
SO$_4$-Independent	1.24	1.09	1.11	1.06	1.59	1.09	1.13	1.13	1.19	1.06	1.07	1.06
Oxidation, %	24.7	11.9	10.6	10.4	18.1	13.6	11.7	11.6	22.7	11.7	10.5	10.4
Solid Solution, wt.%	70.5	91.5	88.9	91.8	64.2	89.8	88.4	88.0	75.4	91.4	90.9	91.0
Gypsum, wt.%	11.8	0.0	0.0	0.0	3.2	0.0	0.0	0.0	9.9	0.0	0.0	0.0
CaCO$_3$, wt.%	14.6	6.4	7.3	4.1	29.0	6.3	8.5	8.8	11.4	4.0	4.6	4.3
Inerts, wt.%	1.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.6	1.5	1.6
Ca, mg/g	300	303	300	295	314	296	299	301	289	296	296	294
Mg, mg/g	0	0	0	0	0	0	0	0	0	0	0	0
SO$_3$, mg/g	365	493	486	504	332	473	477	476	390	494	498	499
Total S (as SO$_4$), mg/g	581	671	653	675	487	657	648	646	606	671	668	669
SO$_4$, mg/g	143	80	69	70	88	90	76	75	138	78	70	70
CO$_3$, mg/g	88	38	44	25	174	38	51	53	68	24	28	26
Closures												
Weight, %	-1.7	-0.8	-2.3	-2.8	-2.7	-2.7	-2.2	-2.0	-2.6	-3.0	-3.0	-3.3
Molar, %	-0.1	-0.4	-0.1	-0.5	-0.8	-0.4	-0.9	-0.6	-1.5	0.1	-0.2	-0.4
Acceptable, %	6.0	6.5	6.5	6.6	5.9	6.4	6.4	6.4	6.1	6.5	6.6	6.6

Table A-12

(Continued)

Radian Number	1-D-L	2-D-L	3-D-L	4-D-L	1-A/C-U	2-A/C-U	3-A/C-U	4-A/C-U	1-B/D-U	2-B/D-U	3-B/D-U	4-B/D-U	1-L-S
Date	5/11/93	5/16/93	5/17/93	5/18/93	5/11/93	5/16/93	5/17/93	5/18/93	5/11/93	5/16/93	5/17/93	5/18/93	
Time	1024	1030	0950	0820	0935	1000	0920	0735	1000	1020	0940	0815	
Ca, mm/g	7.81	7.39	7.43	7.51	7.44	7.44	7.46	7.37	8.32	7.71	7.61	7.63	9.50
Mg, mm/g													
SO$_3$, mm/g	3.82	4.75	5.88	5.67	4.08	5.97	6.02	6.24	2.23	5.14	5.76	5.54	0.05
Total S (as SO$_4$), mm/g	4.86	5.66	6.68	6.42	5.54	6.75	6.73	6.97	3.15	5.98	6.52	6.27	
SO$_4$, mm/g	1.04	0.91	0.80	0.75	1.46	0.78	0.71	0.73	0.92	0.84	0.76	0.73	
CO$_3$, mm/g	3.18	0.54	0.66	1.10	2.06	0.83	1.00	0.50	5.08	1.90	1.16	1.39	9.54
Inerts, wt%	1.54	1.55	1.55	1.43	1.55	1.57	1.59	1.61	1.64	1.59	1.53	1.46	1.78
Solids, wt%	4.90	14.00	11.80	10.80	9.20	12.20	13.80	12.40	6.80	11.00	12.60	10.40	18.90
pH	5.85	5.17	5.46	5.55	6.35	6.08	6.22	6.16	6.41	6.18	6.20	6.19	
Temp, °C	56.8	57.5	58.0	55.8	56.4	56.3	57.5	54.5	56.5	56.9	57.5	55.8	
Reagent Util, %													
Ca-Independent	60.4	92.7	91.0	85.4	72.9	89.1	87.1	93.3	38.3	75.9	84.9	81.9	0.5
SO$_4$-Independent	59.3	92.7	91.1	85.4	72.3	88.8	86.6	93.2	38.9	75.4	84.8	81.8	-0.4
Reagent Ratio													
Ca-Independent	1.65	1.08	1.10	1.17	1.37	1.12	1.15	1.07	2.61	1.32	1.18	1.22	
SO$_4$-Independent	1.69	1.08	1.10	1.17	1.38	1.13	1.15	1.07	2.57	1.33	1.18	1.22	
Oxidation, %	21.3	30.4	12.0	11.7	26.4	11.6	10.6	10.5	29.3	14.0	11.7	11.7	0.0
Solid Solution, wt.%	59.1	73.4	87.5	84.0	63.1	88.4	88.0	91.1	34.5	78.5	85.4	82.1	0.6
Gypsum, wt.%	6.2	21.2	0.0	0.0	12.8	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0
CaCO$_3$, wt.%	31.8	5.4	6.6	11.0	20.6	8.3	10.0	5.0	50.8	19.0	11.6	13.9	95.4
Inerts, wt.%	1.5	1.6	1.6	1.4	1.6	1.6	1.6	1.6	0.0	0.0	0.0	0.0	1.8
Ca, mg/g	312	296	297	300	297	298	298	295	333	308	305	305	380
Mg, mg/g	0	0	0	0	0	0	0	0	0	0	0	0	0
SO$_3$, mg/g	306	380	470	454	326	478	482	499	178	411	461	443	4
Total S (as SO$_4$), mg/g	466	655	642	617	532	648	646	669	303	574	626	602	0
SO$_4$, mg/g	99	199	77	72	141	75	68	70	89	80	73	70	0
CO$_3$, mg/g	191	32	40	66	124	50	60	30	305	114	70	83	573
Closures													
Weight, %	-2.3	1.7	-4.0	-3.6	-2.7	-2.3	-1.5	-2.7	-3.6	-1.6	-1.8	-2.7	-2.5
Molar, %	-1.4	0.2	0.6	-0.1	-1.1	-0.9	-1.8	-0.7	0.5	-1.1	-0.4	-0.2	-0.5
Acceptable, %	5.9	6.1	6.5	6.3	5.9	6.4	6.4	6.5	6.1	6.1	6.3	6.3	7.1

Table A-13

Long-Term DBA Test Liquid-Phase Analytical Results

Radian Number:	1-C-L	2-C-L	3-C-L	4-C-L	1-A/C-U	2-A/C-U	3-A/C-U	4-A/C-U
Date	5/11/93	5/16/93	5/17/93	5/18/93	5/11/93	5/16/93	5/17/93	5/18/93
Time	0945	0945	0900	0720	0935	1000	0920	0735
Ca, mm/L	23.5	29.0	20.9	21.2	24.5	18.8	18.7	13.9
Mg, mm/L	119	102	108	95.9	98.9	94.9	100	96.6
Na, mm/L	30.3	24.3	25.4	21.8	26.5	22.9	22.0	20.9
K, mm/L								
Cl, mm/L	30.4	26.0	28.0	24.3	25.4	23.6	25.3	24.0
F, mm/L								
CO_3, mm/L	4.3	3.4	4.3	4.3	4.7		4.0	3.8
NO_3, mm/L								
SO_3, mm/L	20.1	38.7	34.3	32.5	11.5	14.9	11.2	12.5
SO_4, mm/L	65.8	50.5	50.2	42.5	64.1	49.9	53.4	46.8
S_2O_3, mm/L	34.0	26.2	31.3	22.1	27.0	23.3	25	12.1
Tot Hyd SO_4, mm/L	196	202	188	164	171	162	168	158
S/N, mm/L	42.4	60.5	40.9	45.1	41.9	50.6	53.1	74.4
DBA, mm/L	8.8	9.2	9.1	8.4	7.0	8.6	8.7	
pH	5.72	5.05	5.19	5.32	6.35	6.08	6.22	6.16
Temp, °F	55.6	56.5	57.9	55.4	56.4	56.3	57.5	54.5
Ca, mg/L	940	1160	837	848	983	753	749	556
Mg, mg/L	2890	2490	2610	2330	2400	2310	2440	2350
Na, mg/L	696	559	584	501	609	525	506	482
K, mg/L	0	0	0	0	0	0	0	0
Cl, mg/L	1080	921	994	860	901	837	898	851
F, mg/L	0	0	0	0	0	0	0	0
CO_3, mg/L	259	204	257	255	281	220	240	229
NO_3, mg/L	0	0	0	0	0	0	0	0
SO_3, mg/L	1610	3100	2750	2600	922	1200	894	1000
SO_4, mg/L	6320	4850	4820	4080	6160	4790	5130	4490
S_2O_3, mg/L	3810	2940	3510	2480	3020	2610	2800	1360
DBA, mg/L	1140	1190	1180	1090	910	1120	1130	
Charge Imbalance								
Calculated, %	0.9	-0.9	0.3	2.2	-0.9	-0.6	-1.1	2.2
Acceptable, %	7.1	7.0	6.9	6.4	6.6	6.9	7.1	7.9
Relative Saturation								
Gypsum	1.0	1.1	0.8	0.7	1.1	0.7	0.8	0.5
$CaSO_3*0.5H_2O$	9.4	7.6	6.4	8.4	11.8	10.4	8.6	7.5
$CaCO_3$	0.05	0.003	0.006	0.01	0.5	0.1	0.2	0.1

APPENDIX B

Other Process Data

Control room data were recorded manually during the tests from the control room indicators. Tables B-1 and B-2 summarize these data for the baseline, DBA parametric, and formate parametric tests. In Table B-1, flue gas pressure drop data are given for various sections of each absorber module based on five pressure taps at various elevations. The flue gas velocity in the test module (Module C) was kept approximately constant by adjusting the system bypass to maintain a constant pressure drop of 0.7 inches H_2O across the mist eliminator (ME). Individual module pH data in the table were recorded from the control room charts. Data separated by a slash in the table indicates two separate probes with different readings. Data separated by a dash indicates a range of pH values recorded during a test. In Table B-2, a single value implies that the value did not change during a test. Two values separated by a dash denotes the range for a process variable that changed during a test.

Table B-3 shows results of the individual slurry flow rate measurements made during the baseline and DBA parametric tests. Not all of these measurements are valid due to flow disturbances at some of the test locations. See Section 2.5.5 for discussion of these data.

Table B-4 shows daily average control room data for the DBA consumption test. These averages exclude periods of operation with partial flue gas bypass.

Table B-1

Individual Module Control Room Data

Tests		Individual Module ΔP's (inches H$_2$O)					Individual Module pHs (Control Room)			
		A	B	C	D		A	B	C	D
Baseline										
B-1	Overall			5.4		Upper			6.2	
	Lower Loop			2.8		Lower			5.5	
	Upper Loop			2.9						
	ME			0.7						
B-2	Overall			5.4		Upper			5.9	
	Lower Loop			2.9		Lower			5.1	
	Upper Loop			3.0						
	ME			0.7						
B-3	Overall			5.4		Upper			6.0	
	Lower Loop			2.75		Lower			5.8	
	Upper Loop			2.95						
	ME			0.7						
B-4	Overall			5.1		Upper			5.7	
	Lower Loop			2.7		Lower			5.0	
	Upper Loop			2.8						
	ME			0.7						
B-5	Overall			6.3		Upper			6.0	
	Lower Loop			3.3		Lower			5.5	
	Upper Loop			3.2						
	ME			0.9						
B-6	Overall			5.6		Upper			6.3	
	Lower Loop			2.9		Lower			5.7	
	Upper Loop			3.0						
	ME			0.7						

Table B-1

(Continued)

Tests		Individual Module ΔP's (inches H$_2$O)					Individual Module pHs (Control Room)			
		A	B	C	D		A	B	C	D
DBA Parametric										
DBA-1	Overall	5.9	5.1	5.7	6.1	Upper	6.2/6.3 [a]	6.3		
	Lower Loop	2.3	2.1	2.9	2.4	Lower	5.4/5.7	5.4	5.7	5.6
	Upper Loop	3.0	2.7	3.0	2.9					
	ME	0.5	0.6	0.7	0.75					
DBA-1 Day 2	Overall			5.6		Upper	6.3	6.2/6.3		
	Lower Loop			2.9		Lower	5.3/5.6	5.4	5.8	5.3/5.5
	Upper Loop			2.9						
	ME			0.7						
DBA-2	Overall	5.9	5.1	5.6	6.1	Upper	5.8/5.9	6.2		
	Lower Loop	2.2	2.0	2.9	2.4	Lower	5.1/5.3	5.5/5.6	4.9	5.6/5.7
	Upper Loop	2.8	2.7	2.9	2.9					
	ME	0.5	0.55	0.7	0.7					
DBA-3	Overall	5.7	4.9	5.2	5.7	Upper	5.7	6.2		
	Lower Loop	2	1.8	2.6	1.7	Lower	4.8/5.1	5.6/5.7	4.6/4.8	5.4-5.6
	Upper Loop	2.7	2.6	2.8	3.2					
	ME	0.45	0.48	0.7	0.65					
DBA-4	Overall	5.7	4.8	5	5.6	Upper	6.2-6.3	6.1/6.2		
	Lower Loop	1.9	1.8	2.4	1.7	Lower	5.4/5.5	5.3	5.4-5.7	5.4/5.6
	Upper Loop	2.8	2.6	2.8	3.1					
	ME	0.5	0.45	0.7	0.65					
DBA-5 Day 1	Overall	5.2	4.6	4.8	5.5	Upper	6.25	6/6.1		
	Lower Loop	1.9	1.7	2.2	2.2	Lower	5.3/5.4	5.5	5.5/5.8	5.4/5.5
	Upper Loop		2.5	2.8	2.5					
	ME	0.4	0.7	0.62						

Table B-1

(Continued)

Tests		Individual Module ΔP's (inches H₂O)					Individual Module pHs (Control Room)			
		A	B	C	D		A	B	C	D
DBA-5 Day 2	Overall	5.0	4.3	4.6	5.3	Upper	6.3	6.25		
	Lower Loop	1.7	1.6	2.1	2.1	Lower	5.3	5.7	5.6/5.7	5.4/5.5
	Upper Loop	2.6	2.5	2.8	2.5					
	ME	0.48	0.35	0.7	0.61					
DBA-6	Overall	4.9	4.1	4.3	5.2	Upper	5.8	6.2/6.3		
	Lower Loop	1.6	1.5	1.9	1.9	Lower	4.9/5.1	5.5	4.8	5.5/5.6
	Upper Loop	2.6	2.5	2.7	2.5					
	ME	0.45	0.24	0.7	0.6					
DBA-7	Overall	4.9	4.4	4.2	5.2	Upper	6.4			
	Lower Loop	1.6	1.5	1.9	1.9	Lower			5.5-5.7	
	Upper Loop	2.6	2.5	2.8	2.5					
	ME	0.45	0.53	0.7	0.6					
Formate Parametric Tests										
FOR-1	Overall	4.3	4.0	4.3	3.2	Upper	6.3-6.4	6.2-6.3		
	Lower Loop	1.3	1.3	2.0	1.0	Lower	5.5-5.6	5.3-5.4	5.5-5.6	5.5-5.7
	Upper Loop	2.6	2.4	2.7	1.7					
	ME	0.43	0.46	0.7	0.4-0.5					
FOR-2	Overall	4.4	4.1	4.1	4.6	Upper	5.8	6.2-6.3		
	Lower Loop	1.3	1.3	1.8	1.6	Lower	5.0-5.2	5.7-5.9	4.7-4.9	5.5-5.6
	Upper Loop	2.6	0.43	2.8	0.65					
	ME	0.43	0.24	0.7	2.2					
FOR-3	Overall	4.4	4.0	4.0	3.4-4.8	Upper	5.7	6.2-6.5		
	Lower Loop	1.3	1.3	1.7	1.0-1.6	Lower	4.9-5.5	5.6-5.8	4.7-4.9	5.8-6.2
	Upper Loop	2.5	2.4	2.7	1.9-2.5					
	ME	0.46	0.44	0.7	0.3-0.55					

Table B-1

(Continued)

Tests		Individual Module ΔP's (inches H₂O)					Individual Module pHs (Control Room)			
		A	B	C	D		A	B	C	D
FOR-4	Overall	4.4	3.1	4.0	3.5-3.9	Upper	6.3-6.4	6.3-6.4		
	Lower Loop	1.3	1.0	1.75	1.1-1.2	Lower	5.5-5.6	5.4-5.5	5.5-5.6	5.3-5.8
	Upper Loop	2.4	2.0	2.7	1.9-2.1					
	ME	0.43	0.3-0.4	0.7	0.35-0.4					
FOR-5	Overall	4.2-5.5	3.0-4.0	4.0	3.0-4.2	Upper	6.3-6.6	6.2-6.5		
	Lower Loop	1.25	1.1-1.4	1.7	0.7-1.9	Lower	5.4-5.8	5.4-5.5	5.4-5.8	5.4-5.7
	Upper Loop	2.6	2.2-2.4	2.8	1.6-2.3					
	ME	0.46	0.36-0.47	0.7	0.25-0.45					
FOR-6	Overall	4.2	4.0	4.0	4.8	Upper	5.8	6.3-6.4		
	Lower Loop	1.2	1.3-1.8	1.6-1.7	1.5	Lower	5.3-5.4	5.4-5.5	4.8-5.0	5.4-5.8
	Upper Loop	2.5	2.3	2.8	2.5					
	ME	0.44	0.46	0.7	0.50					

*Two pH readings separated by a slash indicate two separate probes.

Table B-2

Overall System Control Room Data

Tests	Unit Load (MW)	Inlet Temp. (°F)	Inlet Pressure (in. H$_2$O)	ΔP (in. H$_2$O)	Inlet CO$_2$ (%)	Inlet SO$_2$ (lbs/MMBtu)	Outlet SO$_2$ (lbs/MMBtu)
				Overall System Conditions			
Baseline							
B-1	620		10.6	9.4	10.6	4.3-4.4	
B-2	680		10	9.2	10.9	4.0-4.5	
B-3	630		10.4	8.9	10.4	4.3	
B-4	610	325	10.3	8.5	10.3	4.4-4.6	
B-5	620	325	11.5	10.2	10.6	4.6-5.1	
B-6	670	325	10.6	9	10.9	4.4-4.6	
DBA Parametric							
DBA-1	620	340		9.5	10.9	3.6-3.7	0.45
DBA-1 Day 2	620	340	10.5	9.3	10.8	3.9-4.0	0.83
DBA-2	670	330	10.4	9.4	11	3.9-4.3	0.8-0.9
DBA-3	670-610	330	10	8.8	11-10.5	4.6-5.1	1.1
DBA-4	680-465	320		8.8	11.2-9.4	4.7-5.0	0.9-0.45
DBA-5 Day 1	630-680	325	9.9	8.6	10.6-11.2	4.5-4.7	0.87
DBA-5 Day 2	630-610	340	9.8	8.5	10.9-10.6	4.8-5.1	0.9-0.6
DBA-6	675	328	9.8	8.5	10.9	4.2-4.5	1.0
DBA-7	680			8.3	11.2	3.9-3.5	

Table B-2

(Continued)

Tests	Unit Load (MW)	Inlet Temp. (°F)	Inlet Pressure (in. H_2O)	ΔP (in. H_2O)	Inlet CO_2 (%)	Inlet SO_2 (lbs/MMBtu)	Outlet SO_2 (lbs/MMBtu)
					Overall System Conditions		
Formate Parametric Tests							
FOR-1	400-430	310-315	7.3-7.8	7.2-7.4	8.5-9.1	3.3-4.1	0.09-0.22
FOR-2	450-575	310-320	8.0	7.3	9.0-10.2	3.0-3.8	0.18-0.48
FOR-3	370-450	315-330	7.8	7.3	8.1-9.4	3.9	0.21-0.33
FOR-4	390	315-320	7.7	7.2	8.6-8.9	3.0-3.5	0.28
FOR-5	400-480	310-335	8.2	7.5	(a)	(a)	(a)
FOR-6	400-500	310-320	7.9	7.3	(a)	(a)	(a)

(a) Meter off line.

Table B-3

Results of Slurry Flow Rate Measurements

Date	Time	Location	Flow Rate (gpm)
2/22/93	1300	Upper Pump 1C3 discharge	21,200
		Upper Pump 1C1 discharge	25,300
		Header between 1C1 and 1C3 (1C1 flow)	19,000
		1C1 suction line	12,900
	1430	Main upper loop header before individual spray headers (1C1 + 1C3 flow)	25,700
2/23/93	0820	Main upper loop header	24,800
	0850	Main lower loop header	11,300
	0910	Presaturator spray line off lower loop header	860
2/24/93	1600	Main mist eliminator wash header (four-tower flow)	1,250
3/9/93	1610	Main lower loop header	10,200
	1700	Main upper loop header	24,250
	1720	Lower loop header to upper loop tank	620

Table B-4

Other Process Data for the Long-Term DBA Consumption Test

Tests		Average Module ∆Ps (inches H_2O)[a]					Average Module pHs (Control Room)[a]			
		A	B	C	D		A	B	C	D
C-1	Overall	5.2	4.8	5.2	6.1	Upper	5.9	6.0		
	Lower Loop	1.6	1.8	2.1	2.2	Lower	5.2	5.2	5.2	5.4
	Upper Loop[b]	2.5	2.2	2.8	2.4					
	ME	0.62	0.67	1.2	0.63					
C-2	Overall	5.1	4.8	5.0	5.8	Upper	6.0	6.0		
	Lower Loop	1.5	1.9	2.0	2.0	Lower	5.2	5.2	5.1	5.4
	Upper Loop	2.9	2.7	3.3	2.9					
	ME	0.59	0.64	1.0	0.72					
C-3	Overall	4.4	4.1	4.2	5.0	Upper	6.0	6.0		
	Lower Loop	1.4	1.5	1.7	1.7	Lower	5.2	5.0	5.1	5.2
	Upper Loop	2.5	2.4	2.9	2.5					
	ME	0.46	0.50	0.82	0.56					
C-4	Overall	4.3	4.0	4.2	4.9	Upper	6.0	6.0		
	Lower Loop	1.2	1.4	1.7	1.7	Lower	5.2	5.1	5.2	5.2
	Upper Loop	2.5	2.3	2.7	2.4					
	ME	0.46	0.50	0.82	0.54					
C-5	Overall	5.4	5.1	5.3	6.0	Upper	6.0	6.0		
	Lower Loop	1.8	2.0	2.1	2.1	Lower	5.1	5.1	5.0	5.2
	Upper Loop	2.5	2.3	2.9	2.6					
	ME	0.59	0.67	1.1	0.72					

Table B-4

(Continued)

Tests		Average Module ΔPs (inches H_2O)[a]				Average Module pHs (Control Room)[a]			
		A	B	C	D	A	B	C	D
C-6	Overall	5.4	4.7	5.0	5.8	Upper	6.0	6.0		
	Lower Loop	1.9	1.8	2.0	2.0	Lower	5.1	5.3	5.0	5.3
	Upper Loop	2.4	2.3	2.8	2.5					
	ME	0.55	0.63	1.0	0.68					

Tests	Average System Conditions[b]					
	Unit Load (MW)	Inlet Temp. (°F)	ΔP (in. H_2O)	Inlet SO_2 (lbs/MMBtu)	Outlet SO_2 (lbs/MMBtu)	SO_2 Removal (%)
C-1	562	334	8.3	3.75	0.04	98.9
C-2	542	328	7.8	3.04	0.06	98.0
C-3	440	318	5.2	2.83	0.05	98.2
C-4	432	308	5.9	3.34	0.04	98.8
C-5	575	329	8.1	3.73	0.06	98.4
C-6	579	326	7.9	3.54	0.07	98.0

[a]Average of system conditions when bypass dampers closed.

[b]Upper loop ΔPs obtained from single reading (not averaged).

APPENDIX C

Settling and Filtration Test Results

Two methods were used to examine solids dewatering properties during these tests: settling tests, and filter leaf tests. Settling tests were performed onsite using lower-loop slurry samples to ascertain the effect of DBA and formate on sedimentation properties. The bulk settling procedure detailed in Method C2 of EPRI's <u>FGD Chemistry and Analytical Methods Handbook</u> was followed (rake action was not simulated). Filter leaf tests, as described in Method C3 of EPRI's Handbook, were performed to assess changes in the solids filtration rate and solids water retention under vacuum filtration.

Settling Tests

Batch settling tests were performed on slurry from the Module C lower loop to determine both settling rates and final solids underflow concentrations. The tests were performed as follows. A completely mixed slurry sample was poured into a 2-L cylinder. The solids settled as a bulk mass (hindered settling). By noting the solids interface level with time, the settling rate was determined. The final underflow concentration was determined by allowing the solids to compact to their equilibrium point. Settling rates are reported as the unit area (UA, ft^2-day/ton) required to reach a 30 wt.% underflow concentration.

Table C-1 presents the results of the settling tests. The UA required for a 30 wt.% underflow concentration and the final underflow concentration are reported. In some cases, the tests were terminated before a 30% underflow concentration was reached. For these tests, the settling data were extrapolated. Initial slurry solids content, solids oxidation percentage, and additive concentrations for the test samples are also shown in the table.

It should be noted that much of the variation in calculated unit areas is due to differences in initial slurry solids contents among the tests.

Table C-1

Pirkey Settling Test Results [a]

Test Series Description	Settling Test ID	Date	Time	Additive Conc (ppm)	Sulfite Oxidation (%)	Initial Solids (wt.%)	UA @ 30 wt % (ft²-day/ton)	UA Std Dev	UF Solids at End of Test (wt.%)
Baseline	1-1	2-22-93	1600	0	NA	12.6	19		36
	1-2	2-23-93	0830	0	NA	12.6	26		34
	1-3	2-23-93	1700	0	NA	12.9	28		33
	Mod.A-1	2-23-93	1700	0	18.5	13.7	23		32
	Mod.A-2	2-24-93	0830	0	18.6	12.3	31		31
Average				0	18.6	12.8	25	5	33
DBA Parametric	1-1	3-10-93	0930	420	13.7	17.4	12		41
	1-2	3-10-93	1415	430	NA	17.5	9.9		42
	1-3	3-10-93	1530	430	13.1	17.7	9.9		41
Average				430	13.4	17.5	11	1.2	41
DBA Parametric	5-1	3-16-93	0713	NA	NA	18.8	3.1		51
	5-2	3-16-93	1211	1500	10.8	18.8	3.2		51
	5-3	3-16-93	1502	1500	10.9	18.9	3.0		52
Average				1500	10.9	18.8	3.1	0.1	51
Pre-Formate		4-12-93	1205	0	15	9	70	-	26
Formate Parametric	1-1	4-13-93	1232	410	17.0	9.9	43		31
	1-2	4-14-93	0723	500	14.8	11.6	64		30
	1-3	4-14-93	1128	500	14.8	12.8	48		29
Average				470	15.5	11.4	52	11	30
Formate Parametric	5-1	4-19-93	0723	2200	10.4	12.7	41		30
	5-2	4-20-93	0720	2400	10.7	13.0	48		31
	5-3	4-20-93	1330	2400	10.6	13.5	26		30
Average				2300	10.6	13.1	38	11	30

Table C-1

(Continued)

Test Series Description	Settling Test ID	Date	Time	Additive Conc. (ppm)	Sulfite Oxidation (%)	Initial Solids (wt.%)	UA @ 30 wt.% (ft²·day/ton)	UA Std Dev	UF Solids at End of Test (wt.%)
Pre-Consumption		5-11-93	0945	0	22.7	10.1	74		28
DBA Consumption	1	5-16-93	0945	1180	11.7	12.7	11		34
	2	5-17-93	0900	(b)	10.5	14.3	10		38
	3	5-18-93	0700	1090	10.4	11.7	12		36
Average				1130	10.7	12.9	11	1	36

[a] All settling tests done with Module C lower-loop slurry except where designated otherwise.

[b] DBA not analyzed.

C-4

Filter Leaf Tests

       Filter leaf tests simulate the performance of a rotary drum vacuum filter. Two separate tests were performed: form filtration and cake moisture. The form filtration test was performed on lower-loop slurry samples to determine the effective solids filtration rates (lb/hr/ft^2 filter area). The test was performed by measuring the time from the start of the filtration apparatus until the first cracks appeared on the surface of the filter cake. The test results give an indication of the required filtration surface and indicate the ease with which water is drawn from the solids. Samples were adjusted initially to 30 wt.% solids so that individual test results could be compared. The cake moisture test was performed by applying a vacuum to a sample for a constant time period and measuring the water content in the resulting cake. This test measures the ability of the filtered solids to retain water. Filter leaf test samples were taken concurrently with settling test samples. Table C-2 summarizes filter leaf test conditions and results.

Table C-2

Filter Leaf Test Conditions and Results
(All Samples from Module C Lower Loop)

Summary of Test Conditions	
Filter Cloth Type	POPR 873
Cloth Area	0.0873 ft^2
Form Filtration Vacuum	20.00 in. Hg
Cake Solids Drying Time	120 sec
Cake Solids Test Vacuum	12 - 17 in. Hg
Cake Thickness	0.5 - 0.75 in.

Test Results				
Test	Date	Sample Designation	Final Cake Solids Wt.%	Form Filtration Rate (lb/hr/ft^2)
Baseline	2/23/93	1-L-1	75	800
DBA Parametric Test 1	3/10/93	1-L-4	66	1200
DBA Parametric Test 1	3/10/93	1-L-5	73	680
DBA Parametric Test 1	3/10/93	1-L-6	60	1000
DBA Parametric Test 5	3/16/93	5-L-4	75	640
DBA Parametric Test 5	3/16/93	5-L-5	75	790
DBA Parametric Test 6	3/16/93	5-L-6	73	770
Formate Parametric Test 1	4/13/93	1-L-1	50	1100
Formate Parametric Test 1	4/13/93	1-L-2	51	1000
Formate Parametric Test 1	4/13/93	1-L-3	74	480

Table C-2

(Continued)

Test Results				
Test	Date	Sample Designation	Final Cake Solids Wt.%	Form Filtration Rate (lb/hr/ft^2)
Formate Parametric Test 5	4/19/93	5-L-1	53	920
Formate Parametric Test 5	4/19/93	5-L-2	51	920
Formate Parametric Test 5	4/19/93	5-L-3	55	1000
Long-Term Pre-Test	5/11/93	1-C-L	55	430
Long-Term DBA Test	5/16/93	2-C-L	65	1500
Long-Term DBA Test	5/17/93	3-C-L	65	1000
Long-Term DBA Test	5/18/93	4-C-L	67	1000

APPENDIX D

Detailed Material Balance Data for the DBA Consumption Test

THIS VERSION HAS THE ACTUAL LAB DATA FOR THE DBA CONSUMPTION TEST
TOTAL DBA PLUS ERROR PROPAGATION USING 2ND AND FINAL INVENTORIES
DATE: 5/12/93
Time: 0845

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	DBA conc. (ppm)	Slurry S.G.	% solids	DBA in liquid (lb)	Assumed % DBA in solids	solids (lb)	DBA in solids (lb)
A/C MODULE UPPER	20000	23	460000	908	1.067	9.2	3377	0.116	376145	436
B/D MODULE UPPER	20000	23	460000	955	1.0605	6.8	3623	0.116	276326	321
A LOWER	8959	6	53754	1057	1.054	9.1	454	0.116	42947	50
B LOWER	8959	6	53754	1019	1.048	6	450	0.116	28156	33
C LOWER	8959	6	53754	1140	1.073	10.1	493	0.116	48526	56
D LOWER	8959	6	53754	1110	1.054	4.9	499	0.116	23126	27
A THICKENER	71275	17	1337500	738	1.023	4	7329	0.116	455905	529
B THICKENER	71275	17	1337500	777	1.023	4	7716	0.116	455905	529
LS SLURRY STORAGE	8064	26.6	214502	335	1.3	35	507	0	812996	0
UNDERFLOW STORAGE	7216	9	64944	638	1.3	40	270	0.116	281311	326
TOTALS			4089462.4				24718		2801344	2306

TOTAL DBA INVENTORY CHANGE SINCE LAST INVENTORY (LB	0
TANKER LEVEL (GAL)	5178
DBA IN TANKER (LB OF 25%)	46084
DBA ADDED SINCE LAST INVENTORY	0
A LIMESTONE BELT SCALE (TONS)	5559
B LIMESTONE BELT SCALE (TONS)	7134
LIMESTONE USED SINCE LAST INVENTORY (TONS)	0
TONS SO2 REMOVED SINCE LAST INVENTORY	0
AVERAGE LS UTILIZATION	
A CAKE BELT SCALE (TONS)	0
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)	0
AVERAGE PERCENT SOLIDS	60
DBA LOST WITH CAKE LIQUID SINCE LAST INVENTORY (LBS	0
DBA NON SOLUTION LOSS (LB/TON SO2)	0

DATE: 5/15/93
Time: 0930

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	DBA conc. (ppm)	Slurry S.G.	% solids	DBA in liquid (lb)	% DBA in solids	solids (lb)	DBA in solids (lb)
A/C MODULE UPPER	20000	23	460000	1118	1.08	12.2	4070	0.233	504878	1176
B/D MODULE UPPER	20000	23	460000	1290	1.0865	11	4788	0.233	457958	1067
A LOWER	8959	6	53754	1123	1.0865	12.4	479	0.233	60326	141
B LOWER	8959	6	53754	1302	1.0865	13.1	551	0.233	63732	148
C LOWER	8959	6	53754	1191	1.073	12.7	500	0.233	61018	142
D LOWER	8959	6	53754	1561	1.107	14	667	0.233	69396	162
A THICKENER	71275	17	1337500	678	1.023	4	6733	0.233	455905	1062
B THICKENER	71275	17	1337500	660	1.023	4	6554	0.233	455905	1062
LS SLURRY STORAGE	8064	32.5	262080	539	1.3	35	996	0	993323	0
UNDERFLOW STORAGE	7216	12.5	90200	692	1.3	40	406	0.233	390710	910
TOTALS			4162296				25745		3513150	5871

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TOTAL DBA INVENTORY CHANGE SINCE LAST INVENTORY (LB        2265

TANKER LEVEL (GAL)                                         1743
DBA IN TANKER (LB)                                        15513
25% DBA ADDED SINCE LAST INVENTORY                       30572

A LIMESTONE BELT SCALE (TONS)                             6326
B LIMESTONE BELT SCALE (TONS)                             7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)               1177
TONS SO2 REMOVED SINCE LAST INVENTORY                     663
AVERAGE LS UTILIZATION                                   92.6
A CAKE BELT SCALE (TONS)                                 2564
B CAKE BELT SCALE (TONS)                                    7
CAKE PRODUCED SINCE LAST INVENTORY                       2564
AVERAGE PERCENT SOLIDS                                     63
DBA LOST WITH CAKE LIQUID SINCE LAST INVENTORY (LBS      1252

DBA NON SOLUTION LOSS (LB/TON SO2)                        6.2
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D-3

DATE: 5/16/93
Time: 1030

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	DBA conc. (ppm)	Slurry S.G.	% solids	DBA in liquid (lb)	% DBA in solids	solids (lb)	DBA in solids (lb)
A/C MODULE UPPER	20000	23	460000	1133	1.08	13.8	4049	0.233	571091	1331
B/D MODULE UPPER	20000	23	460000	1016	1.0865	12.6	3704	0.233	524570	1222
A LOWER	8959	6	53754	1149	1.0865	14.7	478	0.233	71516	167
B LOWER	8959	6	53754	1216	1.0865	12.6	518	0.233	61299	143
C LOWER	8959	6	53754	1177	1.073	14.3	486	0.233	68706	160
D LOWER	8959	6	53754	1295	1.107	11.8	567	0.233	58491	136
A THICKENER	71275	17	1337500	722	1.023	4	7170	0.233	455905	1062
B THICKENER	71275	17	1337500	-738	1.023	4	7329	0.233	455905	1062
LS SLURRY STORAGE	8064	33.2	267725	524	1.3	35	989	0	1014717	0
UNDERFLOW STORAGE	7216	18.6	134218	620	1.3	40	542	0.233	581377	1355
TOTALS			4211958.4				25830		3863577	6638

TOTAL DBA INVENTORY CHANGE SINCE LAST INVENTORY (LB   852

TANKER LEVEL (GAL)   6016
DBA IN TANKER (LB)   53542
25% DBA ADDED SINCE LAST INVENTORY   7110

A LIMESTONE BELT SCALE (TONS)   6713
B LIMESTONE BELT SCALE (TONS)   7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)   376
TONS SO2 REMOVED SINCE LAST INVENTORY   210
AVERAGE LS UTILIZATION   91
A CAKE BELT SCALE (TONS)   3569
B CAKE BELT SCALE (TONS)   7
CAKE PRODUCED SINCE LAST INVENTORY   1006
AVERAGE PERCENT SOLIDS   71
DBA LOST WITH CAKE LIQUID SINCE LAST INVENTORY (LBS   379

DBA NON SOLUTION LOSS (LB/TON SO2)   2.6

DATE: 5/18/93
Time: 0800

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	DBA conc. (ppm)	Slurry S.G.	% solids	DBA in liquid (lb)	% DBA in solids	solids (lb)	DBA in solids (lb)
A/C MODULE UPPER	20000	23	460000	1130	1.0865	12.4	4129	0.233	516243	1203
B/D MODULE UPPER	20000	23	460000	1024	1.048	10.4	3691	0.233	417636	973
A LOWER	8959	6	53754	1153	1.136	12.9	512	0.233	65618	153
B LOWER	8959	6	53754	989	1.0605	10.1	423	0.233	47961	112
C LOWER	8959	6	53754	1088	1.067	11.7	460	0.233	55899	130
D LOWER	8959	6	53754	1049	1.0605	10.8	445	0.233	51285	119
A THICKENER	71275	17	1337500	746	1.023	4	7408	0.233	455905	1062
B THICKENER	71275	17	1337500	722	1.023	4	7170	0.233	455905	1062
LS SLURRY STORAGE	8064	29.05	234259	531	1.3	35	877	0	887878	0
UNDERFLOW STORAGE	7216	13	93808	637	1.3	40	389	0.233	406339	947
TOTALS			4138083.2				25503		3360668	5762

TOTAL DBA INVENTORY CHANGE SINCE LAST INVENTORY (LB   -1203

TANKER LEVEL (GAL)	3573
DBA IN TANKER (LB)	31800
25% DBA ADDED SINCE LAST INVENTORY	21743
A. LIMESTONE BELT SCALE (TONS)	7336
B LIMESTONE BELT SCALE (TONS)	7823
LIMESTONE USED SINCE LAST INVENTORY (TONS)	875
TONS SO2 REMOVED SINCE LAST INVENTORY	483
AVERAGE LS UTILIZATION	91
A CAKE BELT SCALE (TONS)	5683
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY	2113
AVERAGE PERCENT SOLIDS	65
DBA LOST WITH CAKE LIQUID SINCE LAST INVENTORY (LBS)	943
DBA NON SOLUTION LOSS (LB/TON SO2)	11.8

CUMULATIVE OVERALL SUMMARY

TOTAL DBA ADDED (LB)	7213
DBA INVENTORY (LB)	31265
INITIAL DBA INVENTORY (LB)	31616
INVENTORY CHANGE TO DATE (LB)	-352
TOTAL SOLUTION LOSS (LB)	1322
TOTAL SO2 REMOVED (TONS)	693
NON-SOLUTION LOSS (LB DBA/TON SO2)	9.0
AVG DBA CONCENTRATION	1167
TOTAL CONSUMPTION (LB DBA/TON SO2)	10.9
UNCERTAINTY (95%) =	4.0 4.0

THIS VERSION HAS THE ACTUAL LAB DATA FOR THE DBA CONSUMPTION TEST
ADIPIC COMPONENT USING SECOND AND FINAL INVENTORIES
DATE: 5/12/93
Time: 0845

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Adipic acid (ppm)	Slurry S.G.	% solids	Adipic Acid in liquid (lb)	Assumed % Adipic in solids	Adipic Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	242	1.067	9.2	900	0.005	19
B/D MODULE UPPER	20000	23	460000	250	1.0605	6.8	949	0.005	14
A LOWER	8959	6	53754	322	1.054	9.1	138	0.005	2
B LOWER	8959	6	53754	263	1.048	6	116	0.005	1
C LOWER	8959	6	53754	341	1.073	10.1	148	0.005	2
D LOWER	8959	6	53754	309	1.054	4.9	139	0.005	1
A THICKENER	71275	17	1337500	207	1.023	4	2056	0.005	23
B THICKENER	71275	17	1337500	254	1.023	4	2522	0.005	23
LS SLURRY STORAGE	8064	26.6	214502	139	1.3	35	210	0	0
UNDERFLOW STORAGE	7216	9	64944	213	1.3	40	90	0.005	14
TOTALS			4089462.4				7268		99

TOTAL ADIPIC ACID INVENTORY CHANGE SINCE LAST INVEN   0

TANKER LEVEL (GAL)   5178
DBA IN TANKER (LB)   46084
25% DBA ADDED SINCE LAST INVENTORY (LB)   0
ADIPIC ACID ADDED SINCE LAST INVENTORY (LB)   0
A LIMESTONE BELT SCALE (TONS)   5559
B LIMESTONE BELT SCALE (TONS)   7134
LIMESTONE USED SINCE LAST INVENTORY (TONS)   0
SO2 REMOVED SINCE LAST INVENTORY (TONS)   0
AVERAGE LIMESTONE UTILIZATION
A CAKE BELT SCALE (TONS)   0
B CAKE BELT SCALE (TONS)   7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)   0
AVERAGE PERCENT SOLIDS IN CAKE   60
ADIPIC ACID LOST WITH CAKE LIQUID SINCE LAST INVENT   0

ADIPIC ACID NON SOLUTION LOSS (LB/TON SO2)   0

D-6

DATE: 5/15/93
Time: 0930

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Adipic Acid (ppm)	Slurry S.G.	% solids	Adipic Acid in liquid (lb)	Assumed % Adipic in solids	Adipic Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	313	1.08	12.2	1139	0.01	50
B/D MODULE UPPER	20000	23	460000	394	1.0865	11	1463	0.01	46
A LOWER	8959	6	53754	330	1.0865	12.4	141	0.01	6
B LOWER	8959	6	53754	389	1.0865	13.1	165	0.01	6
C LOWER	8959	6	53754	335	1.073	12.7	141	0.01	6
D LOWER	8959	6	53754	479	1.107	14	205	0.01	7
A THICKENER	71275	17	1337500	198	1.023	4	1966	0.01	46
B THICKENER	71275	17	1337500	192	1.023	4	1907	0.01	46
LS SLURRY STORAGE	8064	32.5	262080	167	1.3	35	309	0	0
UNDERFLOW STORAGE	7216	12.5	90200	222	1.3	40	130	0.01	39
TOTALS			4162296				7565		252

TOTAL ADIPIC ACID INVENTORY CHANGE SINCE LAST INVEN 449

TANKER LEVEL (GAL)	1743
DBA IN TANKER (LB)	15513
25% DBA ADDED SINCE LAST INVENTORY (LB)	30572
ADIPIC ACID ADDED SINCE LAST INVENTORY (LB)	1452
A LIMESTONE BELT SCALE (TONS)	6326
B LIMESTONE BELT SCALE (TONS)	7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)	1177
SO2 REMOVED SINCE LAST INVENTORY (TONS)	663
AVERAGE LIMESTONE UTILIZATION	92.6
A CAKE BELT SCALE (TONS)	2564
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)	2564
AVERAGE PERCENT SOLIDS IN CAKE	63
ADIPIC ACID LOST WITH CAKE LIQUID SINCE LAST INVENT	409
ADIPIC ACID NON SOLUTION LOSS (LB/TON SO2)	0.9

D-7

DATE: 5/16/93
Time: 1030

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Adipic Acid (ppm)	Slurry S.G.	% solids	Adipic Acid in liquid (lb)	Assumed % Adipic in solids	Adipic Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	349	1.08	13.8	1247	0.01	57
B/D MODULE UPPER	20000	23	460000	311	1.0865	12.6	1134	0.01	52
A LOWER	8959	6	53754	348	1.0865	14.7	145	0.01	7
B LOWER	8959	6	53754	412	1.0865	12.6	175	0.01	6
C LOWER	8959	6	53754	378	1.073	14.3	156	0.01	7
D LOWER	8959	6	53754	447	1.107	11.8	196	0.01	6
A THICKENER	71275	17	1337500	212	1.023	4	2105	0.01	46
B THICKENER	71275	17	1337500	234	1.023	4	2324	0.01	46
LS SLURRY STORAGE	8064	33.2	267725	175	1.3	35	330	0	0
UNDERFLOW STORAGE	7216	18.6	134218	194	1.3	40	169	0.01	58
TOTALS			4211958.4				7982		285

TOTAL ADIPIC ACID INVENTORY CHANGE SINCE LAST INVEN   450

TANKER LEVEL (GAL)	6016
DBA IN TANKER (LB)	53542
25% DBA ADDED SINCE LAST INVENTORY (LB)	7110
ADIPIC ACID ADDED SINCE LAST INVENTORY (LB)	338
A LIMESTONE BELT SCALE (TONS)	6713
B LIMESTONE BELT SCALE (TONS)	7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)	376
SO2 REMOVED SINCE LAST INVENTORY (TONS)	210
AVERAGE LIMESTONE UTILIZATION	91.8
A CAKE BELT SCALE (TONS)	3569
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)	1005
AVERAGE PERCENT SOLIDS IN CAKE	71
ADIPIC ACID LOST WITH CAKE LIQUID SINCE LAST INVENT	120
ADIPIC ACID NON SOLUTION LOSS (LB/TON SO2)	-1.1

DATE: 5/18/93
Time: 0800

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Adipic Acid (ppm)	Slurry S.G.	% solids	Adipic Acid in liquid (lb)	Assumed % Adipic in solids	Adipic Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	358	1.0865	12.4	1308	0.01	52
B/D MODULE UPPER	20000	23	460000	313	1.048	10.4	1128	0.01	42
A LOWER	8959	6	53754	364	1.136	12.9	162	0.01	7
B LOWER	8959	6	53754	306	1.0605	10.1	131	0.01	5
C LOWER	8959	6	53754	347	1.067	11.7	147	0.01	6
D LOWER	8959	6	53754	330	1.0605	10.8	140	0.01	5
A THICKENER	71275	17	1337500	227	1.023	4	2254	0.01	46
B THICKENER	71275	17	1337500	213	1.023	4	2115	0.01	46
LS SLURRY STORAGE	8064	29.05	234259	177	1.3	35	292	0	0
UNDERFLOW STORAGE	7216	13	93808	230	1.3	40	140	0.01	41
TOTALS			4138083.2				7817		247

TOTAL ADIPIC ACID INVENTORY CHANGE SINCE LAST INVEN   -202

TANKER LEVEL (GAL)   3573
DBA IN TANKER (LB)   31800
25% DBA ADDED SINCE LAST INVENTORY (LB)   21743
ADIPIC ACID ADDED SINCE LAST INVENTORY (LB)   1033
A LIMESTONE BELT SCALE (TONS)   7336
B LIMESTONE BELT SCALE (TONS)   7823
LIMESTONE USED SINCE LAST INVENTORY (TONS)   875
SO2 REMOVED SINCE LAST INVENTORY (TONS)   483
AVERAGE LIMESTONE UTILIZATION   90.8
A CAKE BELT SCALE (TONS)   5683
B CAKE BELT SCALE (TONS)   7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)   2114
AVERAGE PERCENT SOLIDS IN CAKE   65
ADIPIC ACID LOST WITH CAKE LIQUID SINCE LAST INVENT   318

ADIPIC ACID NON SOLUTION LOSS (LB/TON SO2)   1.9

CUMULATIVE OVERALL SUMMARY (SECOND TO FINAL INVENTORY)

TOTAL ADIPIC ACID ADDED (LB)   1371
ADIPIC ACID INVENTORY (LB)   8065
INITIAL ADIPIC ACID INVENTORY (LB)   7817
INVENTORY CHANGE TO DATE (LB)   248
TOTAL SOLUTION LOSS (LB)   438
TOTAL SO2 REMOVED (TONS)   693
NON-SOLUTION LOSS (LB/TON SO2)   1.0
AVG ADIPIC ACID CONCENTRATION (PPM)   361
TOTAL CONSUMPTION (LB/TON SO2)   1.6

THIS VERSION HAS THE ACTUAL LAB DATA FOR THE DBA CONSUMPTION TEST
GLUTARIC COMPONENT USING SECOND AND FINAL INVENTORIES
DATE: 5/12/93
Time: 0845

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Glutaric acid (ppm)	Slurry S.G.	% solids	Glutaric Acid in liquid (lb)	Assumed % Glutaric in solids	Glutaric Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	532	1.067	9.2	1979	0.065	244
B/D MODULE UPPER	20000	23	460000	564	1.0605	6.8	2140	0.065	180
A LOWER	8959	6	53754	575	1.054	9.1	247	0.065	28
B LOWER	8959	6	53754	610	1.048	6	270	0.065	18
C LOWER	8959	6	53754	646	1.073	10.1	280	0.065	32
D LOWER	8959	6	53754	633	1.054	4.9	285	0.065	15
A THICKENER	71275	17	1337500	408	1.023	4	4052	0.065	296
B THICKENER	71275	17	1337500	406	1.023	4	4032	0.065	296
LS SLURRY STORAGE	8064	26.6	214502	175	1.3	35	265	0	0
UNDERFLOW STORAGE	7216	9	64944	333	1.3	40	141	0.065	183
TOTALS			4089462.4				13688		1292

TOTAL GLUTARIC INVENTORY CHANGE SINCE LAST INVENTOR   0

TANKER LEVEL (GAL)   5178
DBA IN TANKER (LB OF 25%)   46084
25% DBA ADDED SINCE LAST INVENTORY (LB)   0
GLUTARIC ACID ADDED SINCE LAST INVENTORY (LB)   0
A LIMESTONE BELT SCALE (TONS)   5559
B LIMESTONE BELT SCALE (TONS)   7134
LIMESTONE USED SINCE LAST INVENTORY (TONS)   0
SO2 REMOVED SINCE LAST INVENTORY (TONS)   0
AVERAGE LIMESTONE UTILIZATION
A CAKE BELT SCALE (TONS)   0
B CAKE BELT SCALE (TONS)   7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)   0
AVERAGE PERCENT SOLIDS   60
GLUTARIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE   0

GLUTARIC ACID NON SOLUTION LOSS (LB/TON SO2)   0

DATE: 5/15/93
Time: 0930

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Glutaric Acid (ppm)	Slurry S.G.	% solids	Glutaric Acid in liquid (lb)	% Glutaric in solids	Glutaric Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	722	1.08	12.2	2628	0.13	656
B/D MODULE UPPER	20000	23	460000	809	1.0865	11	3003	0.13	595
A LOWER	8959	6	53754	698	1.0865	12.4	298	0.13	78
B LOWER	8959	6	53754	836	1.0865	13.1	354	0.13	83
C LOWER	8959	6	53754	763	1.073	12.7	321	0.13	79
D LOWER	8959	6	53754	994	1.107	14	424	0.13	90
A THICKENER	71275	17	1337500	412	1.023	4	4091	0.13	593
B THICKENER	71275	17	1337500	404	1.023	4	4012	0.13	593
LS SLURRY STORAGE	8064	32.5	262080	321	1.3	35	593	0	0
UNDERFLOW STORAGE	7216	12.5	90200	381	1.3	40	224	0.13	508
TOTALS			4162296				15948		3276

TOTAL GLUTARIC INVENTORY CHANGE SINCE LAST INVENTOR   4244

TANKER LEVEL (GAL)   1743
DBA IN TANKER (LB OF 25%)   15513
25% DBA ADDED SINCE LAST INVENTORY (LB)   30572
GLUTARIC ACID ADDED SINCE LAST INVENTORY (LB)   4204
A LIMESTONE BELT SCALE (TONS)   6326
B LIMESTONE BELT SCALE (TONS)   7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)   1177
SO2 REMOVED SINCE LAST INVENTORY (TONS)   663
AVERAGE LIMESTONE UTILIZATION   92.6
A CAKE BELT SCALE (TONS)   2564
B CAKE BELT SCALE (TONS)   7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)   2564
AVERAGE PERCENT SOLIDS   63
GLUTARIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE   672

GLUTARIC ACID NON SOLUTION LOSS (LB/TON SO2)   -1.1

D-11

DATE: 5/16/93
Time: 1030

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Glutaric Acid (ppm)	Slurry S.G.	% solids	Glutaric Acid in liquid (lb)	% Glutaric in solids	Glutaric Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	734	1.08	13.8	2623	0.13	742
B/D MODULE UPPER	20000	23	460000	661	1.0865	12.6	2409	0.13	682
A LOWER	8959	6	53754	755	1.0865	14.7	314	0.13	93
B LOWER	8959	6	53754	764	1.0865	12.6	325	0.13	80
C LOWER	8959	6	53754	745	1.073	14.3	307	0.13	89
D LOWER	8959	6	53754	831	1.107	11.8	364	0.13	76
A THICKENER	71275	17	1337500	450	1.023	4	4469	0.13	593
B THICKENER	71275	17	1337500	481	1.023	4	4776	0.13	593
LS SLURRY STORAGE	8064	33.2	267725	310	1.3	35	585	0	0
UNDERFLOW STORAGE	7216	18.6	134218	365	1.3	40	319	0.13	756
TOTALS			4211958.4				16492		3704

TOTAL GLUTARIC INVENTORY CHANGE SINCE LAST INVENTOR   972

TANKER LEVEL (GAL)   6016
DBA IN TANKER (LB OF 25%)   53542
25% DBA ADDED SINCE LAST INVENTORY (LB)   7110
GLUTARIC ACID ADDED SINCE LAST INVENTORY (LB)   978
A LIMESTONE BELT SCALE (TONS)   6713
B LIMESTONE BELT SCALE (TONS)   7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)   376
SO2 REMOVED SINCE LAST INVENTORY (TONS)   210
AVERAGE LIMESTONE UTILIZATION   91.8
A CAKE BELT SCALE (TONS)   3569
B CAKE BELT SCALE (TONS)   7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)   1005
AVERAGE PERCENT SOLIDS   71
GLUTARIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE   215

GLUTARIC ACID NON SOLUTION LOSS (LB/TON SO2)   -1.0

D-12

DATE: 5/18/93
Time: 0800

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Glutaric Acid (ppm)	Slurry S.G.	% solids	Glutaric Acid in liquid (lb)	% Glutaric in solids	Glutaric Acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	745	1.0865	12.4	2722	0.13	671
B/D MODULE UPPER	20000	23	460000	680	1.048	10.4	2451	0.13	543
A LOWER	8959	6	53754	757	1.136	12.9	336	0.13	85
B LOWER	8959	6	53754	657	1.0605	10.1	281	0.13	62
C LOWER	8959	6	53754	708	1.067	11.7	299	0.13	73
D LOWER	8959	6	53754	680	1.0605	10.8	289	0.13	67
A THICKENER	71275	17	1337500	476	1.023	4	4727	0.13	593
B THICKENER	71275	17	1337500	453	1.023	4	4498	0.13	593
LS SLURRY STORAGE	8064	29.05	234259	323	1.3	35	534	0	0
UNDERFLOW STORAGE	7216	13	93808	370	1.3	40	226	0.13	528
TOTALS			4138083.2				16362		3215

TOTAL GLUTARIC INVENTORY CHANGE SINCE LAST INVENTOR   -619

TANKER LEVEL (GAL)	3573
DBA IN TANKER (LB OF 25%)	31800
25% DBA ADDED SINCE LAST INVENTORY (LB)	21743
GLUTARIC ACID ADDED SINCE LAST INVENTORY (LB)	2990
A LIMESTONE BELT SCALE (TONS)	7336
B LIMESTONE BELT SCALE (TONS)	7823
LIMESTONE USED SINCE LAST INVENTORY (TONS)	875
SO2 REMOVED SINCE LAST INVENTORY (TONS)	483
AVERAGE LIMESTONE UTILIZATION	90.8
A CAKE BELT SCALE (TONS)	5683
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)	2114
AVERAGE PERCENT SOLIDS	65
GLUTARIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE	552
GLUTARIC ACID NON SOLUTION LOSS (LB/TON SO2)	6.3

CUMULATIVE OVERALL SUMMARY (SECOND TO FINAL INVENTORY)

TOTAL GLUTARIC ACID ADDED (LB)	3967
GLUTARIC ACID INVENTORY (LB)	19577
INITIAL GLUTARIC INVENTORY (LB)	19224
INVENTORY CHANGE TO DATE (LB)	353
TOTAL SOLUTION LOSS (LB)	767
TOTAL SO2 REMOVED (TONS)	693
NON-SOLUTION LOSS (LB/TON SO2)	4.1
AVG GLUTARIC CONCENTRATION (PPM)	752
TOTAL CONSUMPTION (LB/TON SO2)	5.2

D-13

THIS VERSION HAS THE ACTUAL LAB DATA FOR THE DBA CONSUMPTION TEST
SUCCINIC ACID USING SECOND AND FINAL INVENTORIES
DATE: 5/12/93
Time: 0845

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Succinic acid (ppm)	Slurry S.G.	% solids	Succinic acid in liquid (lb)	Assumed % Succinic in solids	Succinic acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	134	1.067	9.2	498	0.046	173
B/D MODULE UPPER	20000	23	460000	141	1.0605	6.8	535	0.046	127
A LOWER	8959	6	53754	160	1.054	9.1	69	0.046	20
B LOWER	8959	6	53754	146	1.048	6	65	0.046	13
C LOWER	8959	6	53754	153	1.073	10.1	66	0.046	22
D LOWER	8959	6	53754	168	1.054	4.9	76	0.046	11
A THICKENER	71275	17	1337500	123	1.023	4	1221	0.046	210
B THICKENER	71275	17	1337500	117	1.023	4	1162	0.046	210
LS SLURRY STORAGE	8064	26.6	214502	21	1.3	35	32	0	0
UNDERFLOW STORAGE	7216	9	64944	92	1.3	40	39	0.046	129
TOTALS			4089462.4				3762		915

TOTAL SUCCINIC ACID INVENTORY CHANGE SINCE LAST INV   0

TANKER LEVEL (GAL)   5178
DBA IN TANKER (LB OF 25%)   46084
25% DBA ADDED SINCE LAST INVENTORY (LB)   0
SUCCINIC ACID ADDED SINCE LAST INVENTORY (LB)   0
A LIMESTONE BELT SCALE (TONS)   5559
B LIMESTONE BELT SCALE (TONS)   7134
LIMESTONE USED SINCE LAST INVENTORY (TONS)   0
SO2 REMOVED SINCE LAST INVENTORY (TONS)   0
AVERAGE LIMESTONE UTILIZATION
A CAKE BELT SCALE (TONS)   0
B CAKE BELT SCALE (TONS)   7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)   0
AVERAGE PERCENT SOLIDS   60
SUCCINIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE   0

SUCCINIC ACID NON SOLUTION LOSS (LB/TON SO2)   0

DATE: 5/15/93
Time: 0930

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Succinic acid (ppm)	Slurry S.G.	% solids	Succinic acid in liquid (lb)	% Succinic in solids	Succinic acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	83	1.08	12.2	302	0.093	470
B/D MODULE UPPER	20000	23	460000	87	1.0865	11	323	0.093	426
A LOWER	8959	6	53754	95	1.0865	12.4	41	0.093	56
B LOWER	8959	6	53754	77	1.0865	13.1	33	0.093	59
C LOWER	8959	6	53754	93	1.073	12.7	39	0.093	57
D LOWER	8959	6	53754	88	1.107	14	38	0.093	65
A THICKENER	71275	17	1337500	69	1.023	4	685	0.093	424
B THICKENER	71275	17	1337500	64	1.023	4	636	0.093	424
LS SLURRY STORAGE	8064	32.5	262080	51	1.3	35	94	0	0
UNDERFLOW STORAGE	7216	12.5	90200	89	1.3	40	52	0.093	363
TOTALS			4162296				2242		2343

TOTAL SUCCINIC ACID INVENTORY CHANGE SINCE LAST INV	-91
TANKER LEVEL (GAL)	1743
DBA IN TANKER (LB OF 25%)	15513
25% DBA ADDED SINCE LAST INVENTORY (LB)	30572
SUCCINIC ACID ADDED SINCE LAST INVENTORY (LB)	1987
A LIMESTONE BELT SCALE (TONS)	6326
B LIMESTONE BELT SCALE (TONS)	7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)	1177
SO2 REMOVED SINCE LAST INVENTORY (TONS)	663
AVERAGE LIMESTONE UTILIZATION	92.6
A CAKE BELT SCALE (TONS)	2564
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)	2564
AVERAGE PERCENT SOLIDS	63
SUCCINIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE	170
SUCCINIC ACID NON SOLUTION LOSS (LB/TON SO2)	2.9

D-15

DATE: 5/16/93
Time: 1030

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Succinic acid (ppm)	Slurry S.G.	% solids	Succinic acid in liquid (lb)	% Succinic in solids	Succinic acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	50	1.08	13.8	179	0.093	531
B/D MODULE UPPER	20000	23	460000	44	1.0865	12.6	160	0.093	488
A LOWER	8959	6	53754	46	1.0865	14.7	19	0.093	67
B LOWER	8959	6	53754	40	1.0865	12.6	17	0.093	57
C LOWER	8959	6	53754	54	1.073	14.3	22	0.093	64
D LOWER	8959	6	53754	17	1.107	11.8	7	0.093	54
A THICKENER	71275	17	1337500	60	1.023	4	596	0.093	424
B THICKENER	71275	17	1337500	23	1.023	4	228	0.093	424
LS SLURRY STORAGE	8064	33.2	267725	39	1.3	35	74	0	0
UNDERFLOW STORAGE	7216	18.6	134218	61	1.3	40	53	0.093	541
TOTALS			4211958.4				1356		2649

TOTAL SUCCINIC ACID INVENTORY CHANGE SINCE LAST INV	-580
TANKER LEVEL (GAL)	6016
DBA IN TANKER (LB OF 25%)	53542
25% DBA ADDED SINCE LAST INVENTORY (LB)	7110
SUCCINIC ACID ADDED SINCE LAST INVENTORY (LB)	462
A LIMESTONE BELT SCALE (TONS)	6713
B LIMESTONE BELT SCALE (TONS)	7634
LIMESTONE USED SINCE LAST INVENTORY (TONS)	376
SO2 REMOVED SINCE LAST INVENTORY (TONS)	210
AVERAGE LIMESTONE UTILIZATION	91
A CAKE BELT SCALE (TONS)	3569
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)	1006
AVERAGE PERCENT SOLIDS	71
SUCCINIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE	43
SUCCINIC ACID NON SOLUTION LOSS (LB/TON SO2)	4.8

Sample location	Tank mult. (gal/ft)	Tank ht. (ft)	Actual Tank vol. (gal)	Succinic acid (ppm)	Slurry S.G.	% solids	Succinic acid in liquid (lb)	% Succinic in solids	Succinic acid in solids (lb)
A/C MODULE UPPER	20000	23	460000	27	1.0865	12.4	99	0.093	480
B/D MODULE UPPER	20000	23	460000	31	1.048	10.4	112	0.093	388
A LOWER	8959	6	53754	32	1.136	12.9	14	0.093	61
B LOWER	8959	6	53754	26	1.0605	10.1	11	0.093	45
C LOWER	8959	6	53754	33	1.067	11.7	14	0.093	52
D LOWER	8959	6	53754	39	1.0605	10.8	17	0.093	48
A THICKENER	71275	17	1337500	43	1.023	4	427	0.093	424
B THICKENER	71275	17	1337500	56	1.023	4	556	0.093	424
LS SLURRY STORAGE	8064	29.05	234259	31	1.3	35	51	0	0
UNDERFLOW STORAGE	7216	13	93808	37	1.3	40	23	0.093	378
TOTALS			4138083.2				1323		2300

TOTAL SUCCINIC ACID INVENTORY CHANGE SINCE LAST INV	-383
TANKER LEVEL (GAL)	3573
DBA IN TANKER (LB OF 25%)	31800
25% DBA ADDED SINCE LAST INVENTORY (LB)	21743
SUCCINIC ACID ADDED SINCE LAST INVENTORY (LB)	1413
A LIMESTONE BELT SCALE (TONS)	7336
B LIMESTONE BELT SCALE (TONS)	7823
LIMESTONE USED SINCE LAST INVENTORY (TONS)	875
SO2 REMOVED SINCE LAST INVENTORY (TONS)	483
AVERAGE LIMESTONE UTILIZATION	91
A CAKE BELT SCALE (TONS)	5683
B CAKE BELT SCALE (TONS)	7
CAKE PRODUCED SINCE LAST INVENTORY (TONS)	2113
AVERAGE PERCENT SOLIDS	65
SUCCINIC ACID LOST WITH CAKE LIQUID SINCE LAST INVE	74
SUCCINIC ACID NON SOLUTION LOSS (LB/TON SO2)	3.6

CUMULATIVE OVERALL SUMMARY (SECOND TO FINAL INVENTORY)

TOTAL SUCCINIC ACID ADDED (LB)	1875
SUCCINIC ACID INVENTORY (LB)	3623
INITIAL SUCCINIC INVENTORY (LB)	4586
INVENTORY CHANGE TO DATE (LB)	-963
TOTAL SOLUTION LOSS (LB)	117
TOTAL SO2 REMOVED (TONS)	693
NON-SOLUTION LOSS (LB/TON SO2)	3.9
AVG CONCENTRATION (PPM)	53
TOTAL CONSUMPTION (LB/TON SO2)	4.1

APPENDIX E

FGDPRISM Description and Calibration Details

FGDPRISM uses the two-film theory to predict inter-phase mass transfer. The theory is based on the assumption that the transfer of a species can be modeled as diffusion through thin, stagnant films that exist on both sides of the gas/liquid interface. It also assumes that the liquid and gas are in equilibrium at the interface and that the interface provides no resistance to mass transfer.

Version 2.0 of EPRI's FGDPRISM computer model was used. Version 2.0 incorporates two major changes to the model in how gas/liquid mass transfer is calculated for droplet sprays. These additions made to the scrubber algorithms in Version 2.0 are:

- Droplets can interact and coalesce in the droplet trajectory program, and

- The liquid-film mass transfer is dependent on droplet residence time (the mass transfer coefficient decreases as droplet residence time increases).

In Version 1.1, the droplet trajectory calculations did not account for the fact that droplets collide and that some of the collisions cause droplets to combine. With the high mist density inside a spray absorber, a larger number of droplet collisions would be expected. By including the interaction of droplets in the trajectory calculations, the predicted importance of tower height was decreased (a deficiency of Version 1.1, which was found to over-predict the effects of tower height on spray tower SO_2 removal performance).

The second improvement of the gas/liquid mass transfer calculations deals with the effect of residence time on the liquid-film mass transfer. The previous version of FGDPRISM used an average, constant value for the liquid-film thickness throughout the absorber. A more rigorous approach was instituted with Version 2.0, wherein the liquid-film thickness changes (the thickness increases) as the droplets travel through the absorber. This is a more accurate representation because, as the droplets exit a nozzle, they have a great deal of internal turbulence which promotes mass transfer (i.e., a thinner liquid film). As the droplets travel further down the tower,

a more accurate representation because, as the droplets exit a nozzle, they have a great deal of internal turbulence which promotes mass transfer (i.e., a thinner liquid film). As the droplets travel further down the tower, this turbulence decays and the mass transfer rate decreases. Therefore, in Version 2.0, an algorithm was implemented to change the liquid-film thickness as a function of droplet residence time. This modification also results in less sensitivity to tower height or spacing between headers than was predicted with Version 1.1.

Another important modification in Version 2.0 of FGDPRISM is the limestone dissolution methodology. Previously, the limestone dissolution rate equation required only a single rate constant. The rate equation was primarily a function of pH and $CaCO_3$ relative saturation. The new methodology used in Version 2.0 is a combined surface reaction/diffusion rate model. Here, the limestone dissolution rate is controlled by two series resistances:

1) Diffusion of chemical species through a stagnant film surrounding the dissolving limestone particle, and

2) A surface reaction rate that accounts for the inhibiting effects of species such as sulfite and magnesium.

The diffusion rate is a function of the film thickness and the concentrations of species such as calcium and carbonate at the limestone surface and in the bulk solution. Values for the diffusion film thicknesses in the absorber and the reaction tank are calculated by FGDPRISM using a correlation based on data obtained from limestone testing at EPRI's. The particle size distribution of the limestone is the main factor used to determine the diffusion film thickness. The equation for the diffusion rate is:

$$\text{Rate} = \text{area} * \sum_j \frac{D_j}{\delta} (C_{ij} - C_{bj}) \qquad \text{(E-1)}$$

C_{bj} = concentration of species j in bulk; and

δ = film thickness;

$$\delta = \frac{d_P}{2 + \text{constant} \ (d_p)^{1.5}}$$

d_P = particle diameter.

The overall diffusion rate is calculated using the rate for each particle size (typically the particle size distribution is divided into 20 discrete particle sizes) and summing over the entire limestone particle size distribution.

The surface reaction rate is a function of the solution composition at the limestone surface and the limestone reactivity. The rate is calculated from the following equation:

$$\text{Surface Reaction Rate} = \frac{k \cdot (1 - CaCO_3 \ RS')^{3.0}}{(CaCO_3 \ RS') \cdot (CaSO_3 \ RS)} \cdot A \tag{E-2}$$

where: k = rate constant;

           $CaSO_3 \ RS$ = relative saturation of $CaSO_3$;

           $CaCO_3 \ RS'$ = $CaCO_3$ RS corrected for the effect of magnesium, that is:

           $CaCO_3 \ RS'$ = $CaCO_3$ RS + (576.13 • $MgCO_3$ RS); and

           A = limestone surface area.

The exponent 3.0 in the surface reaction rate equation and the constant 576.13 in the corrected $CaCO_3$ relative saturation expression are based on experimental data from EPRI's HSTC. For the Pirkey calibration, however, the 576.13 constant was reduced to essentially zero (0.13). With the constant set at 576.13, several cases were calculating a zero dissolution rate

when the $CaCO_3$ term approached a value of 1.0. By decreasing the constant to near zero (0.13), the $MgCO_3$ effect on the rate constant was removed, and the model calculated a dissolution rate for these cases. The $MgCO_3$ effect on the reaction rate was part of the revised limestone dissolution methodology of Version 2.0, but did not appear to accurately fit the Pirkey data.

The limestone reactivity can be adjusted by changing a variable called the surface area factor, and the limestone reaction rate constant (k) to match the observed limestone utilization and pH in the reaction tanks. A separate limestone reaction rate constant can be specified for each loop for the Pirkey system to best match the pH in the respective reaction tanks. The reaction rate constant for each loop was adjusted independently to achieve the observed upper- and lower-loop pH values at the measured limestone utilization levels. The limestone reaction constant was $1.0x10^{-5}$ for the upper loop, and $4.0x10^{-6}$ for the lower loop. The surface area factor remained at the 1.0 default value for the upper and lower loops.

The calibration procedure also includes gas-liquid mass transfer rate calculations, with both gas-film and liquid-film thicknesses being adjusted to match the mass transfer character-istics of the absorber. For the spray sections in the absorber, the model predicts gas/liquid surface area by determining the trajectory of each slurry droplet as it passes through the absorber. These calculations cannot be verified, however, since there is no method of directly measuring the surface area of the spray in an absorber. Instead, the mass transfer film thicknesses are varied to match observed SO_2 removals, since the surface area and film thicknesses together determine the SO_2 removal performance.

For the Pirkey absorber, separate film thicknesses were specified for the upper- and lower-loop spray sections and the upper-loop tray. For the upper-loop spray section, the liquid-film thickness was fixed at 5.6 microns and the gas-film thickness was 50 microns. A smaller liquid-film thickness, 0.9 microns, was necessary in the lower loop to achieve the measured SO_2 removals at low liquid-phase alkalinity. A larger gas-film thickness (60 microns) in the lower loop

E-5

was required to match measured SO_2 removal in the additive tests with high liquid-phase alkalinity. For the tray, the liquid diffusion film thickness was 7.5 microns and the gas diffusion film thickness was 50 microns. FGDPRISM predicted that very little SO_2 removal occurred across the tray.

The determination of the calcium sulfite and sulfate precipitation rate constants is also part of the model calibration. These rate constants are used to match predicted and measured relative saturation values calculated for solid calcium sulfite and sulfate compounds. The solid solution precipitation rate constant was $5.0x10^{-8}$ for the upper loop and $2.0x10^{-7}$ for the lower loop. These rate constants were varied to improve the observed sulfite/sulfate split in the upper- and lower-loop reaction tanks, and better match the relative saturations of the sulfite species.

In addition to the calibration parameters, several input values are adjusted to match the liquid chemistry present in the upper and lower loops of the absorber. For example, the HCl fraction of the flue gas is varied to match the chloride level of the absorber, and a second makeup stream (with only magnesium) is varied in rate to match the magnesium concentration in the slurry. Once the chemistry of the lower loop is approximated, the carryup rate from the lower loop to the upper loop is varied to match the upper-loop chemistry. For the Pirkey system, the carryup rate simulates the absorber slurry flow from the lower-loop header which is used to maintain level in the upper-loop reaction tank.

Table E-1 compares the predicted results with the measured SO_2 removal, utilization, and pH for all of the calibration cases. The test and run number were included for each case to reference information presented previously in the report. Table E-2 compares the predicted results with the measured results for tests that were not included in the calibration.

E-6

Table E-1

Results of FGDPRISM Calibration for Pirkey Station

		Baseline Test 2		Baseline Test 3		Baseline Test 4		Baseline Test 6	
		Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
SO₂ Removal (%)	Overall	91.7	89.6	95.3	93.3	85.0	83.0	96.7	96.2
	Upper Loop	80	84.0	89	87.8	80	76.8		92.6
	Lower Loop		34.6	58	44.8	25	26.8		47.9
Overall NTU		2.49	2.26	3.06	2.70	1.90	1.77	3.41	3.27
Slurry pH	Upper Loop	5.91	5.88	6.04	6.01	5.71	5.75	6.33	6.13
	Lower Loop	5.24	5.66	5.70	5.72	5.04	5.58	5.72	5.73
Utilization (%)	Upper Loop	90.4	89.0	88.3	88.5	94.3	93.9	65.2	66.8
	Lower Loop	93.9	92.4	84.2	84.0	96.9	96.8	77.7	77.5

		DBA Test 1, Runs 3&4		DBA Test 2, Runs 3&4		DBA Test 4, Runs 3&4		DBA Test 5, Runs 1&2	
		Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
SO₂ Removal (%)	Overall	98.6	98.9	92.0	92.2	99.0	99.0	99.3	99.1
	Upper Loop	97	96.6	88	87.8	97	96.6	97	96.5
	Lower Loop	62	66.8	33	36.0	67	69.9	74	73.9
Overall NTU		4.27	4.51	2.53	2.55	4.61	4.61	4.96	4.61
Slurry pH	Upper Loop	6.17	6.21	5.68	5.71	6.31	6.19	6.33	6.06
	Lower Loop	5.67	5.58	4.96	5.13	5.64	5.62	5.62	5.24
Utilization (%)	Upper Loop	82.6	85.7	96.7	96.2	84.9	86.0	88.6	89.2
	Lower Loop	86.0	84.7	97.9	98.1	91.6	90.9	87.8	86.9

		Formate Test 1, Runs 7&8		Formate Test 1, Runs 5&6		Formate Test 5, Run 6	
		Observed	Predicted	Observed	Predicted	Observed	Predicted
SO₂ Removal (%)	Overall	61.0	63.5	98.3	98.9	99.2	99.4
	Upper Loop	49.5	63.5	96	96.5	97	96.6
	Lower Loop			58	68.7	71	82.2
Overall NTU		0.94	0.93	4.07	4.42	4.83	4.96
Slurry pH	Upper Loop	6.33		6.25	6.29	6.38	6.45
	Lower Loop	5.50	5.51	5.53	5.69	5.74	5.78
Utilization (%)	Upper Loop	87.0	88.1	82.8	84.9	84.5	88.1
	Lower Loop			87.0	87.4	87.3	87.6

Table E-2

FGDPRISM Simulation Results for the Remaining Pirkey Test Cases

		Baseline Test 1		Formate Test 2		Formate Test 3, Rns 1&2		Formate Test 3, Rns 3&4	
		Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
SO$_2$ Removal (%)	Overall	97.1	97.1	93.5	94.2	93.8	95.3	94.4	97.6
	Upper Loop		94.5	91	90.2	92	92.0	92	95.1
	Lower Loop		47.2	24	40.8	26	40.7	27	51.0
Overall NTU		3.54	3.54	2.73	2.85	2.78	3.06	2.88	3.73
Slurry pH	Upper Loop	6.3	6.07	5.72	5.97	5.71	5.87	5.67	6.17
	Lower Loop	5.7	5.69	4.82	4.93	4.81	4.86	4.74	4.98
Utilization (%)	Upper Loop	67.5	71.7	96.6	95.0	97.1	97.1	97.1	92.0
	Lower Loop	79.7	80.7	98.2	98.5	98.8	99.0	98.7	98.5

		Formate Test 4		Formate Test 6		DBA Test 3	
		Observed	Predicted	Observed	Predicted	Observed	Predicted
SO$_2$ Removal (%)	Overall	98.6	99.3	96.9	98.9	93.9	95.8
	Upper Loop	97	96.5	95	96.3	91	92.1
	Lower Loop	53	78.6	43	69.8	31	46.7
Overall NTU		4.27	4.96	3.47	4.51	2.80	3.17
Slurry pH	Upper Loop	6.22	6.39	5.72	6.27	5.69	5.75
	Lower Loop	5.47	5.65	4.80	5.15	4.80	5.13
Utilization (%)	Upper Loop	92.6	93.6	97.0	97.3	97.0	97.2
	Lower Loop	93.5	94.0	98.4	98.6	95.8	97.8

		DBA Test 6, Runs 1&2		DBA Test 6, Runs 3&4		DBA Test 7	
		Observed	Predicted	Observed	Predicted	Observed	Predicted
SO$_2$ Removal (%)	Overall	96.0	98.9	97.1	99.0	99.5	99.5
	Upper Loop	94	96.8	95	96.5	98	96.8
	Lower Loop	35	69.0	43	70.8	76	83
Overall NTU		3.22	4.51	3.54	4.61	5.30	5.30
Slurry pH	Upper Loop	5.69	6.27	5.68	6.23	6.28	6.3
	Lower Loop	4.81	5.14	5.02	5.19	5.65	5.74
Utilization (%)	Upper Loop	96.6	95.4	96.8	96.4	81.9	82.0
	Lower Loop	98.3	98.2	97.5	97.7	83.3	82.7

Appendix F

Detailed Cost Calculations

The following spreadsheets show more details of the cost calculations for the various SO_2 removal upgrade options discussed in Section 4. The cost and capacity factors used in the calculations are listed at the top of the page. Table F-1 assumes 75% baseline limestone utilization and Table F-2 assumes 87% baseline limestone utilization.

The first five columns show the assumed operating conditions (slurry pH, DBA concentration, and limestone utilization required to obtain the SO_2 removal efficiency shown in column 6.

Column 7 is the required DBA feed rate based on the measured consumption rate (10.9 lb DBA/ton SO_2 removed with 1100 ppm in the reaction tank). It is assumed that the consumption rate is linear with concentration. Columns 8 is the annualized cost of the DBA additive system, and Column 9 is the annual cost of the DBA itself.

Column 9 is the additional cost of fan power (assuming 80% fan efficiency) associated with each option. Fan power increases substantially when the bypass damper is closed with either 3- or 4-module operation. A substantial savings in fan power ($140,000/yr) is obtained with the use of DBA, however, because of reducing scaling due to improved control of oxidation.

Column 10 is the additional cost of pumping power. Operation with 3 modules instead of 4 saves pumping power, but this savings is more than offset by increased fan power except at lower than average loads.

Columns 11 and 12 show the additional costs for reagent and for increased sludge production, respectively, and column 13 is the total annual cost of each option compared to the baseline case.

Table F-1

75% Baseline Limestone Utilization

This spreadsheet calculates the cost of
an additional ton of SO2 removal at
SWEPCo's Pirkey Station using DBA

Parameter	Value
Change in flue gas delta P with DBA	-1
lb/hr flue gas (average total @490 MW)	7200000
$/kwhr	0.05
DBA Capital Cost @ 100 lb/hr	300000
$/lb pure DBA	0.26
Total DBA loss rate (lb/ton SO2)	10.9
$/ton prepared limestone	14
$/ton additional sludge produced	2
Change in flue gas delta P to scrub all gas	1.6
Change in flue gas delta P for three modules	2.6
versus four modules at 490MW (avg load)	1.3

Additive rate and tons of SO2 are based on 8.5 tons SO2/hr
(3.6 lb/mm BTU 1992 average and 65% capacity factor)
Pump power based on 8000 hrs/year operation
Fan power based on 8000 hrs/yr at avg load of 490MW

Slurry pH Lower	Upper	DBA (ppm)	LS Utilization Upper	Lower	SO2 % Removal	DBA feed lb/hr	DBA Capital $/yr	DBA Addtnl $/yr	Addtnl Fan KW $/yr	Addtnl Pump KW $/yr	DBA Reagent $/yr	Addtnl O & M $/yr	Total Annual Cost $	Marginal Cost $/ton SO2	Average Cost $/ton SO2	Addtnl Tons SO2 Available	Net Annual SO2 Value ($1000) @ $250/ton	@ $150/ton
BASELINE (CURRENT) OPERATING CONDITIONS (29% bypass)																		
5.5	6.3	0	85	75	70.8	0	0	0	0	0	0	0	1617856	0	0	21764		
OPERATE WITH THREE MODULES (26% BYPASS)																		
5.5	6.3	0	85	75	70.8	0	0	0	177000	-200000	0	0	-23000	0	0	21764	23	23
CLOSE BYPASS DAMPERS TO SCRUB ALL FLUE GAS (4 MODULES)																		
5.5	6.3	0	85	75	97.9	0	0	0	220000	0	620000	99000	939000	46	46	1555	4100	2100
CLOSE BYPASS DAMPERS TO SCRUB ALL FLUE GAS (3 MODULES)																		
5.5	6.1	0	85	75	90.2	0	0	0	570000	-200000	440000	70000	880000	61	61	7308	2700	1300
ADD DBA, USE LOWER SETPOINTS (3 MODULES)																		
5.3	6	500	93	94	94.8	39	44000	88000	440000	-200000	110000	76000	558000	31	31	3908	3900	2100
ADD DBA WITHOUT LOWERING SETPOINTS (4 MODULES)																		
5.5	6.3	250	85	76	98.9	20	40000	46000	0	80000	610000	102000	878000	42	42	786	4400	2300
5.5	6.3	500	85	78	99.3	41	45000	93000	0	80000	560000	101000	879000	4	41	558	4400	2300
5.5	6.3	750	85	79	99.4	61	47000	139000	0	80000	540000	101000	907000	320	43	471	4400	2300
5.5	6.3	1000	85	80	99.5	82	49000	186000	0	80000	510000	101000	926000	257	43	397	4400	2300
5.5	6.3	1250	85	80	99.5	102	51000	232000	0	80000	520000	101000	984000	992	46	338	4400	2200
5.5	6.3	1500	85	80	99.6	123	53000	279000	0	80000	520000	101000	1033000	870	48	282	4300	2200

Table F-1

(Continued)

This spreadsheet calculates the cost of
an additional ton of SO2 removal at
SWEPCo's Pirkey Station using DBA

Parameter	Value
Change in flue gas delta P with DBA	-1
lb/hr flue gas (average total @490 MW)	7200000
$/kwhr	0.05
DBA Capital Cost @ 100 lb/hr	300000

Additive rate and tons of SO2 are based on 8.5 tons SO2/hr
(3.6 lb/mm BTU 1992 average and 65% capacity factor)
Pump power based on 8000 hrs/year operation
Fan power based on 8000 hrs/yr at avg load of 490MW

Parameter	Value
$/lb pure DBA	0.26
Total DBA loss rate (lb/ton SO2)	10.9
$/ton prepared limestone	14
$/ton additional sludge produced	2
Change in flue gas delta P to scrub all gas	1.6
Change in flue gas delta P for three modules	2.6
versus four modules at 490MW (avg load)	1.3

Slurry pH Lower	Upper	DBA (ppm)	LS Utilization Upper	Lower	SO2 % Removal	DBA feed lb/hr	DBA Capital $/yr	Addtnl DBA $/yr	Addtnl Fan KW $/yr	Addtnl Pump KW $/yr	Addtnl Reagent $/yr	Addtnl O & M $/yr	Total Annual Cost $	Marginal Cost $/ton SO2	Average Cost $/ton SO2	Addtnl Tons SO2 Available	Net Annual Value ($1000) @ $250/ton	@ $150/ton
USE LOWER SETPOINTS																		
5.2	6	250	93	93	97.4	20	40000	45000	80000	180000	85000		430000	22	22	1952	4500	2500
5.2	6	500	94	93	97.9	40	44000	91000	80000	170000	87000		472000	106	23	1555	4600	2600
5.2	6	1000	95	93	98.7	81	49000	184000	80000	160000	88000		561000	157	27	986	4600	2600
5.2	6	1250	95	93	98.9	101	51000	231000	80000	170000	89000		621000	299	30	786	4600	2500
5.2	6	1500	95	93	99.2	122	53000	278000	80000	170000	90000		671000	313	32	626	4600	2500
5.2	6	2000	95	93	99.3	163	55000	371000	80000	170000	90000		766000	746	36	498	4600	2400
USE LOWER SETPOINTS																		
4.8	5.7	500	98	96	95.4	39	44000	89000	80000	50000	76000		339000	19	19	3449	4200	2400
4.8	5.7	1000	99	96	97.1	80	49000	181000	80000	60000	81000		451000	89	23	2188	4400	2500
4.8	5.7	1500	99	96	97.9	120	52000	274000	80000	80000	83000		569000	187	28	1555	4500	2500
4.8	5.7	2000	99	96	98.3	161	55000	367000	80000	90000	85000		677000	341	33	1238	4500	2400

Table F-1

(Continued)

This spreadsheet calculates the cost of
an additional ton of SO2 removal at
SHEPCo's Pirkey Station using DBA

Parameter	Value
Change in flue gas delta P with DBA	-1
lb/hr flue gas (average total @490 MW)	7200000
$/kwhr	0.05
DBA Capital Cost @ 100 lb/hr	300000

Additive rate and tons of SO2 are based on 8.5 tons SO2/hr
(3.6 lb/mm BTU 1992 average and 65% capacity factor)
Pump power based on 8000 hrs/year operation
Fan power based on 8000 hrs/yr at avg load of 490MW

Parameter	Value
$/lb pure DBA	0.26
Total DBA loss rate (lb/ton SO2)	10.9
$/ton prepared limestone	14
$/ton additional sludge produced	2
Change in flue gas delta P to scrub all gas	1.6
Change in flue gas delta P for three modules	2.6
versus four modules at 490MW (avg load)	1.3

Slurry pH Lower	Slurry pH Upper	DBA (ppm)	LS Utilization	SO2 % Upper	SO2 % Lower Removal	DBA Removal lb/hr	DBA feed Capital $/yr	Addtnl DBA $/yr	Addtnl Fan KW $/yr	Addtnl Pump KW $/yr	Addtnl Reagent $/yr	Addtnl O & M $/yr	Total Annual Cost $	Marginal Cost $/ton SO2	Average Cost $/ton SO2	Addtnl Tons SO2 Available	Net Annual Value ($1000) @ $250/ton	@ $150/ton
BASELINE (CURRENT) OPERATING CONDITIONS (29% bypass)																		
5.5	6.3	0	85	87	70.8	0	0	0	0	0	1394704	0	0	0	0	21764		
OPERATE WITH THREE MODULES (26% BYPASS)																		
5.5	6.3	0	85	87	70.8	0	0	0	0	177000	-200000	-0	-23000	0	0	21764	23	23
CLOSE BYPASS DAMPERS TO SCRUB ALL FLUE GAS (4 MODULES)																		
5.5	6.3	0	85	87	97.9	0	0	0	0	220000	530000	91000	841000	42	42	1555	4200	2200
CLOSE BYPASS DAMPERS TO SCRUB ALL FLUE GAS (3 MODULES)																		
5.5	6.1	0	85	87	90.2	0	0	0	570000	-200000	380000	65000	815000	56	56	7308	2800	1400
ADD DBA, USE LOWER SETPOINTS (3 MODULES)																		
5.3	6	500	93	95	94.8	39	44000	88000	440000	-200000	320000	76000	768000	43	43	3908	3700	1900
ADD DBA WITHOUT LOWERING SETPOINTS (4 MODULES)																		
5.5	6.3	250	85	88	98.9	20	40000	46000	80000	0	530000	94000	790000	38	38	786	4500	2400
5.5	6.3	500	85	90	99.3	41	45000	93000	80000	0	510000	94000	822000	141	39	558	4500	2400
5.5	6.3	750	85	91	99.4	61	47000	139000	80000	0	480000	93000	839000	194	39	471	4500	2400
5.5	6.3	1000	85	92	99.5	82	49000	186000	80000	0	460000	93000	868000	393	41	397	4500	2300
5.5	6.3	1250	85	92	99.5	102	51000	232000	80000	0	460000	93000	916000	821	43	338	4400	2300
5.5	6.3	1500	85	92	99.6	123	53000	279000	80000	0	460000	93000	965000	870	45	282	4400	2300

Table F-2

(Continued)

This spreadsheet calculates the cost of
an additional ton of SO2 removal at
SWEPCo's Pirkey Station using DBA

Additive rate and tons of SO2 are based on 8.5 tons SO2/hr
(3.6 lb/mm BTU 1992 average and 65% capacity factor)
Pump power based on 8000 hrs/year operation
Fan power based on 8000 hrs/yr at avg load of 490MW

Parameter	Value
Change in flue gas delta P with DBA	-1
lb/hr flue gas (average total @490 MW)	7200000
$/kwhr	0.05
DBA Capital Cost @ 100 lb/hr	300000
$/lb pure DBA	0.26
Total DBA loss rate (lb/ton SO2)	10.9
$/ton prepared limestone	14
$/ton additional sludge produced	2
Change in flue gas delta P to scrub all gas	1.6
Change in flue gas delta P for three modules	2.6
versus four modules at 490MW (avg load)	1.3

Slurry pH Lower	Upper	DBA LS (ppm)	Utilization Upper	Utilization Lower	SO2 % Removal	DBA feed lb/hr	DBA feed Capital $/yr	DBA Addtnl $/yr	Addtnl DBA Fan KW $/yr	Addtnl Pump KW $/yr	Addtnl Reagent $/yr	Addtnl O & M $/yr	Total Annual Cost $	Marginal Cost $/ton SO2	Average Cost $/ton SO2	Addtnl Tons SO2 Available	Net Annual Value ($1000) @ $250/ton	@ $150/ton
USE LOWER SETPOINTS																		
5.2	6	250	93	93	97.4	20	40000	45000	80000	400000	85000		650000	33	33	1952	4300	2300
5.2	6	500	93	94	97.9	40	44000	91000	80000	390000	87000		692000	106	34	1555	4400	2300
5.2	6	1000	93	95	98.7	81	49000	184000	80000	390000	88000		791000	174	38	986	4400	2300
5.2	6	1250	93	95	98.9	101	51000	231000	80000	390000	89000		841000	249	40	786	4400	2300
5.2	6	1500	93	95	99.2	122	53000	278000	80000	390000	90000		891000	313	42	626	4400	2300
5.2	6	2000	93	95	99.3	163	55000	371000	80000	400000	90000		996000	824	47	498	4300	2200
USE LOWER SETPOINTS																		
4.8	5.7	500	96	98	95.4	39	44000	89000	80000	270000	76000		559000	31	31	3449	4000	2200
4.8	5.7	1000	96	99	97.1	80	49000	181000	80000	290000	81000		681000	97	35	2188	4200	2300
4.8	5.7	1500	96	99	97.9	120	52000	274000	80000	300000	83000		789000	171	39	1555	4300	2200
4.8	5.7	2000	96	99	98.3	161	55000	367000	80000	310000	85000		897000	341	44	1238	4200	2200

Column 13 shows the marginal cost of additional SO_2 removal, and column 14 shows the average cost of additional SO_2 removal in dollars per ton. For options with a single operating condition, such as closing the bypass damper, the marginal and average cost are the same. For the DBA options, individual cases are shown at increasing DBA concentrations. For these cases, the marginal cost of additional SO_2 removal refers to the immediately previous case rather than to the baseline case. This shows how the marginal cost of additional removal rises very steeply as the removal efficiency exceeds 99%. The maximum economical DBA concentration and SO_2 removal efficiency can be determined by inspecting the marginal cost from one step to the next.