DOE/PC/91338--T2
DE93 012463

High SO_2 Removal Efficiency Testing

DE-AC22-92PC91338

Technical Progress Report

Prepared for:

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

Prepared by:

Gary Blythe
Radian Corporation
P.O. Box 201088
Austin, TX 78720-1088

20 January 1993

1.0 INTRODUCTION

This document provides a discussion of the technical progress on DOE-PETC project number DE-AC22-92PC91338, "High Efficiency SO_2 Removal Testing," for the time period October 1 through December 31, 1992. The project involves testing at full-scale utility flue gas desulfurization (FGD) systems to evaluate low capital cost upgrades that may allow these systems to achieve up to 98% SO_2 removal efficiency. The options to be evaluated primarily involve the addition of organic acid buffers to the FGD systems. The "base" project involves testing at one site, Tampa Electric Company's Big Bend Station. Up to five optional sites may be added to the program at the discretion of DOE/PETC. By December 31, 1992, two of those five options had been exercised--for testing at Hoosier Energy's Merom Station and Southwestern Electric Power Company's Pirkey Station.

The remainder of this document is divided into three sections. Section 2, Project Summary, provides a brief overview of the technical efforts on this project during the quarter. Section 3, Testing Results, provides the details of these technical efforts, including data tables, figures, and plots. The baseline and parametric testing efforts for the base program and testing for Option I are discussed in separate subsections. In Section 4, Plans for the Next Reporting Period, an overview is provided of the technical progress that is anticipated for the first quarter of calendar year 1993.

2.0 PROJECT SUMMARY

Baseline testing at the "base" site, Tampa Electric Company's (TECo's) Big Bend Station, commenced on September 28 and was completed on October 2. Initial results from this testing were presented in the previous Technical Progress Report, but a more complete discussion is provided in this report.

Parametric testing was conducted at the Big Bend site during this quarter to evaluate the effects of dibasic acid (DBA) addition on system SO_2 removal performance. The parametric tests were conducted from November 2 through 19. A DBA consumption rate test was also conducted, after the parametric tests were completed. The DBA consumption test was conducted from November 21 through 25.

Options I and II to the base program were exercised by DOE/PETC at the end of the previous quarter. These options involve testing at Hoosier Energy Rural Electric Cooperative Inc.'s Merom Station and Southwestern Electric Power Company's Pirkey Station, respectively.

Testing was conducted at Merom Station during November. Previously, Radian Corporation was the test contractor for EPRI-funded performance additive testing at this site. This EPRI-funded testing involved the equivalent of baseline testing, parametric testing with both DBA and sodium formate performance additives, and an additive consumption test with the DBA additive. The results of the prior testing will be available to support the objectives of this DOE project. Consequently, the only testing required at the Merom site was to conduct consumption tests with the sodium formate additive. After a brief baseline repeat test, two sodium formate consumption tests were conducted during the time period from November 11 through 23. Results from the consumption tests are presented and discussed in this report.

Testing at Pirkey Station is not scheduled to be conducted until the February through April 1993 timeframe. It is now anticipated that both DBA and sodium formate will be evaluated as performance upgrade additives at this site.

No other options were exercised by DOE-PETC during the current quarter. However, efforts continue to negotiate Host Site Agreements for Options III and IV (for testing at PSI Energy's Gibson Station and Duquesne Electric's Elrama Station, respectively).

3.0 TESTING RESULTS

The test results available to date are for the baseline and parametric testing conducted at the Big Bend site, and for two additive consumption tests conducted at the Merom site. The results for each of these three testing efforts are discussed in separate subsections below.

3.1 Tampa Electric Big Bend Station - Baseline Tests

The objectives of the baseline tests were to characterize the FGD system performance at baseline conditions (without DBA additive) and to obtain process data suitable for calibrating EPRI's FGDPRISM to the TECo FGD system. Table 1 summarizes the initial test plan.

3.1.1 Summary

The baseline tests were completed as scheduled with very few operating or sampling problems. All of the performance data appear reasonable with the exception of two of the 15 quench section (lower loop) exit gas SO_2 concentration measurements that were significantly higher than the corresponding absorber inlet SO_2 concentrations. The measured overall average SO_2 removal efficiency for the test module at TECo's normal operating set points (gas velocity 7.5 ft/s, lower loop pH 4.2, upper loop pH 5.7) was 94%. At the highest operating pH levels, removal efficiency increased to 98%. At the lowest operating pH levels, removal efficiency decreased to 80%. At the highest gas velocity tested (11.1 ft/s), the overall average SO_2 removal efficiency was reduced to 85% at TECo's normal operating pH set points.

Results of off-site chemical analyses for slurry solids show that limestone utilization averaged 99.2% at TECo's normal operating pH of 4.2 in the quench section. Utilization decreased to 80% at pH 5.2 in the quench. Limestone utilization in the upper

Table 1

Original Baseline Test Plan for Big Bend

Test Number	Objective	Performance Indicators	Duration (Days)	Upper Loop pH	Lower Loop pH	Gas Velocity (ft/sec)
1	Characterize baseline performance under normal operating conditions	SO_2 Removal Utilization Oxidation Solids Dewatering Relative Saturation	2	5.7	4.8	7.5
2 3	Characterize performance with high upper loop pH	SO_2 Removal Utilization Relative Saturation	0.5 0.5	6.5 6.5	3.2 - 4.8[*] 5.5	7.5 7.5
4	Characterize performance with low upper loop pH	SO_2 Removal Utilization Relative Saturation	0.5	5.0	3.2	7.5
5	Characterize performance with normal upper loop pH, high velocity	SO_2 Removal Utilization Relative Saturation	0.5	5.7	4.8	10
6 7	Characterize performance with high upper loop pH, high velocity	SO_2 Removal Utilization Relative Saturation	0.5 0.5	6.5 6.5	5.5 5.5	10 10[**]
	Contingency for boiler or scrubber operating problems		1			
	Total baseline duration		6			

[*] Low pH may not be possible due to limestone carryover from upper loop.
[**] Test conducted with maximum L/G possible by operating spare pump.

absorber loop averaged 92% at the normal operating pH of 5.7. Utilization in the upper loop decreased to 78% at an operating pH of 6.2 and increased to 97.4% at an operating pH of 5.0.

Sulfite oxidation was nearly 100% under normal operating conditions in both the lower (quench) and upper (absorber) loops. Oxidation in the upper loop remained at 100% at the higher operating pH but decreased to about 90% in the lower loop at the higher operating pH of 5.2.

3.1.2 Test Approach

Figure 1 illustrates the arrangement of a single scrubber module at TECo's Big Bend Station. Flue gas and slurry sample points are indicated. Three identical modules (plus one spare) treat the flue gas from Unit 4. The baseline tests were done on Module B. Preliminary plans also included limited tests on Module C for comparison with Module B, but Module C was clearly not performing as well as the other modules at the time of the baseline tests and therefore was not included in the tests.

Each of the four (three operating) modules has a separate inlet booster fan. During the course of the baseline tests, the flue gas volume treated by Module B was held constant by setting the B booster fan vane position and holding the common inlet duct pressure constant by varying the flue gas flow to the other modules. By operating in this manner, Module B test conditions were maintained independent of boiler load.

Independent test variables included upper and lower loop slurry pHs, flue gas velocity, and number of upper loop slurry circulation pumps in operation. For each test, the desired conditions were set by TECo operators with the concurrence of the Radian lead engineer. After a period of stable operation (defined by steady control room pH readings for both the upper and lower loop reaction tanks), testing began.

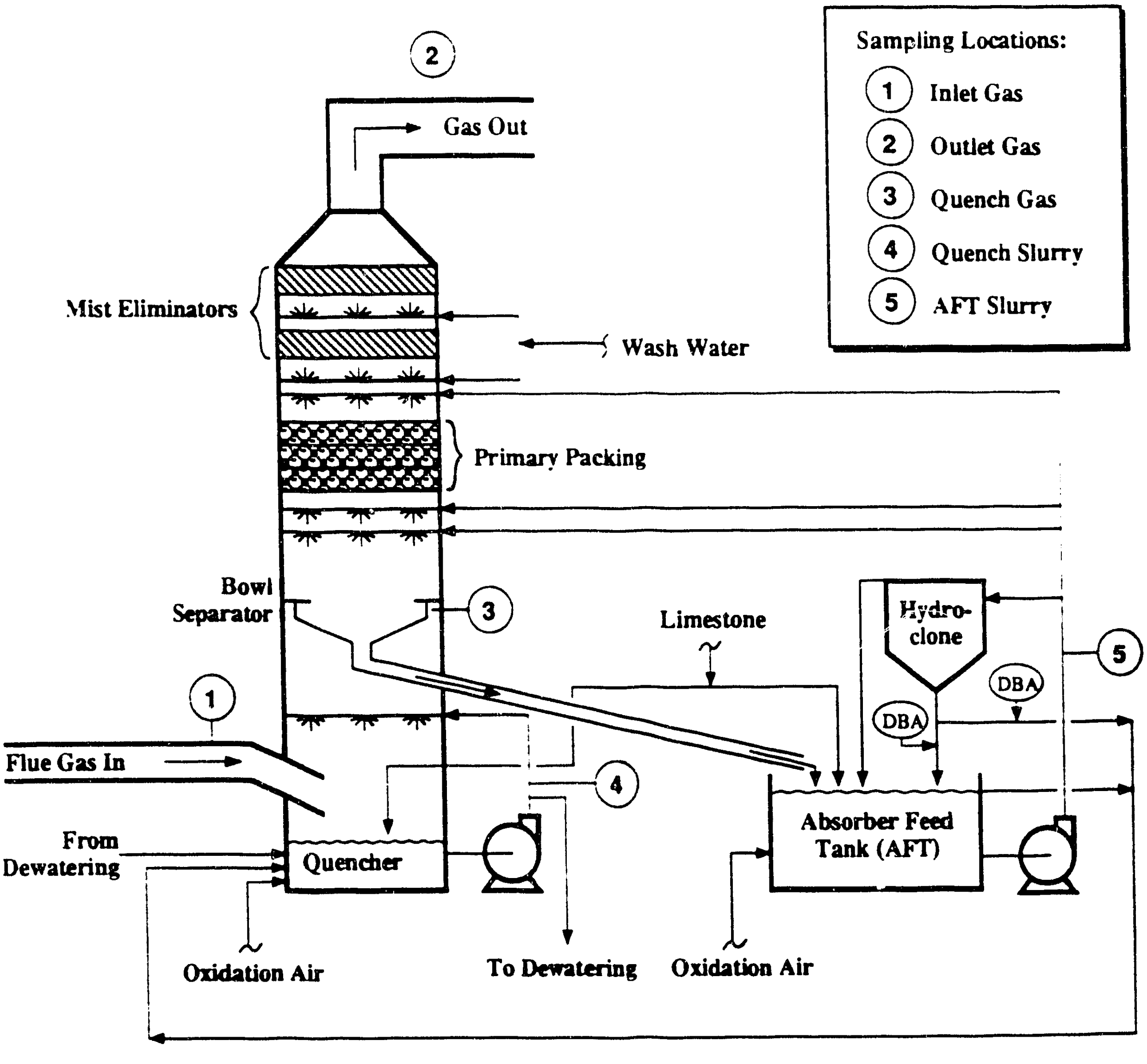


Figure 1. TECO Big Bend Unit 4 Scrubber Module with Sampling Locations

Performance measurements included inlet, outlet, and quench section exit flue gas SO_2 concentrations. Preliminary inlet SO_2 measurements showed good agreement between TECo's on-line SO_2 analyzer and Radian's EPA Method 6 traverses. During all subsequent tests, the inlet SO_2 concentrations were measured by the TECo analyzer, and the quench and outlet SO_2 concentrations were measured simultaneously by the Radian test crew by Method 6.

During a typical test, the flue gas velocity was first measured at the scrubber outlet by pitot traverse. Two Method 6 traverses were done at the module outlet sample location. Concurrently, two single-point Method 6 samples were obtained at the quench section exit gas sample point. Flue gas samples for Orsat analyses were also obtained during each test at both sample locations. Slurry samples from the upper and lower loop recycle pump discharges were obtained by the Radian crew at the beginning of the first Method 6 traverse, in between the two traverses, and at the end of the second traverse. In some cases, velocity traverses were also done following the second Method 6 traverse. Slurry flow rate measurements were also made during the tests using a portable ultrasonic flow meter.

3.1.3 Test Results

SO_2 Removal Results. Table 2 summarizes the actual test conditions and SO_2 removal efficiency results. All reported SO_2 concentrations are corrected to dry flue gas at 3% oxygen content, which is the basis of the TECo inlet SO_2 analyzer data. The first entries in the inlet SO_2 column of Table 2 are for the preliminary inlet SO_2 measurements made at the Module B inlet on September 28. The SO_2 concentration measured by Method 6 traverse averaged about 8% less than that measured by the inlet flue gas analyzer. This is within the expected relative accuracy of the certified analyzer. All of the remaining inlet SO_2 concentrations in Table 2 were measured by the continuous analyzer with the data representing averages over the indicated test duration.

Table 2

Actual Baseline Test Conditions and Results

Test Number	Run Number	Date	Time	Test Conditions					
				Operating pH[a]		Gas Velocity (ft/s)	AFT Pumps Operating	Orsat O_2 (%)	Inlet SO_2 Lear-Siegler
				Quench	AFT				
Prelim		9-28-92	1750-1805			7.8		6.6	2600/2780[c]
Prelim		9-28-92	1830-1845						2560/2830[c]
1	1	9-29-92	1315-1402	3.7/ /4.2	5.3/ /5.8	7.5	2	7.7	2934
1	2	9-29-92	1434-1527	4.1/4.2/4.3	5.7/5.8/5.8		2		2973
1	3	9-29-92	1557-1647	4.1/4.1/4.2	5.8/5.8/5.8	7.5	2		2947
2	1	9-30-92	1145-1303	3.5/3.6/3.9	6.2/6.2/6.2	8.4	2	8.1	2734
2	2	9-30-92	1328-1412	3.4/3.6/3.9	6.2/6.2/6.3		2		2759
3	1	9-30-92	1730-1813	5.2/5.2/5.1	6.2/6.2/6.3		2	8.3	2735
3	2	9-30-92	1835-1920	5.1/5.2/5.1	6.2/6.2/6.3	7.4	2		2690
4	1	10-1-92	0935-1031	2.9/2.7/3.2	5.0/5.1/5.0	7.9	2	6.6	2735
4	2	10-1-92	1055-1138	2.8/2.8/3.2	5.0/5.0/4.9		2		2724
5	1	10-1-92	1415-1500	3.9/4.0/4.2	5.6/5.7/5.6	11.1	2	6.5	2759
5	2	10-1-92	1517-1559	3.9/4.0/4.2	5.6/5.7/5.6	11.2	2		2771
6	1	10-2-92	1027-1111	5.3/5.3/5.1	6.1/6.0/6.0	9.7	3	6.5	2732
6	2	10-2-92	1151-1232	5.3/5.3/5.1	6.0/6.0/6.0	9.1	3		2731
7	1	10-2-92	1452-1541	5.2/5.3/5.1	6.0/6.1/6.0	10.8	2	7.1	2661
7	2	10-2-92	1600-1642	4.9/5.3/5.1	5.8/6.0/6.0	10.8	2		2633

Table 2

(Continued)

Test Number	Run Number	Date	Time	Test Results[b]			SO$_2$ Removal Efficiencies		
				Quench SO$_2$	Outlet SO$_2$				
				M6	M6	DuPont	Quench	Absorber	Overall
Prelim		9-28-92	1750-1805						
Prelim		9-28-92	1830-1845						
1	1	9-29-92	1315-1402	2400	173	174	18	92.8	94.1
1	2	9-29-92	1434-1527	2260	174	156	24	92.3	94.1
1	3	9-29-92	1557-1647	2430	182	153	18	92.5	93.8
2	1	9-30-92	1145-1303	2360	81	108	14	96.6	97.0
2	2	9-30-92	1328-1412	2380	72	105	14	97.0	97.4
3	1	9-30-92	1730-1813	2080	51	70	24	97.5	98.1
3	2	9-30-92	1835-1920	2580	53	75	4	97.9	98.0
4	1	10-1-92	0935-1031	3720	490	476	[d]	[d]	82.1
4	2	10-1-92	1055-1138	2750	606	487	0	78.0	77.8
5	1	10-1-92	1415-1500	3200	402	337	[d]	[d]	85.4
5	2	10-1-92	1517-1559	2660	417	335	4	84.3	85.0
6	1	10-2-92	1027-1111	2550	88	112	7	96.5	96.8
6	2	10-2-92	1151-1232	2440	110	108	11	95.5	96.0
7	1	10-2-92	1452-1541	2160	216	204	19	90.0	91.9
7	2	10-2-92	1600-1642	2120	291	229	19	86.3	88.9

[a] Reported pH values are Radian measurements, local on-line indicator, and control room data, respectivley.

[b] All SO$_2$ concentrations are on a dry gas basis, corrected to 3% oxygen.

[c] The first entry is Radian's Method 6 result at the inlet.

[d] Mid-point SO$_2$ concentrations are greater than the inlet concentrations.

Test 1 sampling began on September 29 after three continuous days of Module B operation at TECo's normal conditions. The Module B quench slurry pH set point was maintained at 4.2 and the AFT slurry pH set point at 5.7 throughout this test. Three complete sets of slurry and slurry filtrate samples were collected on September 29, and three sets of flue gas SO_2 analyses were completed. Three quench slurry settling tests were also conducted on site during Test 1. Two velocity traverses at the Module B outlet indicated that the module was operating at the desired 7.5 ft/s gas velocity.

During Test 1, three sets of slurry pH measurements were made by Radian with a portable pH meter. Table 2 lists the results of Radian's pH measurements along with corresponding pH values indicated concurrently by TECo's on-line process pH instruments. The on-line instrument readings were obtained both at the local readouts near the slurry sample points and from the data acquisition system printout in the control room. Two of the three sets of pH data from Test 1 are in good agreement, but the first pH values measured by Radian were significantly lower than the on-line pH values.

The inlet SO_2 concentration measured by TECo's certified CEM averaged about 2950 ppm (dry basis, corrected to 3% oxygen) and was essentially constant throughout Test 1. The Module B outlet SO_2 concentrations measured by traversing the outlet duct averaged 176 ppm (dry basis, corrected to 3% oxygen). The actual flue gas oxygen concentrations (dry basis) on which the correction was based were determined by Orsat analyses and are shown in the table. The TECo on-line SO_2 analyzer at the Module B outlet, which samples gas from a single point in the duct, indicated an average outlet SO_2 concentration of 161 ppm corrected to the same basis. The overall SO_2 removal efficiency for Module B averaged 94.0% for Test 1. The single-point quench gas SO_2 concentration averaged 2370 ppm, indicating that about 20% of the inlet SO_2 was removed in the quench section (lower loop) of the module.

Test 2 was completed on September 30. This and subsequent tests were short-term tests intended to evaluate the effects of operating pH and flue gas velocity on

SO_2 removal and limestone utilization. For Test 2, the upper-loop pH was increased to 6.2, which was estimated by TECo to be the maximum level that could be maintained without sulfite blinding. The lower-loop pH was allowed to equilibrate without reagent addition by locking out the reagent feed valve. The lower loop operated at a pH of about 3.5 under these conditions. During Test 2, as well as some of the subsequent tests, the Radian pH measurements and the local on-line pH indicators for the lower loop both were somewhat lower than the values recorded by the data acquisition system. Good agreement was generally seen among the upper-loop pH measurements.

With the lower operating pH, the calculated SO_2 removal in the lower-loop decreased to about 14% in Test 2. The higher operating pH in the upper loop increased the overall SO_2 removal to an average of 97.2% in Test 2 compared to 94.1% in Test 1. The outlet SO_2 concentrations measured by TECo's on-line analyzer were about 35% higher than Radian's Method 6 traverse results in Test 2.

Test 3 was also completed on September 30 following a pH set point change to 5.2 in the lower loop. The overall SO_2 removal efficiency for this test (based on the Method 6 outlet measurement) increased to an average of 98.1%. The TECo on-line analyzer again indicated higher outlet SO_2 concentrations than the Method 6 measurements. The quench section exit flue gas samples differed by about 20% for the two runs made during Test 3. It can be seen from the results in Table 2 that relatively small variations in measured SO_2 concentrations at the quench section exit sample point caused large variations in the estimated lower-loop removal efficiency. The fact that the quench section exit flue gas is sampled at a single point also contributes to the uncertainty in the estimated lower-loop SO_2 removal efficiency.

Two Module B outlet velocity traverses were also completed on September 30--one immediately prior to Test 2 and one following Test 3. The measured flue gas volumetric flow rates for these traverses corresponded to average scrubber gas velocities of 8.4 and 7.4 ft/s, respectively. Since flue gas flow conditions were unchanged between the two tests and were the same as for the previous day, the difference between these two values most likely is a result of normal variation in the velocity traverse method results.

Tests 4 and 5 were completed on October 1. The conditions for Test 4 included lower-than-normal operating pH set points for both the upper and lower loops. The flue gas velocity was maintained at the nominal 7.5 ft/s. A Module B outlet traverse prior to Test 4 indicated an actual velocity of 7.9 ft/s.

Test 4 conditions were stabilized at a pH of 5.0 in the upper loop and 2.8 in the lower loop. Under these conditions, the overall SO_2 removal decreased to about 80%. For the first of the two sequential sets of SO_2 concentration measurements during Test 4, the measured quench section exit flue gas SO_2 content was substantially higher than the inlet concentration indicated by the on-line analyzer. The calculations for this Method 6 result have been reviewed without finding an explanation for the contradictory data. In addition, the potential contribution of dissolved SO_2 from slurry droplets evaporating in the heated probe was estimated based on the apparent moisture content of the quench flue gas (calculated from the increases in the sample train impinger weights). This estimate showed that the error could not be accounted for by slurry droplet evaporation in the probe.

The result of the second Test 4 measurement at the quench sample point was similar to the inlet concentration (within the expected range of experimental error), indicating that little or no SO_2 was removed in the lower loop at the operating pH of 2.8.

Test 5 was completed after raising the Module B gas velocity by opening the booster fan inlet vanes to the 100% open position. Velocity traverses before and after Test 5 indicated a scrubber velocity of about 11 ft/s for Test 5. The pH set points were returned to TECo's normal levels (4.2 in the quench and 5.7 in the AFT) for Test 5. Under these conditions, the overall SO_2 removal efficiency averaged 85.2% compared to 94.0% for Test 1 at the same pH and a gas velocity of 7.5 ft/s. In Test 5, one of the two quench gas SO_2 concentration measurements was again higher than the indicated inlet SO_2 concentration.

Tests 6 and 7 were completed on October 2. For these tests, the pH set points were increased to 5.1 in the quench and 6.1 in the AFT. The booster fan inlet vanes remained at the 100% open position. For Test 6, the spare upper-loop recycle pump was activated. This pump was then deactivated for Test 7. Flue gas velocity traverses at the Module B outlet indicated a scrubber velocity of 10.8 ft/s for Test 7. Operating the third absorber pump during Test 6 reduced the scrubber velocity to an average of 9.4 ft/s because of the increased pressure drop across the slurry and packing.

Comparing Tests 5 and 7 at the same gas velocity and slurry flow rates shows that increasing the operating pH levels from normal to high levels increased the overall SO_2 removal efficiency from 85.2% to 90.9%. A comparison of Tests 6 and 7 shows that activating the spare absorber pump increased the overall SO_2 removal from 90.9% to 96.4%. Some of this increase was due to the reduction in gas flow, however.

The on-line Dupont SO_2 analyzer at the Module B outlet (single-point sample) agreed reasonably well with Radian's Method 6 measurements at the higher SO_2 concentrations seen in Tests 4 through 7.

Slurry Flow Rate Measurement Results. Slurry flow rate measurements were repeated at various locations throughout the baseline tests using an ultrasonic Doppler effect flow meter. This instrument processes a signal from a pair of transducers placed on opposite sides of a pipe. The flow rate is indicated instantaneously in ft/s. The instrument also has a totalizer that when calibrated for pipe internal diameter, reads in gallons. Results of these measurements are summarized in Table 3. In this table, flow rates measured directly in ft/s are shown along with the corresponding calculated flow in gal/min. Flow rates shown in gal/min were measured by timing the totalizer for 5 to 10 minutes.

Table 3

Slurry Flow Rate Measurements

Date	Time	Location	Pipe ID (inches)	Velocity (ft/s)	Volume (gpm)
9-28	1000	B Quench	18.75	11.9	10,300
	1530	B Upper Loop Main Header	34.75	10.3	30,500
		B Upper Loop Middle Spray	16.75	11.4	7,850
		B Upper Loop Lower Spray	16.75	12.9	8,900
	1700	B Upper Loop Main Header	34.75	9.9	29,300
9-29	1000	B Upper Loop Main Header	34.75	9.5	28,200
	1420	B Upper Loop Main Header	34.75	10.2	30,200
		B Upper Loop Middle Spray	16.75	11.4	7,850
		B Upper Loop Lower Spray	16.75	13.0	8,950
10-1	1000	B Upper Loop Main Header	34.75	10.2	30,200
		B Upper Loop Middle Spray	16.75	11.0	7,600
		B Upper Loop Lower Spray	16.75	11.0	7,600
	1700	B1 AFT Pump Suction Line	28.75		13,100
		B1 AFT Pump Discharge	22.75		13,700
		B2 AFT Pump Discharge	22.75		13,000

Table 3

(Continued)

Date	Time	Location	Pipe ID (inches)	Velocity (ft/s)	Volume (gpm)
10-2	1000	B1 AFT Pump Discharge	22.75		11,200
		B2 AFT Pump Discharge	22.75		11,200
		B3 AFT Pump Discharge	22.75		12,500
	1200	B1 AFT Pump Discharge	22.75		11,000
		B2 AFT Pump Discharge	22.75		11,000
		B3 AFT Pump Dishcarge	22.75		12,300
	1400	B1 AFT Pump Discharge	22.75		14,200
		B2 AFT Pump Discharge	22.75		12,500

Average Total AFT Flow (two pumps) measured in main header - 29,700 gpm.
Average Total AFT Flow (two pumps) by summing pump discharge - 26,700 gpm.
Average Total AFT Flow (three pumps) by summing pump discharge - 34,600 gpm.
Percent of AFT Flow to middle spray - 26%.
Percent of AFT Flow to lower spray - 28%.
Percent of AFT Flow to packing (by difference) - 46%.

The only available quench flow rate test location was a short horizontal section of pipe just downstream of a "tee." This location was not favorable for flow rate measurements, and the indicated velocity varied from 11.4 to 13.1 ft/s. The steadiest velocity readings at this location were at 11.9 ft/s, which corresponds to a quench slurry flow rate of 10,300 gpm. Since this flow rate is near the design value and the quench flow does not greatly affect overall performance, this flow rate measurement was not repeated.

Several locations were available for upper-loop flow rate measurements. The total flow to the upper loop was measured first at two different locations on the main vertical header leading to the upper loop. At this location, the total slurry flow with two pumps operating averaged 29,700 gpm for five separate measurements. The total flow to the upper loop was also estimated by measuring the flow downstream of the individual slurry pump discharges. The combined flow of two operating upper-loop pumps averaged 26,700 gpm for two separate measurements. With three upper-loop pumps operating, the combined flow averaged 34,600 gpm for two separate measurements.

The slurry flow measurements described above correspond to an operating L/G of about 22 gal/1000 acf in the lower loop and 65 gal/1000 acf in the upper loop at the normal 7.5 ft/s gas velocity in the scrubber. At the higher gas velocity of 11 ft/s, the corresponding L/G's are 15 gal/1000 acf in the lower loop and 44 gal/1000 acf in the upper loop. With three pumps operating and a gas velocity of 9.4 ft/s, the corresponding L/G's were 18 gal/1000 acf in the lower loop and 60 gal/1000 acf in the upper loop.

Process Data. Data are available on-line for most of the process instrumentation. All of the data are stored on magnetic tape, and selected data can be printed at 5-minute intervals. At Radian's request, the data listed in Table 4 were printed in the control room. Table 5 summarizes average values for these data points during the actual testing periods.

Table 4

On-Line Process Data Obtained During Baseline Tests

Data Point	ID Label	Units
FGD Inlet Temperature	FGIT01W	°F
Unit 4 Gross Megawatts	SPUA03A	MW
Total Fuel Flow	FCSF01A	klb/hr
FGD Inlet O_2 Concentration	FGIG04A	volume percent
FGD Inlet SO_2 Concentration	FGIG08A	ppm dry @ 3% O_2
Booster Fan Vane Position	FGIZ02A	percent open
FGD Inlet Pressure	FGIP01W	inches water
Module B Outlet Temperature	IRST03A	°F
Module B Outlet SO_2	FGOG03W	ppm dry @ 3% O_2
Module B Quench Air Flow	FOSF02A	ACFH
Module B AFT Air Flow	FOSF06A	ACFH
B1 Absorber Feed Pump Power	ASAW13A	kW
B2 Absorber Feed Pump Power	ASAW04A	kW
B3 Absorber Feed Pump Power	ASAW05A	kW
B2 Quench Feed Pump Power	ASQW08A	kW
B Quench Slurry Density	ASQD02A	specific gravity
B Quench Slurry pH	ASQC03A	pH units
B Absorber Slurry Density	ASAD02A	specific gravity
B Absorber Slurry pH	ASAC03A	pH units
Module B Pressure Drop	ASQP07A	inches water
B Mist Eliminator Pressure Drop	ASQP05A	inches water

Table 5

Average Values for On-Line Process Data

Tag: Units: Description:	FGDO03W ppm B Out SO_2	FOSF02A acfm Quench	ASAW13A kW #1 Pump	ASAW04A kW #2 Pump	ASAW05A kW #3 Pump	ASQW03A kW Quench P	ASQD02A Spe Gra Quench	ASQC03A pH Quench	ASAD02A Spe Gra Absorber	ASAC03A pH Absorber	FGIG08A ppmv Inlet SO_2
9/29/92 Test 1 Run 1	174	163,176	275	300		167	1.096	4.18	1.104	5.82	2934
9/29/92 Test 1 Run 2	156	162,606	276	300		166	1.097	4.27	1.103	5.83	2973
9/29/92 Test 1 Run 3	153	162,674	275	299		166	1.096	4.25	1.103	5.83	2947
9/30/92 Test 2 Run 1	108	165,413	275	300		168	1.095	3.92	1.108	6.23	2734
9/30/92 Test 2 Run 2	105	165,389	274	298		167	1.096	3.87	1.107	6.25	2759
9/30/92 Test 3 Run 1	70	168,986	273	300		167	1.097	5.07	1.110	6.28	2736
9/30/92 Test 3 Run 2	75	169,609	273	299		167	1.096	5.07	1.112	6.31	2687
10/1/92 Test 4 Run 1	476	173,007	271	307		168	1.093	3.19	1.106	4.95	2737
10/1/92 Test 4 Run 2	487	172,933	272	298		169	1.094	3.18	1.106	4.88	2724
10/1/92 Test 5 Run 1	337	172,457	277	302		168	1.097	4.18	1.118	5.60	2760
10/1/92 Test 5 Run 2	345	172,974	277	302		169	1.096	4.20	1.122	5.62	2771
10/2/92 Test 6 Run 1	112	170,542	254	263	263	171	1.095	5.14	1.102	6.02	2732
10/2/92 Test 6 Run 2	108	171,003	252	261	262	168	1.097	5.13	1.087	6.03	2731
10/2/92 Test 7 Run 1	204	169,510	286	299		170	1.098	5.14	1.109	6.03	2661
10/2/92 Test 7 Run 2	229	168,688	258	295		171	1.095	5.13	1.119	6.03	2633

Slurry Sample Chemical Analysis Results. For Test 1 at normal TECo operating conditions, three complete sets of slurry and slurry filtrate samples were collected and analyzed. For Tests 2 through 7, three slurry samples and one set of slurry filtrate samples were collected. Of the three slurry samples, one was completely analyzed, and the other two were analyzed for solids content and solid carbonate only.

Table 6 summarizes the results of the solids analyses for the slurry samples. The sample designation 1-U-1 refers to Test 1, upper loop, sample 1, and 1-L-1 refers to Test 1, lower loop, sample 1. The complete analytical results shown in Table 6 are for the designated sample, except for the weight percent solids and solid carbonate analyses in Tests 2 through 7. These results are reported as an average for the three separate slurry samples that were analyzed. The pH and temperature values are those measured by Radian as the samples were taken.

Each slurry sample indicated in the table was filtered, and the filter cake was dried and weighed to determine the solids content in weight percent. A portion of the dried solids was then digested in HCl plus H_2O_2. The portion of solids that remained undissolved is reported as "inerts" in weight percent of the solids.

The solid solution was analyzed for Ca and Mg by atomic absorption and for SO_4 by ion chromatography (IC). The IC result is reported as "Total S (as SO_4)" in the table since the acid/peroxide dissolution technique converts sulfite to sulfate before analysis. A separate portion of the dried solids was analyzed for SO_3 (sulfite) by thiosulfate/iodine titration. The value for SO_4 reported in the table is calculated as the difference between the total S and sulfite analyses. 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 the EPRI FGD Chemistry and Analytical Methods Handbook.

Table 6

Results of Solids Analyses

Description:	**1-U-1**[a]	**1-L-1**[b]	**1-U-2**	**1-L-2**	**1-U-3**	**1-L-3**	**2-U-2**
Date	9/29/92	9/29/92	9/29/92	9/29/92	9/29/92	9/29/92	9/30/92
Time	1330	1315	1450	1430	1622	1615	1330
Ca, mm/g	5.82	6.54	5.80	5.69	5.86	5.61	6.15
Mg, mm/g	0.01	0.00	0.01	0.00	0.01	0.03	0.02
SO_3, mm/g	0.00	0.32	0.00	0.00	0.00	0.00	0.00
Total S (as SO_4), mm/g	5.38	5.59	5.36	5.62	5.40	5.53	4.92
SO_4, mm/g	5.38	5.27	5.36	5.62	5.40	5.53	4.92
CO_3, mm/g	0.43	0.04	0.48	0.05	0.51	0.05	1.42[c]
Inerts, wt.% of solids	0.40	1.22	0.73	1.02	0.51	1.52	0.80
Solids, wt.% of slurry	18.8	17.3	19.4	17.3	19.7	17.2	19.7[c]
pH	5.70	3.68	5.73	4.07	5.80	4.07	6.18
Temperature, °C	54.9	51.5	55.0	54.4	55.1	54.7	54.6
Reagent Util., %							
Ca-Independent	92.7	99.3	91.8	99.0	91.3	99.2	77.6
SO_4-Independent	92.7	99.4	91.7	99.1	91.3	99.2	77.0
Reagent Ratio							
Ca-Independent	1.08	1.01	1.09	1.01	1.09	1.01	1.29
SO_4-Independent	1.08	1.01	1.09	1.01	1.10	1.01	1.30
Oxidation, %	100.0	94.3	100.0	100.0	100.0	100.0	100.0
Solid Solution, wt.%	0.0	4.9	0.0	0.0	0.0	0.0	0.0
Gypsum, wt.%	92.6	89.6	92.2	96.7	92.8	95.0	84.7
$CaCO_3$, wt.%	4.3	0.4	4.8	0.5	5.1	0.5	14.2
Inerts, wt.%	0.4	1.2	0.7	1.0	0.5	1.5	0.8
Ca, mg/g	233	262	232	228	234	224	246
Mg, mg/g	0	0	0	0	0	1	0
SO_3, mg/g	0	26	0	0	0	0	0
Total S (as SO_4), mg/g	517	536	515	540	518	530	473
SO_4, mg/g	517	506	515	540	518	530	473
CO_3, mg/g	26	2	29	3	31	3	85
Closures							
Weight, %	-2.7	-0.1	-2.4	-1.7	-1.8	-2.8	-1.1
Molar, %	0.2	7.5	-0.3	0.2	-0.3	0.6	-2.4
Acceptable, %	6.8	6.9	6.8	7.0	6.8	7.0	6.4

Table 6

(Continued)

Description:	**2-L-2**	**3-U-2**	**3-L-2**	**4-U-2**	**4-L-2**	**5-U-2**	**5-L-2**
Date	9/30/92	9/30/92	9/30/92	10/01/92	10/01/92	10/01/92	10/01/92
Time	1330	1850	1840	1040	1030	1525	1515
Ca, mm/g	5.60	6.26	6.07	5.72	5.59	6.08	5.77
Mg, mm/g	0.00	0.02	0.03	0.00	0.00	0.01	0.00
SO_3, mm/g	0.30	0.00	0.49	0.00	0.00	0.00	0.00
Total S (as SO_4), mm/g	5.59	4.95	4.98	5.71	5.78	5.23	5.66
SO_4, mm/g	5.29	4.95	4.49	5.71	5.78	5.23	5.66
CO_3, mm/g	0.05^c	1.31^c	1.22^c	0.15^c	0.01^c	0.70^c	0.06^c
Inerts, wt.% of solids	1.31	0.76	1.52	0.95	1.22	0.12	0.73
Solids, wt.% of slurry	18.1^c	19.1^c	18.4^c	17.8^c	18.7^c	19.6^c	19.6^c
pH	3.51	6.18	5.13	4.93	2.92	5.51	3.85
Temperature, °C	54.1	55.4	54.9	55.0	54.5	55.8	53.4
Reagent Util., % Ca-Independent SO_4-Independent	 99.1 99.1	 79.1 79.1	 80.3 80.0	 97.4 97.4	 99.9 99.9	 88.2 88.5	 98.9 98.9
Reagent Ratio Ca-Independent SO_4-Independent	 1.01 1.01	 1.26 1.26	 1.25 1.25	 1.03 1.03	 1.00 1.00	 1.13 1.13	 1.01 1.01
Oxidation, %	94.6	100.0	90.2	100.0	100.0	100.0	100.0
Solid Solution, wt.%	4.6	0.0	7.6	0.0	0.0	0.0	0.0
Gypsum, wt.%	90.0	85.1	75.7	98.2	99.4	90.0	97.4
$CaCO_3$, wt.%	0.5	13.1	12.2	1.5	0.1	7.0	0.6
Inerts, wt.%	1.3	0.8	1.5	1.0	1.2	0.1	0.7
Ca, mg/g	224	250	243	229	224	243	231
Mg, mg/g	0	0	1	0	0	0	0
SO_3, mg/g	24	0	39	0	0	0	0
Total S (as SO_4), mg/g	536	475	478	548	555	502	543
SO_4, mg/g	508	475	431	548	555	502	543
CO_3, mg/g	3	79	73	9	0	42	4
Closures Weight, % Molar, % Acceptable, %	 -3.6 -0.3 6.9	 -1.0 0.2 6.4	 -3.5 -0.8 6.2	 0.1 -1.2 7.0	 -0.1 -1.7 7.1	 -2.3 1.3 6.7	 -1.1 0.4 7.0

Table 6

(Continued)

Description:	6-U-2	6-L-2	7-U-2	7-L-2
Date	10/02/92	10/02/92	10/02/92	10/02/92
Time	1130	1120	1600	1550
Ca, mm/g	6.23	6.09	6.06	6.09
Mg, mm/g	0.02	0.02	0.01	0.02
SO_3, mm/g	0.00	0.28	0.00	0.64
Total S (as SO_4), mm/g	4.97	5.16	5.25	5.39
SO_4, mm/g	4.97	4.88	5.25	4.75
CO_3, mm/g	1.33[c]	1.09[c]	0.73[c]	0.85[c]
Inerts, wt.% of solids	0.36	0.39	0.32	0.74
Solids, wt.% of slurry	18.4[c]	19.9[c]	18.5	20.4[c]
pH	6.12	5.34	5.91	5.11
Temperature, °C	56.3	55.8	55.8	52.1
Reagent Util., %				
Ca-Independent	78.9	82.6	87.8	86.4
SO_4-Independent	78.7	82.1	88.0	86.1
Reagent Ratio				
Ca-Independent	1.27	1.21	1.14	1.16
SO_4-Independent	1.27	1.22	1.14	1.16
Oxidation, %	100.0	94.6	100.0	88.1
Solid Solution, wt.%	0.0	4.3	0.0	9.9
Gypsum, wt.%	85.4	83.2	90.2	79.8
$CaCO_3$, wt.%	13.3	10.9	7.3	8.5
Inerts, wt.%	0.4	0.4	0.3	0.7
Ca, mg/g	249	244	242	244
Mg, mg/g	0	0	0	0
SO_3, mg/g	0	22	0	51
Total S (as SO_4), mg/g	477	496	504	518
SO_4, mg/g	477	469	504	456
CO_3, mg/g	80	65	44	51
Closures				
Weight, %	-1.1	-1.8	-1.8	-1.6
Molar, %	0.4	-1.2	0.8	-1.1
Acceptable, %	6.4	6.4	6.7	6.3

[a] 1-U-1 designates Test 1, Upper Loop, Sample 1.

[b] 1-L-1 designates Test 1, Lower Loop, Sample 1.

[c] Indicated wt.% solids and solid carbonate content for Tests 2-7 are an average value for three separate slurry samples.

Two calculated values for limestone utilization are reported in Table 6 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 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.

Oxidation is calculated as [1 - moles of sulfite/moles of total S]. Sulfite was detected in only five of the 18 solid samples analyzed. Under normal operating conditions in Test 1, oxidation was essentially 100% in both the upper and lower loops (some sulfite was detected in one of the three lower loop samples). Oxidation remained at 100% in the upper loop under all test conditions, but sulfite was detected in the lower-loop samples in each of the high-pH tests (3, 6, and 7).

The remaining entries in Table 6 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 assumption that each of the individual analyses has an expected error of ±5% at the 95% confidence level. The calculated closures in Table 6 indicate excellent data quality. Only one of the 18 samples (1-L-1) has a closure error slightly higher than the acceptable error. The calcium result for this sample appears to be high. All of the other samples show molar closures well below the acceptable limits.

Results of liquid-phase analyses were not available as of this report date. These results will be included in the technical note that will be issued in January 1993.

Settling rate tests were performed to evaluate baseline solids dewatering properties. Three sets of measurements were performed during Test 1. Since it takes several residence times for solids properties to reach steady state, evaluation of the settling rate during the other tests was not performed. For Test 1, the unit area at an underflow concentration of 30% solids was 0.82 ±0.15 ft^2/ton/day (95% confidence interval). The final underflow concentration was 63.4 ±4.1% solids by weight.

Performance Correlations. Absorber performance can be approximately described by the following expression:

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

where: $SO_{2_{in}}$ and $SO_{2_{out}}$ = inlet and outlet SO_2 concentrations;
K (lb/hr-ft^2) = average overall gas-phase mass transfer coefficient;
A (ft^2) = 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 SO_2 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, that represent mass transfer rates across the gas and liquid films, respectively:

$$1/K = 1/k_g + H/k_l\phi \qquad (2)$$

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. Eq. 1 also shows that NTU should be inversely proportional to gas flow rate (if K and A are independent of gas velocity) and proportional to liquid flow rate (if A is proportional to liquid flow rate).

Figure 2 is a plot of NTU vs. pH for the quench section of the dual-loop module. In this figure, data for tests at different gas velocities are indicated by different data point symbols. It is evident from this plot that the scatter in the SO_2 removal data based on the single-point sample at the quench location does not allow any meaningful conclusions to be drawn regarding the effects of pH and gas velocity on the quench performance. The data do show that the quench section NTU did not exceed 0.3 and was generally 0.2 or less. This compares to an overall NTU (quench plus absorber) ranging from 1.6 to 3.9 for the baseline tests. Therefore, it can be concluded that the quench section contribution to the overall mass transfer performance was less than 10%.

Because the quench section NTU represents at most 10% of the overall NTU for the module, overall performance can be approximately correlated with absorber slurry pH. Figure 3 is a plot of overall module NTU vs. absorber slurry pH. In this plot, the data from Tests 1 through 4 at 7.5 ft/s, Tests 5 and 7 at 11 ft/s, and Test 6 at 9.4 ft/s (with three absorber feed pumps) have been designated by different symbols so that the effects of gas velocity and slurry flow rate on NTU can be illustrated.

In Figure 3, the overall NTU for the module operating at 7.5 ft/s is essentially linear with absorber slurry pH over the range tested. The results for Test 3 with a high quench pH lie slightly above the line for Tests 1, 2, and 4 with a lower quench pH. The NTU for Tests 5 and 7 at 11 ft/s is about 75% of the value at 7.5 ft/s for the same pH level. If K and A in Eq. 1 were independent of gas velocity, NTU at 11 ft/s would be 68% of that at 7.5 ft/s. Therefore, the results indicate that increasing the gas velocity

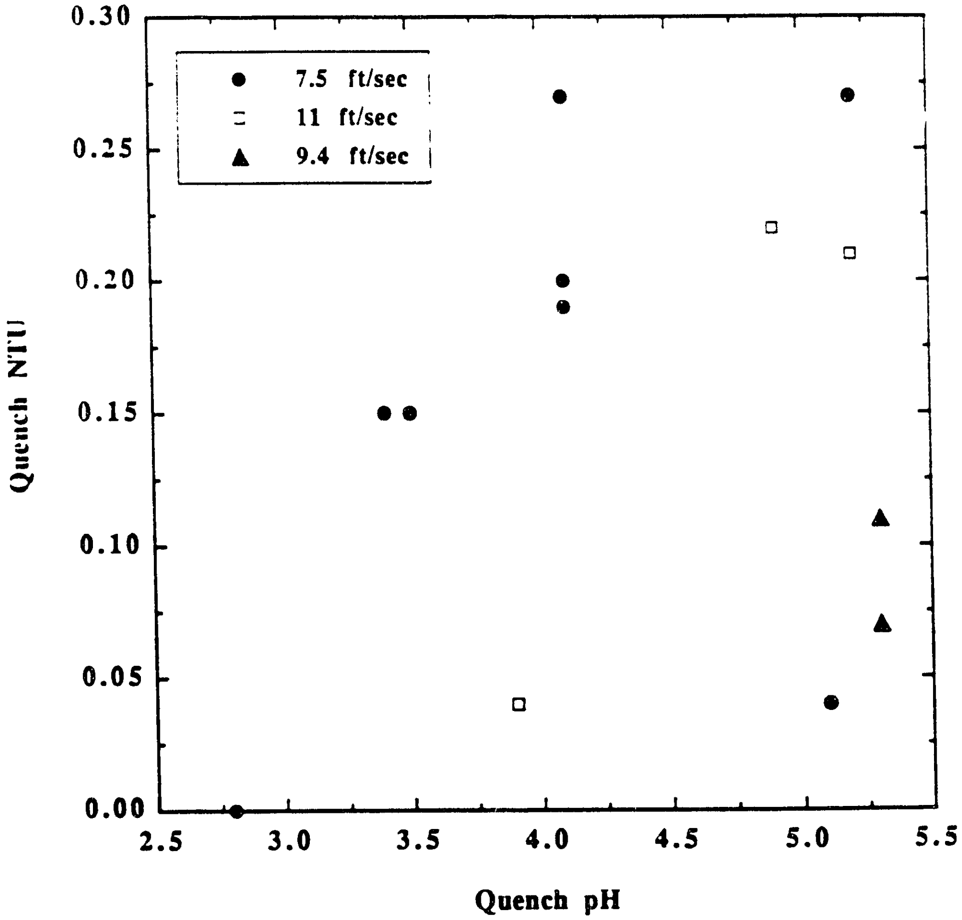


Figure 2. Quench NTU vs. pH

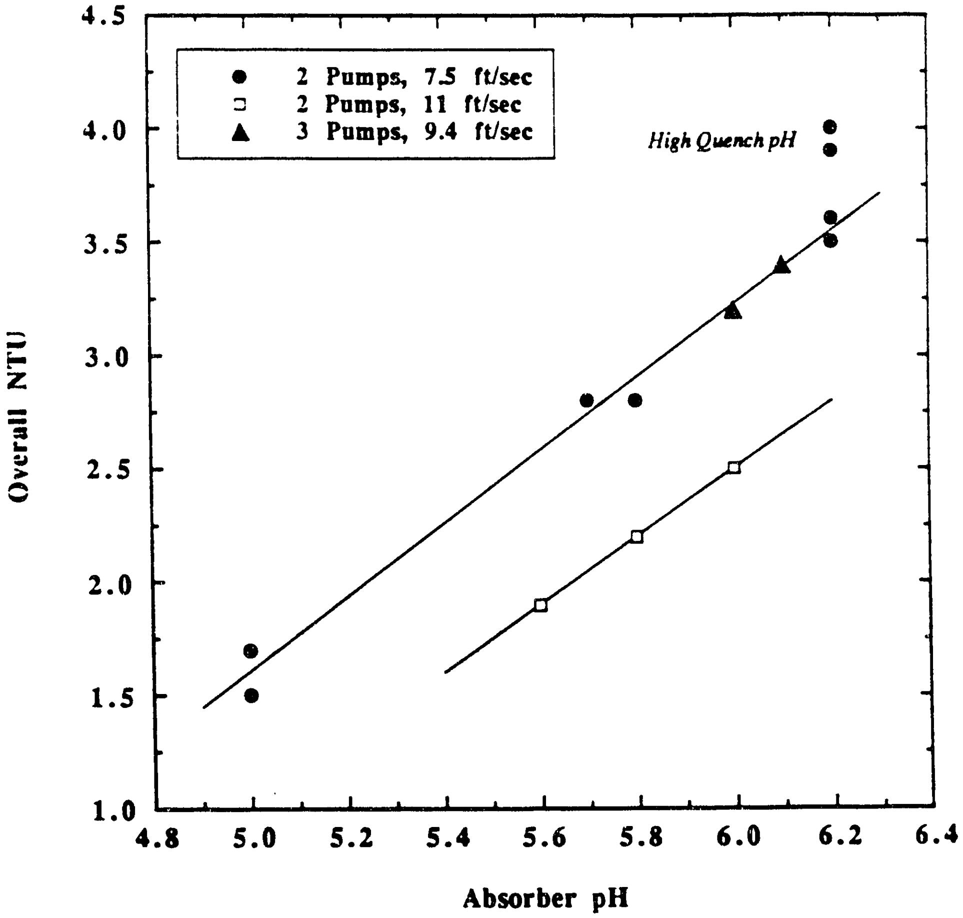


Figure 3. Overall NTU vs. Absorber pH

may have had a small beneficial effect on the product of the mass transfer coefficient and interfacial area for mass transfer.

The results for Test 6 at 9.4 ft/s with three absorber slurry pumps operating fall on the same performance curve as the tests at 7.5 ft/s with two pumps operating. With three pumps operating, the slurry spray rate to the absorber increased from 26,700 to 34,600 gpm. The performance increase due to increased slurry flow offset the decrease due to gas velocity. This effect is consistent with data from EPRI's HSTC pilot unit for which NTU was found to be directly proportional to slurry spray rate at constant pH and gas velocity.

3.2 Tampa Electric Big Bend Station - Parametric Tests

This subsection summarizes preliminary results of the parametric SO_2 removal tests and long-term consumption test using DBA additive at TECo's Big Bend Unit 4 FGD system. Performance data obtained at the site and results of off-site chemical analyses completed to date are presented.

The objective of the parametric SO_2 removal tests was to characterize the performance of a single FGD module as a function of DBA additive concentration and other pertinent process variables. Table 7 summarizes the initial parametric test plan. Test variables other than DBA concentration included upper loop operating pH and flue gas velocity.

Tests were conducted in four groups at increasing levels of DBA concentration. At each of the first three DBA levels, two-day tests (Tests 1, 5, and 9) were done at the normal pH and gas velocity levels. Sufficient time elapsed during these tests to evaluate the effect of DBA addition on solids properties such as settling and filtration rates. The two-day tests were followed by one-day tests at normal pH and high velocity (Tests 2, 6, and 10) and two half-day tests at high pH with normal and high velocities (Test pairs 3

Table 7

Parametric Test Schedule for Big Bend

Objective	Performance Indicators	Test Order	Duration (days)	Upper Loop pH	Lower Loop pH	Quench DBA Conc. (ppm)	Gas Velocity (ft/sec)
Characterize FGD system performance with DBA at normal pH setpoints	SO_2 Removal Utilization Oxidation Solids Dewatering Relative Saturation	1	2	5.8	4.3	250	7.5
		2	1	5.8	4.3	250	11
		5	2	5.8	4.3	500	7.5
		6	1	5.8	4.3	500	11
		9	2	5.8	4.3	1000	7.5
		10	1	5.8	4.3	1000	11
Characterize performance with DBA at high upper loop pH setpoint	SO_2 Removal Utilization Relative Saturation	3	0.5	6.3	3.9	250	11
		4	0.5	6.3	3.9	250	7.5
		7	0.5	6.3	3.9	500	11
		8	0.5	6.3	3.9	500	7.5
		12	0.5	6.3	3.9	1000	11
		13	0.5	6.3	3.9	1000	7.5
Characterize performance at maximum SO_2 removal conditions	SO_2 Removal Utilization Relative Saturation	14	0.5	6.3	4.3	2500	7.5
		15	0.5	6.3	4.3	2500	11
Characterize performance with high velocity, higher L/G (spare pump on)	SO_2 Removal Utilization Relative Saturation	11	1	5.8	4.3	1000	11

and 4, 7 and 8, and 12 and 13). One test (Test 11) was done with three absorber slurry pumps operating instead of the normal two pumps. The final two parametric tests (Tests 14 and 15) were done at very high DBA concentrations.

A long-term, steady-state DBA consumption test followed the parametric tests. The objective of the long-term additive consumption test was to determine the actual DBA feed rate required to maintain a specified DBA concentration in the FGD system liquor. Oxidative degradation is known to be a significant loss mechanism for DBA in a forced-oxidation FGD system. The steady-state rate of DBA degradation was measured during the long-term test by calculating the difference between the amount of DBA fed to the system and the amount leaving the system in the FGD sludge and blow-down liquor. DBA consumption results are reported below.

3.2.1 Summary

The parametric test plan and long-term DBA consumption tests were completed at TECo's Big Bend Unit 4 essentially as planned. Parametric testing began on November 2 and concluded on November 19. A total of 15 SO_2 removal tests were conducted on Module B with DBA concentrations ranging from 45 to 900 ppm in the upper loop slurry liquor and 120 to 2140 ppm in the lower loop slurry liquor. Corresponding Module B SO_2 removal efficiencies ranged from 92.6% to 99.84%. Approximately 250 ppm DBA was required in the upper loop of the test module to meet the 98% removal project objective at TECo's normal operating pH set point of 5.8.

The long-term consumption test began on November 21 and was terminated on November 25 after 90 hours, due to an unscheduled Unit 4 outage. The average DBA nonsolution loss for this time period was 3.7 lb of DBA/ton of SO_2 removed. The total DBA consumption was 4.7 lb/ton of SO_2 removed. The average DBA concentration maintained in the system was 340 ppm in the upper loop slurry liquor and 730 ppm in the lower loop slurry liquor.

3.2.2 Parametric Test Approach

Figure 1 illustrates the arrangement of a single scrubber module at TECo's Big Bend Station, with the flue gas and slurry sample points and DBA addition points indicated. The parametric tests, as were the baseline tests, were done on Module B. During the course of the parametric tests, the flue gas volume treated by Module B was held relatively constant by setting the B booster fan vane position and holding the common inlet duct pressure constant by varying the flue gas flow to the other modules. By operating in this manner, Module B test conditions were maintained independent of boiler load.

Independent variables for the parametric tests included upper loop (absorber) slurry pH, lower and upper loop DBA concentrations, flue gas velocity, and, in one test, the number of upper loop slurry circulation pumps in operation. For each test, the desired conditions other than DBA concentration were set by TECo operators with the concurrence of the Radian lead engineer. DBA concentrations were measured by buffer capacity titration before each test and adjusted by a Radian engineer by transferring DBA from the tanker to the upper and lower loop slurry tanks. DBA was fed to each of the tanks continuously to maintain the desired concentrations during the test.

Most of the SO_2 removal in a double-loop scrubber module occurs in the upper (absorber) loop. The lower loop serves primarily to saturate the flue gas. Slurry from the upper loop overflows from the absorber feed tank (AFT) into the lower loop (quench) tank. Fresh makeup water is added to the upper loop of the module through the mist eliminator wash. Process water returned from the dewatering system is added to the lower loop of the module. With this module configuration, DBA would normally be added only to the upper loop tank. DBA would reach the lower loop tank with the overflow from the upper loop and with process water returned from the dewatering area.

Because the parametric tests were conducted on a single module, DBA concentrations did not reach steady-state levels in other portions of the FGD system. To simulate steady-state conditions in the test module, the expected steady-state distribution of DBA between the upper and lower loops was estimated using material balance calculations. These calculations indicated that the steady-state DBA concentration in the lower loop would be two to four times that in the upper loop. To simulate this distribution during the short-term parametric tests, DBA was added to both loops. As the tests proceeded, the DBA concentration in the process water returning to the lower loop gradually increased. This concentration was measured daily, and the DBA feed rate to the lower loop was adjusted accordingly.

Performance measurements included inlet, outlet, and quench section exit flue gas SO_2 concentrations. Preliminary inlet SO_2 measurements showed good agreement between TECo's on-line SO_2 analyzer and Radian's EPA Method 6 traverses. During all subsequent tests, the inlet SO_2 concentrations were measured by the TECo analyzer, and the quench section exit and absorber outlet SO_2 concentrations were measured simultaneously by the Radian test crew using EPA Method 6.

During a typical test, the flue gas velocity was first measured at the scrubber outlet by pitot traverse. Then, two Method 6 traverses were done at the module outlet sample location. Concurrently, two single-point Method 6 samples were obtained at the quench gas sample point. Flue gas samples for Orsat analyses were also obtained during each pair of Method 6 tests at both sample locations. Slurry samples from the upper and lower loop recycle pump discharges were obtained by the Radian crew at the beginning of each pair of Method 6 traverses, in between the two traverses, and at the end of the second traverse. In some cases, velocity traverses were also done following the second Method 6 traverse.

3.2.3 Results

SO$_2$ Removal Efficiency Results. Table 8 summarizes the actual test conditions and SO$_2$ removal efficiency results. All reported SO$_2$ concentrations are corrected to dry flue gas at 3% oxygen content, which is the basis of the TECo inlet SO$_2$ analyzer data. At the request of TECo, the normal pH set point of 4.2 in the quench tank was reduced to 3.8 for the parametric tests to limit the amount of SO$_2$ removed in the lower loop. This was done to avoid potential limestone blinding problems that could arise if SO$_2$ removal in the lower loop exceeded the oxidation air capacity. pH measurements shown in the table include those made by Radian using a calibrated portable pH meter and those indicated by TECo's on-line process analyzers. DBA concentrations shown in the table are those determined by ion chromatography in Radian's Austin laboratory.

Test 1 sampling began on November 4, two days after DBA was initially added to the Module B process tanks. The upper loop was operated at the normal pH set point of 5.8 throughout this test. Three complete sets of slurry and slurry filtrate samples were collected and three sets of flue gas SO$_2$ analyses were completed during the first test day. Test 1 was concluded the following morning after one additional set of flue gas and slurry samples were obtained. Quench slurry settling tests were also conducted on site during the second day of Test 1. Velocity traverses at the Module B outlet indicated that the module flue gas velocity averaged 7.6 ft/s during the first day of Test 1. The velocity was slightly higher at 8.1 ft/s during the second day.

The inlet SO$_2$ concentration measured by TECo's certified CEM averaged about 2530 ppm (dry basis, corrected to 3% oxygen) and did not vary by more than a few percent throughout Test 1. The Module B outlet SO$_2$ concentrations measured by traversing the outlet duct averaged 138 ppm (dry basis, corrected to 3% oxygen). The actual flue gas oxygen concentrations (dry basis) on which the correction was based were determined by Orsat analyses and are shown in the table. The TECo on-line SO$_2$ analyzer at the Module B outlet, which samples gas from a single point in the duct, indicated an

Table 8

Actual Parametric Test Conditions and Results

Test No.	Run No.	Date (1992)	Time	Absorber pH	Quench pH	Absorber DBA	Quench DBA	Flue Gas Velocity	Outlet Flue Gas O_2	Lear Siegler Inlet SO_2	M6 Quench SO_2	M6 Outlet SO_2	Dupont Outlet SO_2	Quench Rem'l Effi'cy	Absorber Rem'l Effi'cy	Overall Rem'l Effi'cy
1	1	11/04	0832-0914	5.9/5.9[a]	3.5/3.5	93	443	7.6	5.6	2597	2637	133	139	-1.5	94.7	94.9
1	2	11/04	0945-1027	5.9/5.9	3.5/3.5	93	443	7.6	5.6	2553	2494	127	133	2.3	94.8	95.0
1	3	11/04	1215-1256	5.9/5.9	3.8/3.8	47	169	7.6	5.6	2531	2474	117	112	2.2	95.2	95.4
1	4	11/04	1320-1401	5.9/5.9	3.8/3.8	47	169	7.6	5.6	2540	2556	130	128	-0.6	94.9	94.9
1	5	11/04	1640-1721	5.8/5.8	3.4/3.3	70	439	7.6	5.6	2535	2285	136	141	9.9	93.9	94.6
1	6	11/04	1743-1825	5.8/5.8	3.4/3.3	70	439	7.6	5.6	2487	2268	142	124	8.8	93.7	94.3
1	7	11/05	0840-0922	5.8/5.8	3.6/3.5	45	121	8.1	5.9	2480	2333	184	168	5.9	91.8	92.6
1	8	11/05	1005-1046	5.9/5.9	3.5/3.5	114	432	8.1	5.9	2520	2192	133	129	13.0	93.7	94.7
2	1	11/05	1321-1402	5.9/5.8	3.6/3.5	88	338	10.1	6.8	2556	2535	226	175	0.8	90.8	91.2
2	2	11/05	1415-1457	5.9/5.8	3.6/3.5	88	338	10.1	6.8	2558	2568	267	188	-0.4	90.0	89.6
2	3	11/05	1526-1607	5.8/5.8	3.7/3.7	69	149	10.1	6.8	2560	2454	283	NA	4.2	88.0	89.0
2	4	11/05	1624-1705	5.9/5.8	3.6/3.5	69	149	10.1	6.8	2580	2519	282	NA	2.4	88.8	89.1
3	1	11/06	1010-1154	6.3/6.2	3.6/3.5	48	351	7.8	6	2795	2206	67.8	87	21.1	97.2	97.6
3	2	11/06	1210-1251	6.2/6.1	3.8/3.8	48	351	7.8	6	2793	2284	72.4	92	18.2	97.0	97.4
4	1	11/06	1715-1758	6.0/6.0	3.7/3.5	83	319	10.1	6.2	2848	2245	185	145	21.2	92.3	93.5
4	2	11/06	1815-1856	6.0/5.9	3.7/3.6	83	319	10.1	6.2	2807	NA[b]	176	147	NA	NA	93.7
5	1	11/08	1020-1101	5.9/5.9	3.5/3.6	214	1155	7.4	7	2630	2486	85.1	118	5.5	96.5	96.8
5	2	11/08	1125-1220	5.9/5.9	3.5/3.6	214	1155	7.4	7	2528	NA[b]	81.7	141	NA	NA	96.8
5	3	11/08	1425-1506	5.8/5.8	3.7/3.6	215	915	7.4	6.5	2552	NA[b]	62.5	145	NA	NA	97.6
5	4	11/08	1525-1607	5.8/5.8	3.8/3.9	215	915	7.4	6.5	2546	NA[b]	64.5	119	NA	NA	97.5

Table 8

(Continued)

Test No.	Run No.	Date (1992)	Time	Absorber pH	Quench pH	Absorber DBA	Quench DBA	Flue Gas Velocity	Outlet Flue Gas O_2	Lear Siegler Inlet SO_2	M6 Quench SO_2	M6 Outlet SO_2	Dupont Outlet SO_2	Quench Rem'l Effi'cy	Absorber Rem'l Effi'cy	Overall Rem'l Effi'cy
5	5	11/12	0835-0916	5.8/5.8	3.5/3.5	230	509	7.4	7.0	2720	2277	36.4	62	16.3	98.6	98.7
5	6	11/12	0927-1008	5.8/5.8	3.5/3.5	230	509	8.15	7.0	2640	2210	58.6	57	16.3	97.4	97.8
5	7	11/12	1330-1411	5.8/5.8	3.4/3.4	157	366	7.6	5.9	2619	2278	80.7	74	13.0	96.5	96.9
5	8	11/12	1500-1541	5.9/5.8	3.4/3.4	157	366	7.6	5.9	2633	2304	73.3	78	12.5	96.7	97.2
6	1	11/13	0845-0926	5.9/5.8	3.4/3.4	176	402	9.5	6.2	2716	2138	144	129	21.3	93.4	94.7
6	2	11/13	0945-1026	5.9/5.8	3.4/3.4	176	402	9.5	6.2	2721	2315	142	129	14.9	93.8	94.8
6	3	11/13	1320-1401	5.8/5.7	3.4/3.4	140	407	9.5	7.5	2779	2271	159	139	18.3	93.1	94.3
6	4	11/13	1420-1501	5.8/5.8	3.5/3.5	140	407	9.5	7.5	2772	2387	146	131	13.9	93.3	94.7
7	1	11/14	0900-0941	6.1/6.1	3.2/3.2	117	532	7.3	6	2623	2223	47.8	58	15.3	97.9	98.2
7	2	11/14	1000-1041	6.1/6.1	3.7/3.6	117	532	7.3	6	2604	2306	49.6	65	11.4	97.9	98.1
8	1	11/14	1315-1356	6.1/6.1	3.6/3.7	120	347	9.7	7	2828	2681	147	116	5.2	94.5	94.8
8	2	11/14	1410-1451	6.1/6.1	4.1/4.3	120	347	9.7	7	2793	2585	164	120	7.5	94.1	94.1
9	1	11/15	0940-1021	5.9/5.9	3.5/3.5	277	1208	7.5	6.8	2597	2228	50.8	75	14.2	97.7	98.0
9	2	11/15	1041-1122	5.9/5.9	3.5/3.5	277	1208	7.5	6.8	2681	2328	58.5	63	13.2	97.5	97.8
9	3	11/15	1145-1226	5.9/5.9	3.5/3.6	213	1535	7.5	6.8	2754	2463	57.9	69	10.6	97.5	97.9
9	4	11/15	1240-1321	5.8/5.8	3.5/3.5	213	1535	7.5	6.8	2759	2311	74.4	78	16.2	97.1	97.3
9	5	11/16	0935-1016	5.9/5.9	3.5/3.4	365	843	7.2	10.2	2636	2014	13.7	54	23.6	99.3	99.5
9	6	11/16	1035-1116	5.9/5.9	3.5/3.4	365	843	7.2	10.2	2675	1987	27.1	35	25.7	98.8	99.0
9	7	11/16	1440-1521	5.8/5.8	3.4/3.5	309	986	7.2	6.5	2752	2177	31.1	44	20.9	97.4	98.9
9	8	11/16	1540-1622	5.8/5.8	3.4/3.5	309	986	7.2	6.5	2702	2121	42	45	21.5	97.9	98.4

Table 8

(Continued)

Test No.	Run No.	Date (1992)	Time	Absorber pH	Quench pH	Absorber DBA	Quench DBA	Flue Gas Velocity	Outlet Flue Gas O_2	Lear Siegler Inlet SO_2	M6 Quench SO_2	M6 Outlet SO_2	Dupont Outlet SO_2	Quench Rem'l Effi'cy	Absorber Rem'l Effi'cy	Overall Rem'l Effi'cy
10	1	11/17	0900-0941	5.9/5.8	3.5/3.6	417	1217	9.8	8.2	2660	2060	42.8	52	22.6	97.8	98.4
10	2	11/17	1015-1056	5.9/5.8	3.5/3.6	417	1217	9.8	8.2	2670	2446	49.8	58	8.4	97.8	98.1
11	1	11/17	1300-1411	5.7/5.8	3.3/3.6	441	1023	9.2	7.9	2634	2185	26.7	44	17.1	99.0	99.0
11	2	11/17	1430-1511	5.8/5.8	3.4/3.6	441	1023	9.2	7.9	2640	2164	14.5	30	18.0	99.3	99.4
12	1	11/18	1015-1107	6.1/6.1	3.7/3.7	470	1172	7.5	9	2768	2086	7.65	na	24.6	99.6	99.7
12	2	11/18	1117-1210	6.1/6.1	3.7/3.7	470	1172	7.5	9	2702	2073	9.73	70	23.3	99.5	99.6
13	1	11/18	1435-1528	6.1/6.0	3.7/3.7	423	1180	9.8	7.7	2756	2241	39.3	38	18.7	98.3	98.6
13	2	11/18	1543-1636	6.0/6.0	3.7/3.7	423	1180	9.8	7.7	2737	1901	39.2	21	30.6	98.0	98.6
14	1	11/19	0915-1032	6.1/6.1	3.6/3.6	907	2137	7.75	8.3	2927	1768	4.5	17	39.6	99.7	99.8
14	2	11/19	1100-1217	6.0/6.0	3.6/3.6	907	2137	7.75	8.3	2890	2037	8.35	20	29.5	99.6	99.7
15	1	11/19	1505-1546	6.1/6.0	3.6/3.6	881	1800	9.9	8	2901	2308	17.8	37	20.4	99.3	99.4
15	2	11/19	1600-1641	5.9/6.0	3.5/3.6	881	1800	9.9	8	2883	2347	14.4	48	18.6	99.4	99.5

[a] Reported pH values are those measured by Radian and by the on-line pH analyzer, respectively.

[b] Midpoint samples lost due to probe leak.

average outlet SO_2 concentration of 134 ppm for Test 1 (corrected to the same basis). The overall SO_2 removal efficiency for Module B averaged 94.5% for Test 1. The single-point quench section exit gas SO_2 concentration averaged 2400 ppm, indicating that about 5% of the inlet SO_2 was removed in the quench section (lower loop) of the module. During Test 1, DBA concentrations averaged 76 ppm in the upper loop and 330 ppm in the lower loop.

Test 2 was conducted on November 5 by raising the flue gas velocity to the maximum fan capacity. The measured velocity was 10.1 ft/s for Test 2. At this higher velocity with the same operating pH and similar DBA concentrations (72 ppm upper loop average, 290 ppm lower loop average), the average SO_2 removal efficiency decreased to 89.7%. The lower loop removal averaged less than 2% for this test. The outlet SO_2 concentrations measured by TECo's on-line analyzer were about 27% lower than Radian's Method 6 traverse results in Test 2.

Following Test 2, the upper loop pH set point was gradually increased overnight to the maximum level that could be maintained without limestone blinding. Test 3 was completed during the morning of November 6 at a pH of 6.2 in the upper loop with the normal flue gas velocity. Test 4 was completed the same day at the maximum flue gas velocity. It was intended to conduct Tests 3 and 4 at the same high pH set point, but when the flue gas velocity was increased for Test 4, the pH set point had to be lowered to 6.0 to avoid limestone blinding due to the higher rate of SO_2 removal.

The overall SO_2 removal efficiency for Test 3 at the high pH and normal velocity increased to 97.5% compared to 94.5% at the normal pH and velocity (Test 1). DBA concentrations for Test 3 averaged about 50 ppm in the upper loop and 350 ppm in the lower loop. In Test 4, at the high velocity and high pH, SO_2 removal averaged 93.6% with DBA at 83 ppm in the upper loop and 320 ppm in the lower loop compared to 89.7% at the normal pH and high velocity (Test 2).

The DBA concentrations were increased for Test 5. This two-day test was started on November 8 but was not completed until November 12 because of a brief boiler outage to repair a tube leak. For Test 5, the flue gas velocity was returned to the nominal 7.5 ft/s level, and the upper loop pH was returned to 5.8. DBA concentrations averaged about 200 ppm in the upper loop and 740 ppm in the lower loop during Test 5. Overall SO_2 removal increased to an average of 97.4% at these conditions. Slurry samples for settling tests were obtained during Test 5 as during Test 1, the two-day test at the low DBA level.

Tests 6, 7, and 8 were conducted at conditions corresponding to those of Tests 2, 3, and 4, except that the DBA concentrations were maintained at the moderate level. Following Test 8, the DBA concentrations were again increased for the next group, Tests 9 through 13. Tests 9, 10, 12, and 13 followed the same approach as the test groups at the low and moderate DBA levels. During Test 11, the spare upper loop slurry pump was activated to examine the effect of increasing L/G on SO_2 removal efficiency. The final two parametric tests, 14 and 15, were completed at the fourth and highest level of DBA concentration.

The effect of increasing DBA concentration on SO_2 removal efficiency at the various test conditions is discussed below.

<u>Performance Correlations</u>. Figure 4 is a plot of NTU vs. DBA concentration for the quench section of the dual-loop module. In this figure, data for tests at different gas velocities are indicated by different data point symbols. Least-squares linear correlations for the data at the two different flue gas velocities are also shown on the graph. It is evident from this plot that the scatter in the quench SO_2 removal data that was seen during the baseline tests was also exhibited by the parametric test results. There are two likely contributions to the data scatter. First, the quench section SO_2 removal was based on a single-point sample which may not have been representative of the actual average flue gas concentration leaving the quench section. Second, for the low levels of SO_2

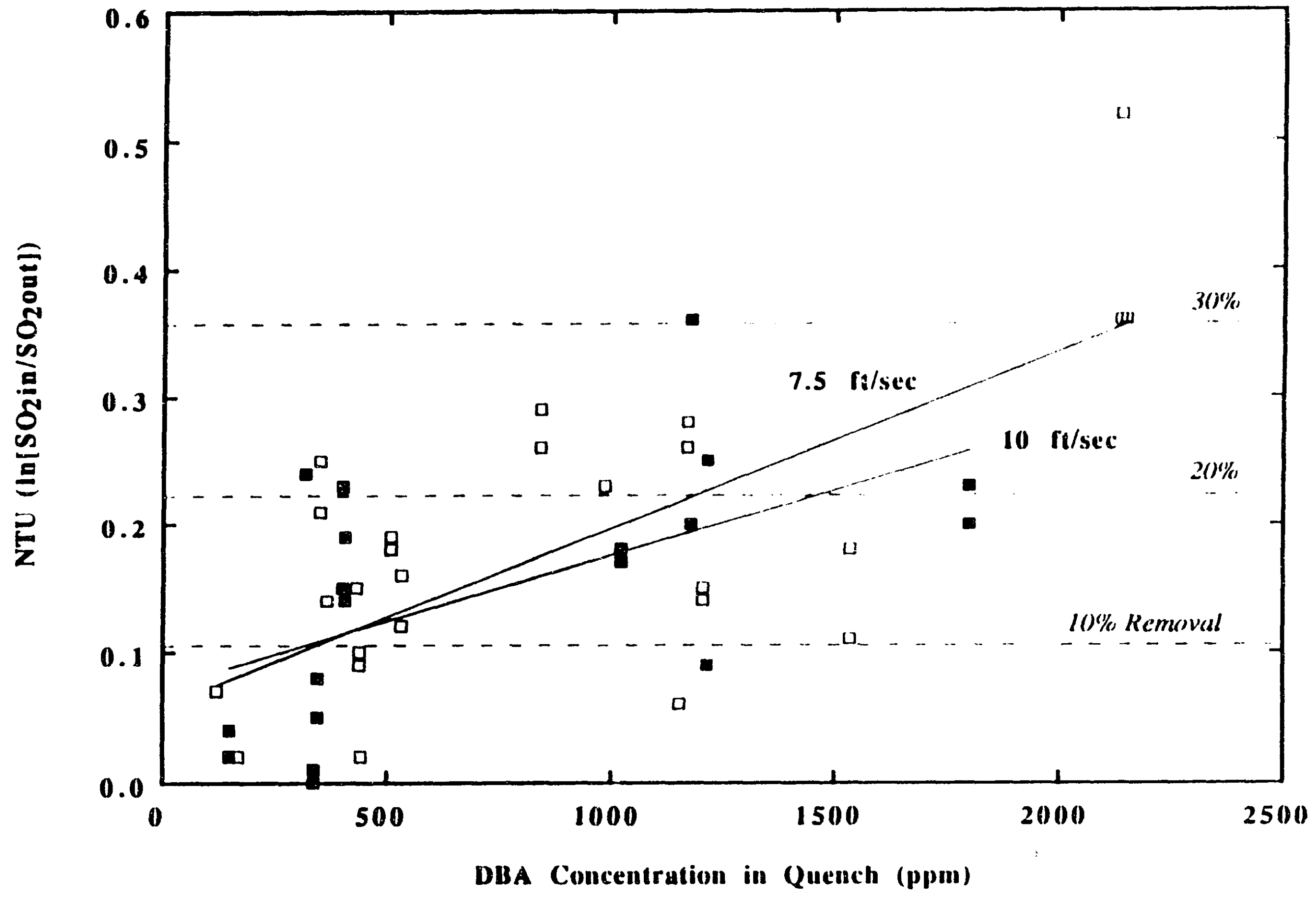


Figure 4. Quench NTU vs. DBA Concentration

removal seen in the quench section, relatively small errors in the measured flue gas SO_2 concentrations will result in large errors in the calculated values for quench section SO_2 removal.

The data in Figure 4 show that the quench section NTU did not exceed 0.3 for most of the tests at all levels of DBA concentration. This result is similar to that seen during the baseline tests. It shows that lowering the pH set point in the quench section from the normal 4.2 level that was used in the baseline tests to 3.8 for the parametric tests was effective in preventing high SO_2 removal in the quench section over the range of DBA concentrations tested. The effectiveness of DBA as a buffer is greatly reduced at pH levels less than 4 because most of the proton-accepting capacity of the DBA ions in solution is already depleted at this pH.

Because the quench section NTU represents at most 10% of the overall NTU for the module, overall performance can be approximately correlated with absorber slurry pH and DBA concentration. Figure 5 is a plot of overall module NTU vs. absorber DBA concentration at the normal and high levels of slurry pH for tests conducted at 7.5 ft/s scrubber gas velocity. Figure 6 is a similar plot for the tests at 10 ft/s gas velocity. In this plot, the data from Test 11 with three absorber feed pumps operating have been designated by different symbols so that the effect of absorber slurry flow rate on NTU can be illustrated. The lines shown on these plots are least-square linear correlations. Because the tests were not always conducted at these exact velocities, the results shown in the figures have been adjusted to 7.5 and 10 ft/s by assuming that the NTU is inversely proportional to the gas velocity (see Eq. 1).

In Figure 5, the overall NTU for the module operating at 7.5 ft/s is essentially linear with absorber DBA concentration from the lowest level to the mid-range concentration. The results for tests with a high absorber pH lie about 0.5 to 0.7 NTU above those for the tests at normal pH. This effect of absorber pH on overall NTU is similar in magnitude to that observed for the baseline tests. These trends indicate that, for this

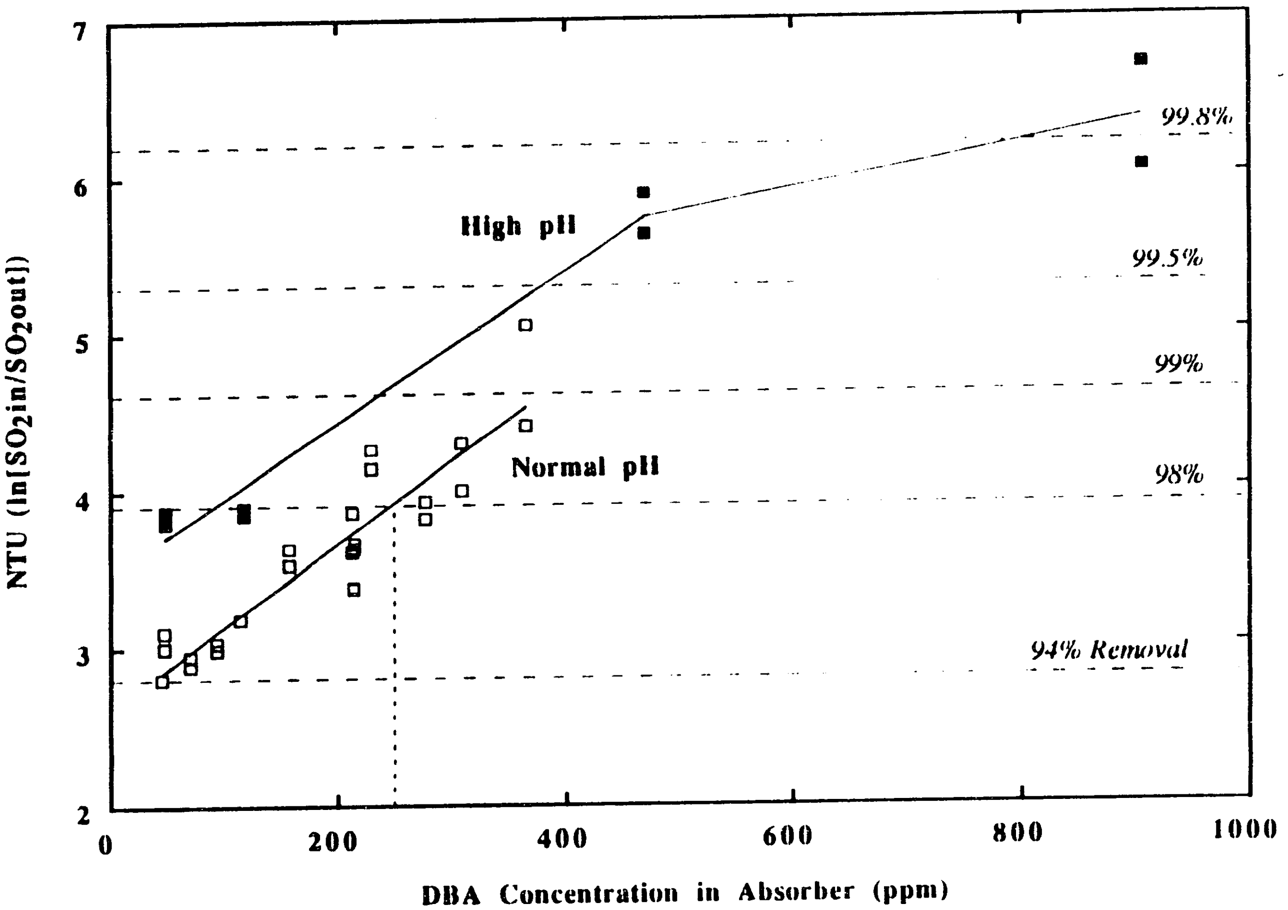


Figure 5. Overall NTU vs. Absorber DBA Concentration (7.5 ft/s)

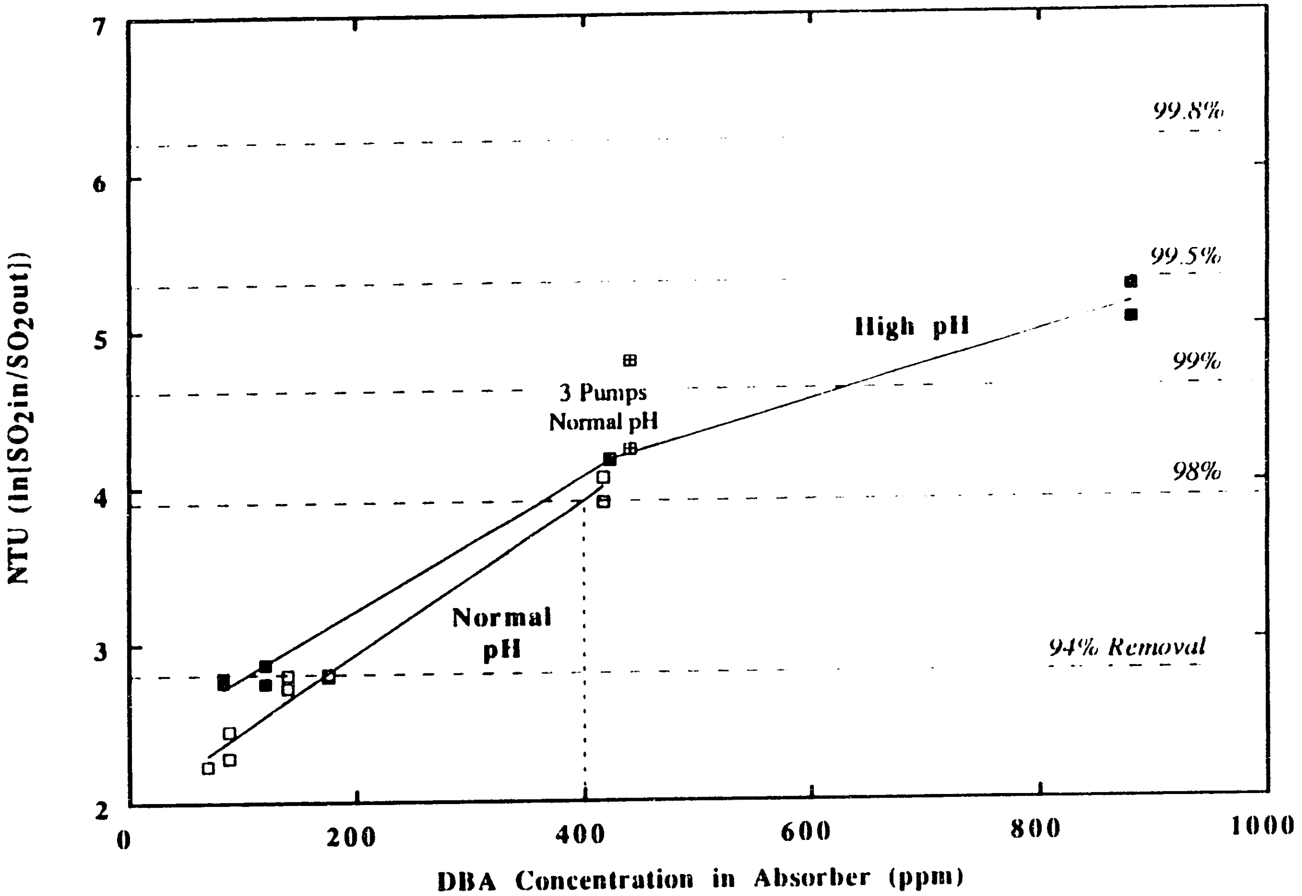


Figure 6. Overall NTU vs. Absorber DBA Concentration (10 ft/s)

range of DBA concentrations and pH, the mass transfer capability of the module has not yet approached the gas-film-limited level.

The results for Test 14, at the highest DBA level and high pH, lie significantly below the level that would be indicated by extrapolating the correlation from the lower DBA levels. This trend is expected based on the form of Eqs. 1 and 2. As the DBA concentration is increased to very high levels, the product of k_l and ϕ becomes large, and the overall mass transfer rate approaches the gas-film-limited rate (i.e., $1/K \approx 1/k_g$). The observation that this occurs at a very high SO_2 removal efficiency of 99.84% (NTU = 6.4) for the TECo scrubber module at only 900 ppm DBA indicates that this absorber configuration is a good gas/liquid contactor. The spray tower absorber at EPRI's High Sulfur Test Center, for example, reached a maximum SO_2 removal efficiency of only 96.6% (NTU = 3.38) at 5000 ppm DBA with an L/G comparable to that of the absorber section of the TECo scrubber.

In Figure 6, the results for the tests at high velocity (10 ft/s) show trends similar to those observed for the normal velocity tests. The difference in performance between the normal pH tests and high pH tests is less for the high velocity tests. This is primarily because the pH increase was less than for the low velocity tests, to avoid limestone blinding. Comparing NTU at the same pH and DBA levels, the increase in gas velocity from 7.5 (Figure 5) to 10 ft/s (Figure 6) decreased NTU by about 20% to 25% as expected based on Eq. 1. This decrease in NTU with increasing velocity is similar in magnitude to that seen in the baseline tests.

In Figure 6, the results for Test 11 with three absorber slurry pumps average about 7% higher than the results with two pumps operating. With three pumps operating, the measured slurry spray rate to the absorber increased from 28,700 to 30,500 gpm or 6%. Therefore, the increase in mass transfer capability is roughly proportional to the slurry flow rate. This effect is consistent with the results of the baseline tests and with data from EPRI's HSTC pilot unit for which NTU was found to be directly proportional to slurry spray rate at constant pH and gas velocity.

Slurry Flow Rate Measurement Results. Slurry flow rate measurements were repeated at various locations during the parametric tests to confirm that flow rates had not changed since the baseline test measurements. Results of these measurements are summarized in Table 9 and compared to the previous measurements.

The total flow to the upper loop was measured on the main vertical header leading to the upper loop. At this location, the total slurry flow with two pumps operating averaged 29,700 gpm for the baseline test measurements compared to 27,200 for the parametric test measurement, a difference of about 8%. The slurry flow to the upper loop was also estimated by measuring the flow downstream of the individual slurry pump discharges. The combined flow of two operating upper loop pumps averaged 26,700 gpm for the baseline tests compared to 29,200 gpm for the parametric tests. Because the sum of the pump discharge flows was higher for the parametric tests while the main AFT header flow was lower, the differences can probably be attributed to variation in the flow instrument itself rather than the slurry flow rates. There was no significant difference in the pump discharge pressures for the baseline versus parametric tests.

With three upper loop pumps operating, the combined flow averaged 34,600 gpm for the baseline tests and 30,500 gpm for the parametric tests. The three-pump discharge pressures were slightly higher during the parametric tests. The increase in mass transfer observed during the parametric tests with three pumps operating was much less than that seen during the baseline tests. This result indicates that the measured difference in flows between the baseline and parametric tests with three pumps operating may be significant.

Quench slurry flow measurements were made with each of the two quench slurry pumps operating alone. The parametric test flow rates were 9100 gpm for the B1

Table 9

Comparison of Baseline and Parametric Slurry Flow Rate Measurements

Location		Average Flow Rate (gpm)		Discharge Pressure (psig)	
		Baseline	Parametric	Baseline	Parametric
Main AFT Header (Two Pumps)		29,700	27,200		
Pump Discharge (Two Pumps)	B1	13,950	14,400	31	32
	B2	12,750	Not Operating	30	
	B3	Not Operating	14,800		31
Pump Discharge (Three Pumps)	B1	11,100	10,200	36	37
	B2	11,100	10,200	30[*]	42[*]
	B3	12,400	10,100	36	37
Quench Header (One Pump)	B1	10,300	9,100	23	21
	B2	Not Operating	9,400		

[*] This pressure gauge did not appear to be operating normally.

quench pump and 9400 gpm for the B2 quench pump. These compare to 10,300 gpm measured for the baseline tests. This difference in quench slurry flow rate would not be expected to affect the SO_2 removal performance significantly.

Process Data. Process data for the parametric tests are being transferred by TECo personnel from magnetic tape storage to diskette for transmittal to Radian. The data have recently been received by Radian, but have not yet been tabulated to be included in this report.

Slurry Sample Chemical Analysis Results. Slurry samples for DBA and the Method 6 impinger analyses for sulfate were given the highest priority in the Radian laboratory. These results were included in Table 8. The remaining solids and liquids analyses will be completed in January 1993, and will be reported in the Technical Note for the TECo tests.

3.2.4 Steady-State DBA Consumption Test

The cost effectiveness of using additives to enhance SO_2 removal is dependent primarily on the consumption rate of the additive. To provide a good measurement of additive consumption at this site, a long-term DBA consumption test was performed on the entire FGD system at TECo's Big Bend Station. For this test, DBA was fed to the absorbers of each of the three operating modules.

Consumption of DBA was determined by performing a DBA mass balance on the FGD system. This required monitoring of DBA addition, blowdown, and inventory levels. As of this report date, only field DBA analyses were available for calculation of the consumption rate. The results presented here are estimates only. The Technical Note for this site will contain results based on DBA analyses from Radian's Austin FGD laboratory.

Test Description. Following the completion of the parametric tests, steady-state DBA feed rates required to obtain 98% SO_2 removal were estimated using the system material balance model. The quench and absorber section reaction tanks for Modules C and D were spiked to their estimated steady-state levels, and DBA addition was started to the absorber loop reaction tanks for Modules B, C, and D, at the estimated steady-state feed rate. DBA feed was accomplished using the same pumping apparatus as in the parametric test.

The system was allowed to approach steady state for 24 hours at full load. The first inventory was then conducted, marking the beginning of the test. The AFT feed rates were adjusted about twice a day to keep absorber loop reaction tank concentrations in the 300 to 400 ppm range. This was particularly difficult as the plant was cycling to lower loads during the night hours. Figure 7 shows module absorber loop feed (reaction) tank concentrations and unit load over the course of the test. The Unit 4 boiler was operated at 90% to 100% load during the day and at 50% to 60% load during night hours. The load periods are identified in Figure 7.

DBA inventories were measured once each day, with each measurement consisting of recording all tank levels, gauging the DBA tanker level, recording limestone and blowdown totalizer readings, and pulling samples from each system vessel. Inventory points are indicated on Figure 8. Originally, seven inventories were to be taken. The beginning, middle, and final inventory samples were to be analyzed in Radian's Austin FGD laboratory. A boiler tube leak resulted in the shutdown of Unit 4, however, and only five inventories were conducted. The consumption test was to last 150 hours, but the boiler tube failure forced the premature end of the test at the 90-hour point.

Sample Collection and Analysis. Samples were collected to determine the FGD system DBA inventory and to determine DBA solution losses. System DBA concentrations were monitored on site daily using a buffer capacity titration (Method S2,

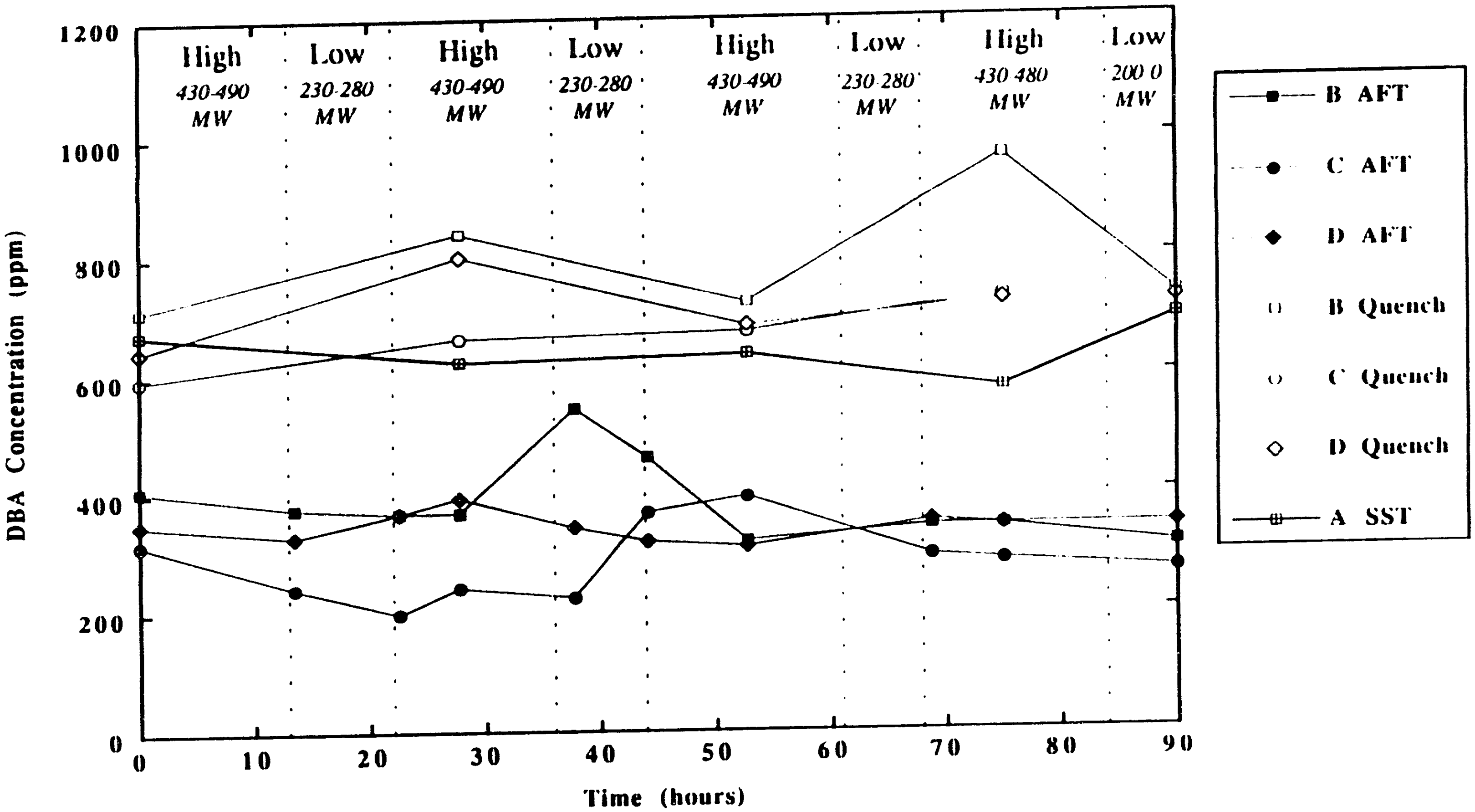


Figure 7. Absorber Feed Tank (AFT), Quench and "A" Sludge Surge Tank (SST) DBA Concentrations

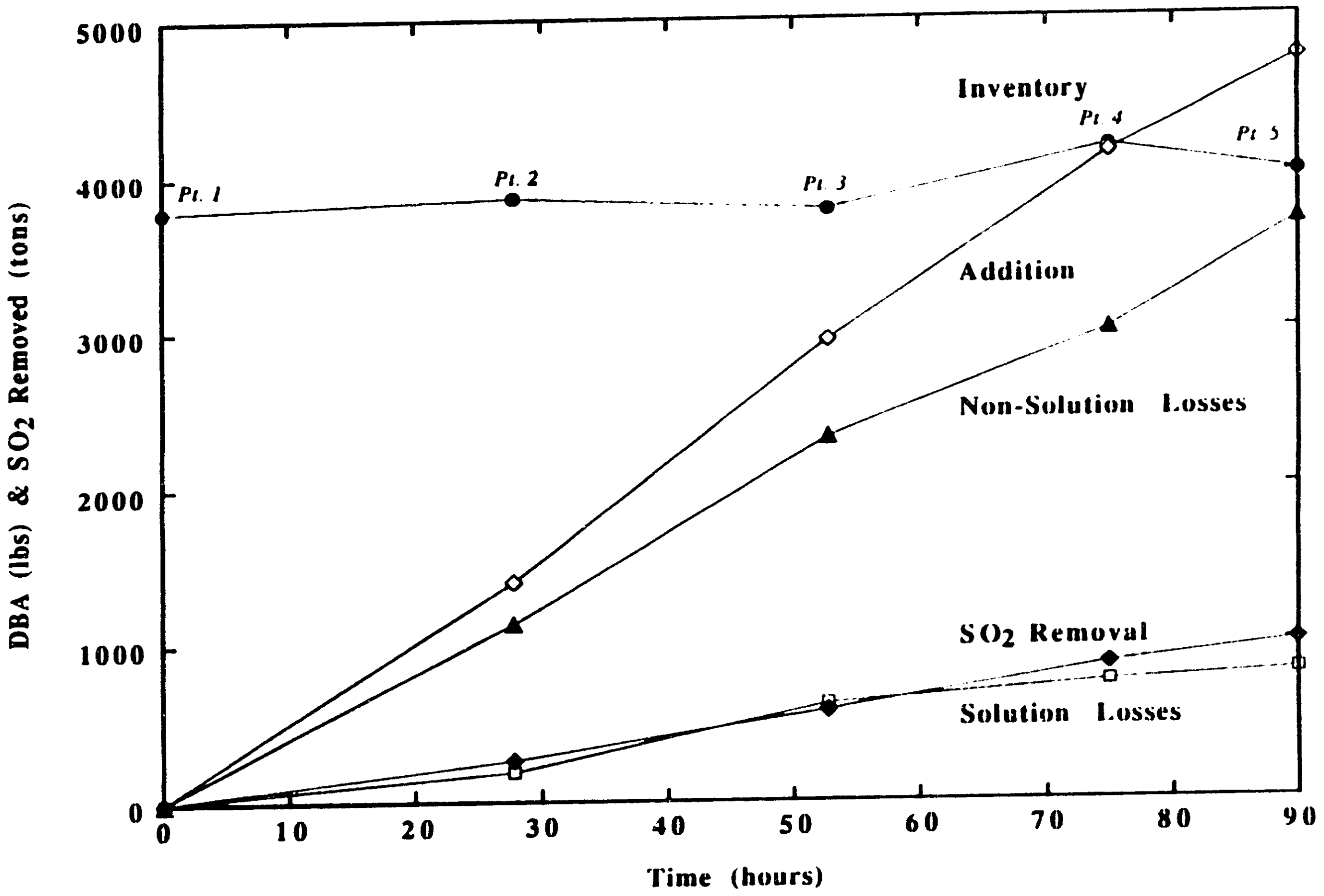


Figure 8. System DBA Mass Balance (Totalized)

EPRI FGD Chemistry and Analytical Handbook, Vol. 2). The buffer capacity measurements were used to determine DBA concentration using a DBA standard curve prepared during the parametric tests. Since the "background" liquor buffering capacity had to be estimated for many of the vessels, the titration method was more useful for tracking concentration changes than for accurately measuring the DBA concentration in ppm.

Samples collected during inventories 1, 4, and 5 are being analyzed in Radian's Austin FGD laboratory. Slurry samples will be analyzed for solids content and slurry liquor samples for DBA components by ion chromatography exclusion (ICE). Filter cake gypsum solids samples are being analyzed for DBA in both the liquid and solid phases. A DBA sample from the tanker will also be analyzed for DBA components.

Results of the slurry liquor DBA analyses and solids content analyses for the consumption test samples are not yet available. Both of these results are required to conduct an accurate DBA consumption calculation. DBA concentrations were estimated on site by measuring the buffer capacity of the liquor, as described above. For this report, these results have been corrected to some extent, using a linear regression of on-site buffer capacity titration results vs. ICE results for the parametric test samples, which have been analyzed. The solids contents of the slurry in the various FGD system vessels were estimated on site when calculating DBA inventories.

When the results of all on-site analyses are completed, the DBA consumption rate calculations will be repeated with the more accurate concentration data.

Consumption Calculation Methodology. The summation of the following terms represents the gross loss of DBA from TECo's FGD system:

1) Solution losses (DBA lost in the blowdown liquor and in liquor adhering to the filter cake). Since filter cake is washed to reduce chloride by a factor of 10, cake losses are expected to be negligible.

Also neglected are minor blowdown losses, such as overflow splashed from the absorber feed tanks.

2) Degradation losses, resulting from DBA participating in reactions which change the chemical structure, such that the reaction products do not contribute to the buffering capacity of the scrubber liquor.

3) Losses resulting from the coprecipitation of DBA into the calcium sulfate crystal structure. Based on previous High Sulfur Test Center data, coprecipitation losses are expected to be negligible for a forced-oxidation process.

4) Losses due to the evaporation of DBA from the system. Based on experience at the High Sulfur Test Center, these losses are also considered to be negligible, as the vapor pressures of DBA components are very low.

The sum of losses 2, 3, and 4 is normally termed "nonsolution losses." Since coprecipitation and vaporization losses are considered negligible, the nonsolution loss rate should be nearly equal to the degradation rate.

Given the assumptions described above, the following form of the system mass balance gives the instantaneous nonsolution loss (degradation) rate:

$$\text{Nonsolution Loss Rate} = \frac{d(\text{Addition})}{dt} - \frac{d(\text{Blowdown})}{dt} - \frac{d(\text{Inventory})}{dt} \qquad (3)$$

Obviously, not enough data were taken to determine instantaneous loss rates during the test period. Instead, the average nonsolution loss rate for a specific test period was estimated using the following equation:

$$\text{Average Nonsolution Loss Rate Over Period } t = \frac{(\text{Addition})_{\text{Total}}}{\Delta t} - \frac{(\text{Blowdown})_{\text{Total}}}{\Delta t} - \frac{(I_t - I_0)}{\Delta t} \quad (4)$$

where: I represents the system DBA inventory.

The DBA addition term was obtained by measuring the change in the DBA tanker level. The DBA blowdown term was obtained by multiplying the total blowdown (read from a flow meter totalizer) by the arithmetic average of the DBA concentrations correlating with the totalizer readings. The following equation was used:

$$\frac{(\text{Blowdown})_{\text{Total}}}{\Delta t} = \frac{\sum_{i=m}^{n} \left[(\text{Tot Read})_i - (\text{Tot Read})_{i-1} \right] \left[C_{DBA.i} + C_{DBA.i-1} \right]}{2t} \quad (5)$$

where the Totalizer Reading (Tot Read) is converted to mass units and C_{DBA} represents the DBA concentration. Figure 6 shows a total DBA mass balance over the course of the test.

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 was estimated by monitoring limestone consumption. A utilization of 99% was used based on the previous test measurements. Total SO_2 removal, calculated from limestone consumption, is also shown on Figure 8.

Results. The average and interim overall DBA consumption rates are presented in Table 10. Also presented are the average AFT and quench DBA concentrations and the average unit load calculated for each consumption rate. Since the time required in the field to gather an inventory data set was approximately 1 to 1.5 hours, the

Table 10

Results of the DBA Consumption Test

Inventory Period	Time (hrs)	Average Load (MW, approximate)	Average AFT DBA Conc. (ppm)	Average Quench DBA Conc. (ppm)	DBA Nonsolution Loss (lb/hr)	DBA Non-solution Loss (lb/ton of SO_2 removed)
Inventory 1 - Inventory 2	28	410	330	710	41	4.3
Inventory 2 - Inventory 3	25	410	360	730	47	3.8
Inventory 3 - Inventory 4	22	410	330	750	30	2.3
Inventory 4 - Inventory 5	15	370	310	770	47	5.1
Inventory 1 - Inventory 5	90	410	340	730	41	3.7

interim consumption rates are likely less accurate than the overall average. The estimated overall average DBA nonsolution loss rate was 3.7 lb/ton SO_2 removed.

Table 11 presents estimated SO_2 removal efficiencies during the consumption test. Approximate module pH set points are also shown, as is the estimated fraction of the total gas flow received by each tower (estimated by vane position).

As noted in the discussion of Baseline results, Module C had previously shown poor SO_2 removal performance. The data in Table 11 demonstrate the lower SO_2 removal efficiency achieved by this module. At full unit load, even with Module C treating a reduced percentage of the total flue gas flow (25% rather than 33%), it did not achieve a high SO_2 removal efficiency. At low unit load, Module C did achieve a high SO_2 removal efficiency. However, at the low load condition, and with the biasing of flue gas flow among the three modules in operation, Module C was operating at only approximately 40% to 45% of the normal flue gas velocity.

Also note that at SO_2 concentrations less than approximately 100 ppm, corresponding to about 96% SO_2 removal, the TECO outlet SO_2 analyzer typically indicated higher SO_2 levels than were determined by EPA Method 6. No Method 6 runs were performed during the consumption tests. Based on previous Method 6 results, though, the actual SO_2 removal levels for Module B at full load and for all three modules at low unit load were probably higher than the levels of 97% to 98% indicated in the table.

DBA Consumption in Waste Handling Area. DBA degradation is thought to occur mainly in the presence of oxidation reactions (such as sulfite oxidation) that occur in the absorber system. At the conclusion of the parametric tests, TECo operating personnel switched out the sludge surge tank (SST) vessels in the waste handling area. The sludge in SST "A," which contained a high DBA concentration following the last parametric test was left idle (not dewatered) during the consumption test, offering the opportunity to determine if DBA degrades during the long residence of slurry in the

Table 11

FGD System Removal Efficiency During Consumption Test

Module	AFT pH	Quench pH	90% to 100% Load SO_2 Removal	50% to 60% Load SO_2 Removal	Estimated Gas Flow
B	5.6	3.7	97.0	97.9	40%
C	5.5	3.7	94.4	98.0	25%
D	5.6	4.0	91.3	97.1	35%
Average			94.4	97.7	

NOTE: pH values are averages estimated from field pH readings. SO_2 removal was estimated from TECo Outlet meters from at least four points during each load period.

waste-handling portion of the FGD system. At the time of the first sample (inventory 1), the tank had been idle approximately 40 hours. Figure 7 shows the DBA concentration in SST "A" over the period of the long-term test. Based on field results, it appears that no DBA degradation occurred in the idle tank. A DBA component analysis (by ICE) will be performed on samples taken from this vessel to confirm this conclusion.

3.3 Hoosier Energy Merom Station - Sodium Formate Consumption Tests

This subsection summarizes preliminary results from the sodium formate consumption tests performed at Hoosier Energy's Merom Station Unit 1 FGD system. Performance data and process data obtained at the site are presented and discussed below. The off-site analyses being performed at Radian Corporation's Austin, Texas laboratories have not yet been completed.

The objectives of the tests were to obtain full-scale sodium formate consumption data, to determine the economic viability of sodium formate addition to enhance system SO_2 removal performance, and to obtain process data suitable for validating the additive consumption calculations in EPRI's FGDPRISM computer model. Baseline and parametric testing, and dibasic acid (DBA) consumption tests have already been performed at Merom Station (Unit 2) under another contract and will be included in the Topical Report for this site, but will not be addressed in this report.

3.3.1 Summary

The test series consisted of a one-day baseline test and two consumption tests (one seven-day and one five-day). During the baseline test, the average SO_2 removal was 90.2% with four modules in service. Absorber feed pH values ranged from 5.7 (Module A) to 5.9 (Modules B, C, D). Due to problems with one of three Unit 1 coal mills after the baseline test was completed, the maximum load for the unit dropped to 325 MW. Therefore, only three modules were kept in service for the two consumption tests to allow full-load gas flow to each absorber in service. The average SO_2 removal for the first consumption test was 93.4%, at an average absorber pH of 5.80 and an average absorber formate ion concentration of 2640 ppm. During the second consumption test, the average formate concentration was increased to 3500 ppm, and the pH was increased to an average of 6.08 for the three modules. At these conditions, the FGD system average SO_2 removal increased to 95.6%.

3.3.2 Test Approach

System Description. Merom Station is a coal-fired facility consisting of two units, each with a maximum generating capacity of 535 MW. Each unit has four L-shaped, cocurrent, packed-tower absorbers with the reaction tanks located in the bottom of the absorbers. The vertical portion of the tower contains three levels of packing in a 26'-7" x 23'-4" cross-section. The packing has an open-grid design with a specific surface area of approximately 13.7 ft^2/ft^3. To inhibit oxidation, an elemental sulfur emulsion is added to the system. Figure 9 is a process diagram for one module at Merom Station.

Test Plan. All tests were conducted on Unit 1 because only three modules were available for service on Unit 2 as a result of a recent fire. However, as mentioned above in the summary, most of the testing on Unit 2 involved operation with only three modules in service, because of unit load restrictions.

A one-day baseline test was conducted to characterize the system performance under normal operating conditions. During the test, sets of diluted filtrate (DF) slurry liquor samples were collected from Modules A and C, as were slurry samples for solids analysis and settling tests. Liquor samples were also taken from the Unit 1 and Unit 2 thickener overflows and Unit 2 Module A to determine the background buffer capacity of the system. The background buffer capacity is used to correct the results of buffer capacity titrations conducted to determine liquor formate concentration on site.

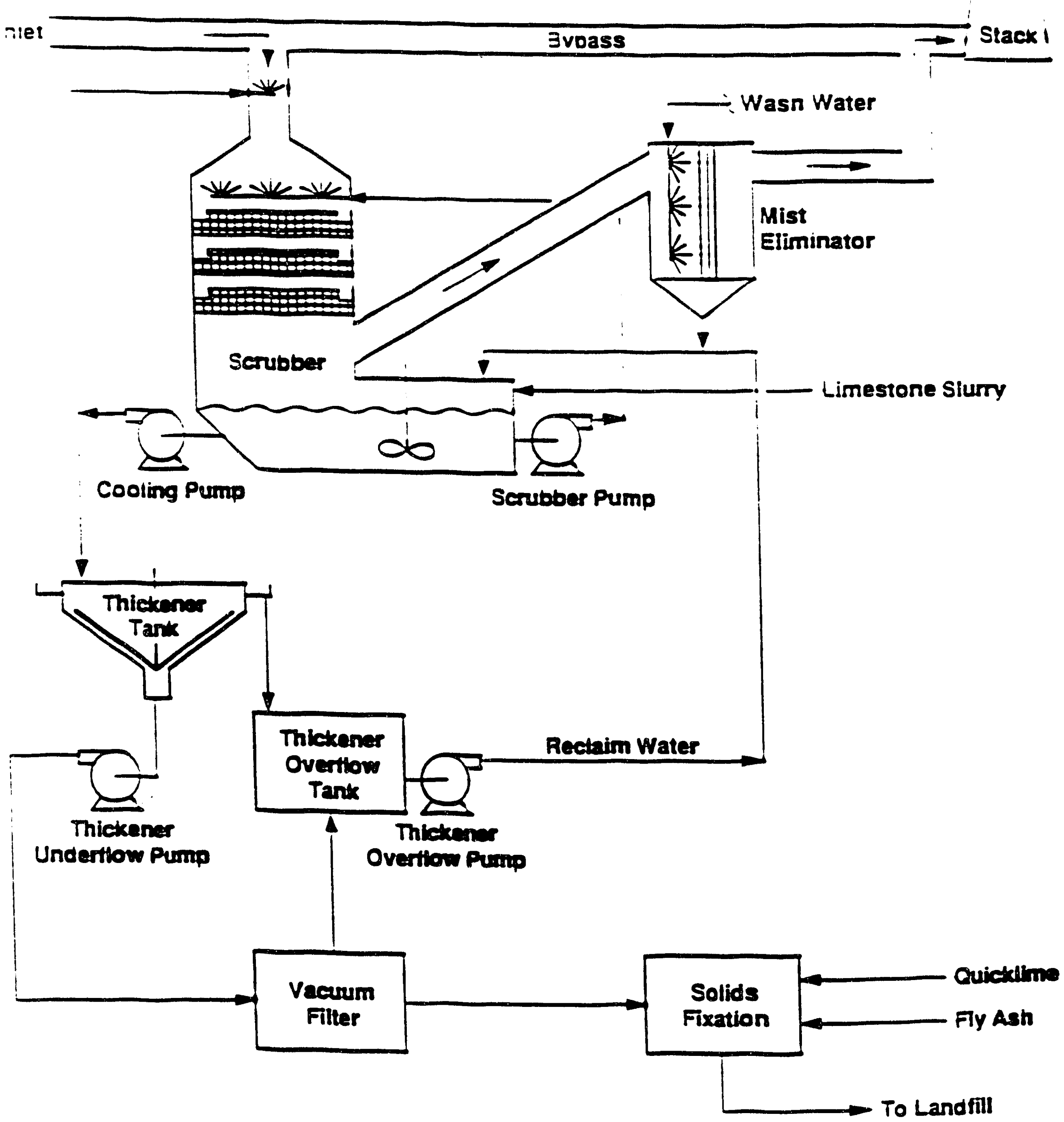


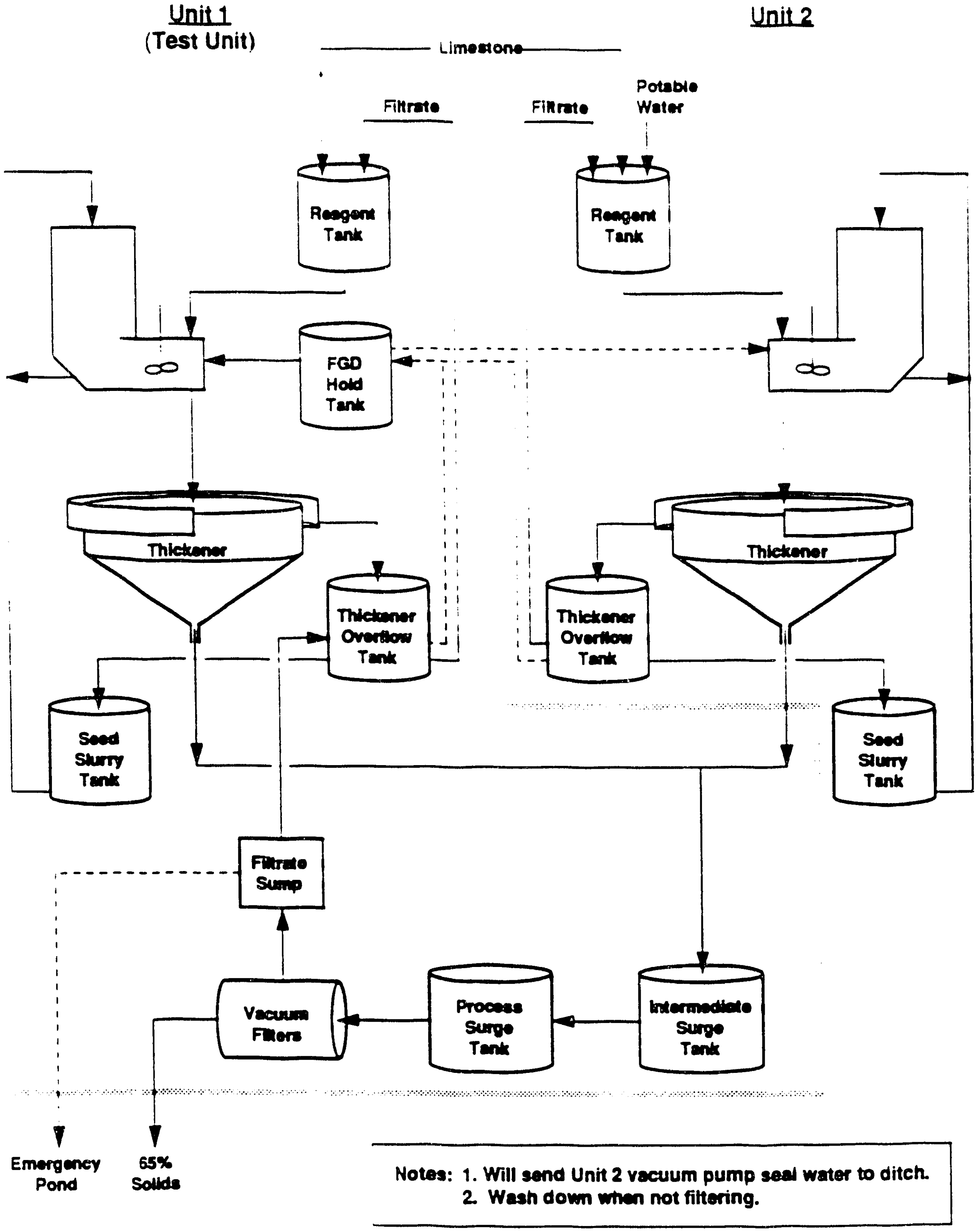
Figure 9. Process Diagram of Hoosier Energy's Merom Station FGD System

This is an approximate method, but serves to help control the sodium formate addition rate.

Following the baseline test, the slurry and liquor flows in Unit 1 were isolated from those for Unit 2 to reduce losses of sodium formate to the other unit. All filtrate from the solids dewatering system was returned only to Unit 1, so the main solution loss from the system was with the moisture in the solids disposed. The method used to isolating Unit 1 from Unit 2 is shown in Figure 10. On occasion, however, the liquor inventory in Unit 1 needed to be reduced, so the FGD hold tank was valved to blow down liquor to Unit 2 Module A. This occurred twice during testing. A portable flow meter located on the piping recorded the volume of slurry released to Unit 2. This record and the daily analysis of the formate concentration in the FGD hold tank allowed an estimate of the sodium formate loss to Unit 2. After isolating the unit, two entire sodium formate tankers (approximately 4500 gallons of 40% sodium formate solution in each) were emptied into the Unit 1 thickener, and one tanker was emptied into the Unit 1 limestone classifier to spike the system formate concentration to the desired value of 2000 to 2500 ppm. Then, sodium formate solution was continuously added to the classifier to maintain the desired sodium formate concentration in the absorber slurry liquor.

The two consumption tests that followed were to be run at or near full load on Unit 1. However, as mentioned previously, due to the shutdown of one of the Unit 1 coal mills, the maximum sustainable load on Unit 1 was limited to 325 MW. To simulate full load operation of the absorbers as closely as possible, only three modules were left in service for both consumption tests.

The objective of the first test was to achieve 95% SO_2 removal at the normal operating pH, through the addition of sodium formate. For the second consumption test, the sodium formate level was to be held constant and the pH increased to achieve 98% SO_2 removal. However, for both tests the test-average system SO_2 removal levels fell somewhat short of the targets.



Notes: 1. Will send Unit 2 vacuum pump seal water to ditch.
2. Wash down when not filtering.

Figure 10. FGD System Configuration for Formate Consumption Test

During each of these tests, three sodium formate inventories were taken by determining the formate levels at the following locations:

- Reaction tanks for the operating modules (1A, 1B, and 1D);
- Limestone slurry tank (LS);
- Intermediate surge tank (IST);
- Process surge tank (PST);
- Thickener overflow (TO);
- Thickener underflow (TU); and
- FGD hold tank (FGD).

Two formate samples were taken from each location. One was analyzed on site by buffer capacity titration, and the other was sent to Radian's laboratories in Austin for formate ion analysis by ion chromatography. The specific gravity and weight percent solids of the slurry in each vessel were determined on site. Settling tests were performed on solids taken from one or both modules during each inventory. The chemistry of Modules A and D was characterized by taking sets of dilute filtrate samples to be analyzed in Austin. Gas samples were taken during the consumption tests to determine the formic acid vapor losses from the unit. These were shipped to Radian's laboratories in Austin for analysis.

In addition to the six inventories, slurry liquor samples from the module reaction tanks and four other tanks (LS, PST, FGD, TO) were analyzed on a daily basis for buffer capacity to track the formate concentrations in the system. Sodium formate addition was adjusted accordingly to maintain the desired concentration. A settling test was also performed on slurry samples from one of the modules each day. Other process data were collected daily from the FGD control room computer, including tank levels, module slurry pH, inlet SO_2 concentration, outlet SO_2 concentration, unit load, fresh limestone to each absorber, and % O_2 in the stack.

3.3.3 Results

Process Data. Table 12 contains the daily average Unit 1 load, SO_2 inlet concentration, SO_2 removal, module pH, formate concentration, and thickener unit area (results of solids settling tests) measured during the test period. During the baseline testing on November 11, the unit maintained a steady load of 475 MW and achieved an average SO_2 removal of 90.2%. These SO_2 removal results are based on Merom Station continuous emissions monitor readings. The Module A slurry pH was 5.66 when measured with a portable pH meter, while the Modules B and D slurry pH values were approximately 5.9. The on-line pH meters indicated pH values of 5.5 for Module A and 5.65 for Modules B and D. This difference is addressed further below. The pH values are not daily averages but are instantaneous measurements made during sampling episodes.

Also shown in Table 12 are the daily load and SO_2 averages for the two consumption tests. Prior to taking Inventory 1 samples on November 12, the maximum load dropped to 325 MW and remained in that range until the second consumption test ended on November 23. As shown in the table, daily SO_2 removal averages ranged from 92.3% to 95.2% for the first consumption test. pH values ranged from 5.50 to 5.90 in Module A, 5.73 to 5.90 in Module B, and 5.68 to 5.91 in Module D. Formate concentrations based on on-site buffer capacity titrations are also shown for each module. On days when no inventory was taken, typically only two modules were sampled. On November 13, problems with the sodium formate tanker and pump were experienced, and no formate samples were taken from the absorber modules. Formate concentrations varied between the modules, and as Table 12 illustrates, the concentrations steadily increased until November 17, then decreased on November 18.

The daily average SO_2 removal for the second consumption test ranged from 94.9% to 96.3%, and module pH values ranged from 5.98 to 6.10 for Module A, 5.99 to 6.15 for Module B, and 6.02 to 6.17 for Module D. The formate concentrations in the modules again increased during this test and varied between the modules each day.

Table 12

Summary of Daily Averages

Day	Unit Load (MW)			SO_2 Inlet (ppm)	SO_2 Removal (%)	Module pH			Formate Concentration (ppm)			Unit Area for 30 wt.% Solids	
	Minimum	Maximum	Average			A	B	D	A	B	D	(ft²/ton/day)	Module Sampled
Baseline													
11/11	473	475	474	2773	90.2	5.66	5.92	5.91	0	0	0	9.2	A
Consumption 1													
11/12	228	326	307	2760	95.2	5.90	6.00	5.91	2180	2206	2516	8.2	A
11/13	202	328	293	2591	93.8	--	--	--	--	--	--	--	--
11/14	303	325	309	2337	92.2	5.59	5.78	5.68	2464	2528	2645	6.8	A
11/15	303	329	306	1928	92.2	5.63	5.73	5.73	2722	--	2967	9.1	A
11/16	304	333	318	2279	93.2	5.80	5.86	--	3199	3264	--	--	--
11/17	302	333	319	2456	93.9	5.50	--	5.71	3573	--	3599	--	
11/18	323	326	324	2576	93.5	5.76	5.90	5.88	3083	3031	3070	11.5	A
Consumption 2													
11/19	323	326	325	2441	95.0	6.04	6.15	6.13	2890	2967	3109	14.0	A
11/20	321	325	324	2569	95.7	6.07	6.14	--	3135	3083	--	10.6	B
11/21	323	326	324	2693	96.3	6.10	6.11	6.17	3186	3135	3457	8.0	D
11/22	323	330	325	2730	95.9	6.06	6.02	6.02	3406	--	3315	9.1	A
11/23	299	330	323	2491	94.9	5.98	5.99	6.03	4218	3999	4618	13.0	A

Concentrations were roughly 3000 ppm on November 19 and increased to over 4000 ppm by November 23.

The last two columns of Table 12 are results from the settling tests performed on site. The thickener unit area required to achieve a 30 wt.% solids underflow, expressed in ft^2 per ton of solids per day, is reported along with the module from which the slurry sample was taken. The baseline unit area was approximately 9 ft^2/ton/day. The solids settling rates were not significantly enhanced or deteriorated by the addition of sodium formate to the system.

Inventory Results. Tables 13, 14, and 15 summarize the results of the on-site buffer capacity tests for Inventories 1, 2, and 3, respectively. These tables show that the concentration of formate throughout the system increased during the first consumption test. Concentrations in the modules averaged 2300 ppm during the first inventory, but increased to slightly over 3000 ppm by Inventory 3.

After Inventory 1 on November 12, the metering pump being used to add sodium formate solution to the system stopped operating and was replaced. The new pump had no flow control, so a system of 1 hour on/1 hour off was instituted until November 14. Then, a bypass was added around the pump to allow a greater range of sodium formate solution flow rate, and the pump was operated continuously. Due to the lack of close control over the sodium formate solution flow rate for most of this period, the formate concentrations throughout the system were higher at Inventory 2. Although not noted in Table 14, the pH values measured during Inventory 2 were lower than previous values due to a limestone slurry shortage on November 14.

Formate samples taken the evening of November 16 and the morning of November 17 indicated a slightly higher formate concentration than desired, so Inventory 3 was delayed one day to allow formate levels to decrease. On the morning of November 17, the FGD hold tank was dumped to Unit 2 for approximately 20 minutes. The

Table 13

Summary of Inventory 1 (11/12/92)

Sample Location	Tank Capacity (gal)	Tank Mult (gal/ft)	Tank Level (ft)	Actual Tank Volume (gal)	On-Site Formate Conc. (ppm)	Specific Gravity	% Solids	Formate at Sample Location (lbs)
Absorbers								
A Module	159,100	8,056	16.3	131,300	2,180	1.08	13.6	2,229
B Module	159,100	8,056	16.4	132,100	2,206	1.07	12.9	2,266
D Module	159,100	8,056	16.4	132,100	2,516	1.09	14.0	2,600
Average					2,301			
Thickener (#1)	1,166,100				2,097	1.08	15.0	18,733
LS Tank (#1)	212,080	8,483	22.1	187,500	4,192	1.21	27.7	5,736
TO Tank (#1)	66,000	8,250	6.1	50,300	2,116	1.01	0.0	897
IST	375,800	9,400	15.0	141,000	1,122	1.26	33.9	1,100
PST	375,800	9,400	19.0	178,600	1,045	1.24	32.9	1,296
Filter Cake					1,045		72.0	
FGD Hold Tank	175,000	5,646	11.0	62,100	1,574	1.00	0.1	815
Seed Slurry Tank	25,400	1,411	12	16,900	2,116	1.01	0.0	302
TOTAL								35,974

Table 14

Summary of Inventory 2 (11/14/92)

Sample Location	Tank Capacity (gal)	Tank Mult (gal/ft)	Tank Level (ft)	Actual Tank Volume (gal)	On-Site Formate Conc. (ppm)	Specific Gravity	% Solids	Formate at Sample Location (lbs)
Absorbers								
A Module	159,100	8,056	16.4	132,100	2,464	1.10	15.0	2,540
B Module	159,100	8,056	16.4	132,100	2,528	1.10	14.9	2,611
D Module	159,100	8,056	16.4	132,000	2,645	1.10	15.4	2,712
Average					2,546			
Thickener (#1)	1,166,100				2,238	1.10	15.0	20,363
LS Tank (#1)	212,080	8,483	16.3	138,300	3,651	1.18	26.8	3,640
TO Tank (#1)	66,000	8,250	5.6	46,200	2,270	1.00	0.0	875
IST	375,800	9,400	7.5	70,500	1,458	1.23	31.0	728
PST	375,800	9,400	18.9	177,700	1,419	1.23	31.1	1,782
Filter Cake					1,419		77.1	
FGD Hold Tank	175,000	5,646	8.3	46,900	1,393	1.00	0.0	545
Seed Slurry Tank	25,400	1,411	12.04	17,000	2,270	1.00	0.0	322
TOTAL								36,117

Table 15

Summary of Inventory 3 (11/18/92)

Sample Location	Tank Capacity (gal)	Tank Mult (gal/ft)	Tank Level (ft)	Actual Tank Volume (gal)	On-Site Formate Conc. (ppm)	Specific Gravity	% Solids	Formate at Sample Location (lbs)
Absorbers								
A Module	159,100	8,056	16.6	133,700	3,083	1.07	11.4	3,262
B Module	159,100	8,056	16.9	136,100	3,031	1.06	10.7	3,260
D Module	159,100	8,056	17.2	138,600	3,070	1.06	10.6	3,364
Average					3,061			
Thickener (#1)	1,166,100				2,948	1.06	15.0	25,847
LS Tank (#1)	212,080	8,483	22.4	190,000	3,960	1.24	30.3	5,430
TO Tank (#1)	66,000	8,250	5.8	47,900	3,057	1.00	0.1	1,220
IST	375,800	9,400	7.0	65,800	1,367	1.20	27.7	651
PST	375,800	9,400	16.7	157,000	1,187	1.19	26.8	1,354
Filter Cake					1,187		73.0	
FGD Hold Tank	175,000	5,646	10.0	56,500	2,219	1.00	0.0	1,045
Seed Slurry Tank	25,400	1,411	14.1	19,900	3,057	1.00	0.0	507
TOTAL								45,941

estimated loss of sodium formate was 536 pounds. Inventory 3 was taken on the morning of November 18. The concentrations throughout the system still remained significantly higher than in previous inventories. On-site analysis of liquor samples from the Unit 2 thickener overflow and Unit 2 Module A yielded formate concentrations of 530 and 1300 ppm, respectively. Duplicate samples were sent to Austin for analysis.

Near the end of Inventory 3 (12:00 pm on November 18), the torque on the Unit 1 thickener rake increased abruptly. The rake was raised, but the problem persisted. Sodium formate addition was stopped until the next day, when a mechanical check of the thickener revealed that a belt on one of the drives had broken. The belt was replaced, and the thickener was placed back on line with no torque problems at approximately 1:00 p.m.

The pH set point for the modules was increased to 5.8 to start the second consumption test. Tables 16, 17, and 18 summarize the data from Inventories 4, 5, and 6, respectively. Similar to the first consumption test, formate concentrations increased significantly during the testing. Concentrations in the absorber modules were roughly 3000 ppm for Inventory 4, 3260 ppm for Inventory 5, and 4280 ppm for Inventory 6.

The plant operated smoothly from November 19 to 22, when the level in the FGD hold tank was lowered again for approximately 50 minutes. The portable flow meter recorded 37,600 gallons of liquor lost to Unit 2, or 1,144 lbs of sodium formate based on the FGD hold tank formate concentration.

However, on-site buffer capacity titrations performed on Unit 2 samples from November 23 showed less sodium formate in Unit 2 than during previous inventories. The blowdown of 1,144 lbs of sodium formate from Unit 1 should have significantly increased the indicated formate level in the Unit 2 FGD liquors. Table 19 summarizes the sodium formate concentrations in Unit 2 during Inventories 3 through 6. These concentrations assume that the measured increase in buffer capacity over baseline levels was

Table 16

Summary of Inventory 4 (11/19/92)

Sample Location	Tank Capacity (gal)	Tank Mult (gal/ft)	Tank Level (ft)	Actual Tank Volume (gal)	On-Site Formate Conc. (ppm)	Specific Gravity	% Solids	Formate at Sample Location (lbs)
Absorbers								
A Module	159,100	8,056	16.6	133,700	2,890	1.09	14.4	3,009
B Module	159,100	8,056	16.6	133,700	2,967	1.09	14.1	3,099
D Module	159,100	8,056	17.6	141,800	3,109	1.10	15.5	3,419
Average					2,989			
Thickener (#1)	1,166,100				2,858	1.09	15.0	25,767
LS Tank (#1)	212,080	8,483	21.8	184,900	3,019	1.25	32.2	3,948
TO Tank (#1)	66,000	8,250	5.2	42,900	2,877	1.00	0.0	1,030
IST	375,800	9,400	13.3	125,000	1,987	1.23	31.5	1,747
PST	375,800	9,400	12.6	118,400	1,767	1.19	26.6	1,525
Filter Cake					1,767		73.8	
FGD Hold Tank	175,000	5,646	3.0	16,900	1,948	1.00	0.0	275
Seed Slurry Tank	25,400	1,411	12.7	17,900	2,877	1.00	0.0	430
TOTAL								44,250

Table 17

Summary of Inventory 5 (11/21/92)

Sample Location	Tank Capacity (gal)	Tank Mult (gal/ft)	Tank Level (ft)	Actual Tank Volume (gal)	On-Site Formate Conc. (ppm)	Specific Gravity	% Solids	Formate at Sample Location (lbs)
Absorbers								
A Module	159,100	8,056	17.2	138,600	3,186	1.11	16.3	3,423
B Module	159,100	8,056	17.6	141,800	3,135	1.10	14.7	3,480
D Module	159,100	8,056	16.8	135,300	3,457	1.13	19.0	3,574
Average					3,259			
Thickener (#1)	1,166,100				3,096	1.11	15.0	28,425
LS Tank (#1)	212,080	8,483	22.0	186,600	3,496	1.25	31.1	4,691
TO Tank (#1)	66,000	8,250	5.6	46,200	3,109	1.00	0.0	1,198
IST	375,800	9,400	7.8	73,300	1,742	1.24	31.2	909
PST	375,800	9,400	30.9	290,500	1,458	1.24	40.9	2,592
Filter Cake					1,458		70.2	
FGD Hold Tank	175,000	5,646	13.4	75,700	2,116	1.01	0.0	1,349
Seed Slurry Tank	25,400	1,411	13.5	19,000	3,109	1.00	0.0	494
TOTAL								50,135

Table 18

Summary of Inventory 6 (11/23/92)

Sample Location	Tank Capacity (gal)	Tank Mult (gal/ft)	Tank Level (ft)	Actual Tank Volume (gal)	On-Site Formate Conc. (ppm)	Specific Gravity	% Solids	Formate at Sample Location (lbs)
Absorbers								
A Module	159,100	8,056	17.0	136,900	4,218	1.06	10.5	4,573
B Module	159,100	8,056	16.6	133,700	3,999	1.08	13.0	4,193
D Module	159,100	8,056	17.0	136,900	4,618	1.07	10.5	5,054
Average					4,278			
Thickener (#1)	1,166,100				3,445	1.07	11.3	31,817
LS Tank (#1)	212,080	8,483	22.1	187,500	6,656	1.22	28.8	9,045
TO Tank (#1)	66,000	8,250	6.2	51,200	3,496	1.00	0.0	1,492
IST	375,800	9,400	17.5	164,500	1,883	1.28	36.2	2,111
PST	375,800	9,400	13.3	125,000	1,522	1.26	33.9	1,322
Filter Cake					1,522		71.3	
FGD Hold Tank	175,000	5,646	8.9	50,200	2,683	1.00	0.0	1,125
Seed Slurry Tank	25,400	1,411	13.5	19,000	3,496	1.00	0.0	556
TOTAL								61,288

Table 19

Summary of Unit 2 Formate Concentrations

Inventory	Formate Concentration (ppm)			
	Thickener Overflow	Module A	Module B	Module C
3	529	1303	--	--
4	606	735	942	606
5	451	322	413	400
6	374	323	374	426

due only to the presence of sodium formate. Because the indicated levels in Unit 2 liquors are relatively low, undetected changes in baseline liquor buffering capacity, due to minor system chemistry variations, could measurably affect the indicated formate concentrations in these liquors. Off-site analyses to be conducted in January will provide a direct measure of sodium formate ion concentration, and may better reflect the additions sodium formate added to the Unit 2 FGD system on November 22.

Late on November 22, a broken water main caused a well water shortage. Limestone slurry production was temporarily stopped, and the Unit 1 scrubbers were taken out of service for approximately 1 hour. This time period was not included in the daily average SO_2 removal. The fourth sodium formate tanker was emptied overnight, and the fifth tanker hooked up to the addition pump. The level in this tanker dropped significantly overnight (20 inches or 2036 gallons of solution in 11 hours), indicating that the sodium formate solution feed rate to the Unit 1 FGD system was higher than planned. Formate samples taken the morning of November 23 showed higher concentrations than did previous inventories, so the final inventory was delayed until mid-afternoon to allow the formate level to decrease. However, the concentrations throughout the system were still extremely high during Inventory 6 as shown in Table 18.

Consumption Results. Consumption data are summarized in Table 20. The consumption rate during the entire first test was 27.1 pounds of NaCOOH per ton of SO_2 removed and dropped to 8.4 pounds per ton of SO_2 removed during the second consumption test. The consumption rates between each of the inventories are also shown in the table. The pounds of sodium formate added to the system were based on the amount of sodium formate pumped from the tanker between the inventories. The losses from the system have not yet been accurately quantified. The two losses from the FGD hold tank to Unit 2 mentioned earlier were based on the on-site analyses of formate in the FGD tank, and must be verified by formate analyses performed in Austin. The losses indicated in Table 20 are based on the on-site buffer capacity titrations.

Table 20

Summary of Sodium Formate Consumption

Time Period	NaCOOH Added (lbs)	Losses to Unit 2 (lbs)	Accumulation in System (lbs)	SO_2 Removed (tons)	Consumption (lbs of NaCOOH/tons of SO_2 Removed)
Consumption Test 1:					
Inventory 1 to Inventory 2	14,764		216	378	38.5
Inventory 2 to Inventory 3	30,722	536	14,845	723	21.2
Inventory 1 to Inventory 3	45,486	536	15,061	1,101	27.1
Consumption Test 2:					
Inventory 4 to Inventory 5	12,326		8,893	409	8.4
Inventory 5 to Inventory 6	22,071	1,144	16,853	490	8.3
Inventory 4 to Inventory 6	34,397	1,144	25,746	899	8.4

Other losses from the system were the moisture leaving with the filter cake and the formate contained in the solids. Filter cake analyses for each of the inventories are being performed in Austin but have not been completed yet, so these losses have not been determined. Vaporization losses were also evaluated and are addressed below. The accumulation in the system is the change in total pounds of sodium formate accounted for in the system from inventory to inventory. The tons of SO_2 removed are based on combustion calculations, and on the on-line SO_2 and unit load data. The consumption rate was calculated by subtracting the indicated losses and accumulations from the pounds added and dividing by the tons of SO_2 removed.

Module Chemistry. Analyses of the diluted filtrate samples taken to characterize the absorber module chemistry have not been completed. Also, limestone utilization and percent sulfite oxidation values have not been determined, so no comparison of these values for the baseline and consumption tests can be made. The pH in the modules was measured with a portable pH meter intermittently during all tests. The pH measured was consistently higher than that read by the on-line monitors. During the baseline testing, the portable meter measured pH values of 5.66 to 5.9, while the on-line monitors measured 5.5 to 5.65. This difference was seen throughout the consumption tests until Inventory 6 (November 23). The on-line pH meters had been calibrated by Merom personnel several times during the test period, but on this morning, the on-line meters were specifically calibrated to read values similar to the portable meter. Because the on-line meters control the limestone addition to the modules, the pH set point was increased to account for the new calibration to maintain the actual module pH values in the target range for the second consumption test (6.0 to 6.1). The pH values measured during Inventory 6 later that afternoon ranged from 5.96 to 6.02 and were in close agreement with the on-line meters.

Gas Sampling. Five gas samples were taken during the first consumption test, and three were taken during the second consumption test, to determine sodium formate vapor losses from the system. Gas was pulled through a sample probe and four cold impingers by a Thomas pump, then sent through a dry gas meter to measure the volume of gas being sampled. The maximum flow achievable was only 0.25 to 0.30 ft^3/min. The first two impingers contained approximately 150 mL each of 0.5 M sodium hydroxide to remove the formate from the passing gas stream. The third impinger was empty. The fourth impinger contained silica gel to remove any remaining water from the gas before it passed through the dry gas meter. After the sampling event, the solutions from the impingers and the probe rinse were shipped to the Austin FGD laboratory for formate analyses. These have not been completed yet. Table 21 summarizes the gas sampling events and the modules that were tested.

3.3.4 Conclusions

As stated previously, all results presented here are based on analyses conducted on site. Results from more accurate analyses being conducted by the Austin FGD laboratory should become available during January 1993, and will be used to verify the levels of formate measured on-site during the inventories. Additive losses in the outlet gas and with the solids will be quantified at that time. In addition, the losses to Unit 2 will be further investigated when the liquor samples taken from Unit 2 are analyzed for formate.

The addition of 2640 ppm sodium formate (an average of the first three inventories) increased SO_2 removal from 90.2% in the baseline test to 93.4%. The combination of adding sodium formate (an average of 3500 ppm for the last three inventories) and raising the slurry pH from 5.8 to 6.1 increased the average removal to 95.6%. The estimated formate consumption rates for consumption tests 1 and 2 were 27.1 and 8.4 pounds of sodium formate per ton of SO_2 removed, respectively. The major difference between the two tests was that the second test was conducted at a higher pH. This may have decreased consumption so markedly by significantly reducing vaporization losses. As more detailed analytical results become available, it may be possible to verify this theory.

Table 21

Summary of Gas Sampling Events

Date	Module Sampled
11-15-92	1A
11-16-92	1B
11-16-92	1B*
11-17-92	1D
11-18-92	1A
11-20-92	1B
11-21-92	1D
11-23-92	1A

*Tested same module using a longer probe and a different pump.

4.0 PLANS FOR THE NEXT REPORTING PERIOD

During the next quarter, the Technical Notes for both the Tampa Electric Big Bend site and the Hoosier Energy Merom site should be completed. The Technical Notes will present and discuss the results of the tests conducted at these sites, as well as the results of FGDPRISM modeling and economic evaluations that address the ability to achieve high SO_2 removal efficiencies with these FGD systems.

Also during the next quarter, baseline testing should be completed at the Pirkey site (Option II). If the testing is completed in February, as anticipated, a Test Report will be submitted to DOE in mid- to late March. Parametric testing at this site is currently scheduled to be conducted during March and April. The results of this testing will probably not be available until the second quarter of calendar year 1993.

We anticipate that Option III, for testing at PSI Energy's Gibson Station, will be exercised during the quarter. However, it will be the subsequent quarter (April through June 1993) before any testing is conducted.

END

DATE
FILMED

5 / 24 / 93