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INNOVATIVE CLEAN COAL TECHNOLOGY (ICCT)

**DEMONSTRATION OF SELECTIVE CATALYTIC REDUCTION (SCR)
TECHNOLOGY FOR THE CONTROL OF NITROGEN OXIDE (NO_x)
EMISSIONS FROM HIGH-SULFUR COAL-FIRED BOILERS**

**Technical Progress Report
Third & Fourth Quarters 1994**

November 1995

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Section 1

SUMMARY

The objective of this project is to demonstrate and evaluate commercially available selective catalytic reduction (SCR) catalysts from U.S., Japanese, and European catalyst suppliers on a high-sulfur U.S. coal-fired boiler. SCR is a post-combustion nitrogen oxide (NO_x) control technology that involves injecting ammonia into the flue gas generated from coal combustion in an electric utility boiler. The flue gas containing ammonia is then passed through a reactor that contains a specialized catalyst. In the presence of the catalyst, the ammonia reacts with NO_x to form nitrogen and water vapor.

Although SCR is widely practiced in Japan and Europe on gas-, oil-, and low-sulfur coal-fired boilers, there are several technical uncertainties associated with applying SCR to U.S. coals. These uncertainties include:

- (1) potential catalyst deactivation due to poisoning by trace metal species present in U.S. coals that are not present in other fuels.
- (2) performance of the technology and effects on the balance-of-plant equipment in the presence of high amounts of SO_2 and SO_3 .
- (3) performance of a wide variety of SCR catalyst compositions, geometries, and methods of manufacture under typical high-sulfur coal-fired utility operating conditions.

These uncertainties are being explored by operating a series of small-scale SCR reactors and simultaneously exposing different SCR catalysts to flue gas derived from the combustion of high sulfur U.S. coal.

The demonstration is being performed at Gulf Power Company's Plant Crist Unit No. 5 (75 MW capacity) near Pensacola, Florida. The project is funded by the U.S. Department of Energy (DOE), Southern Company Services, Inc. (SCS on behalf of the entire Southern electric system), the Electric Power Research Institute (EPRI), and Ontario Hydro. SCS is the participant responsible for managing all aspects of this project.

The project is being conducted in the following three phases:

- Phase I - Permitting, Environmental Monitoring Plan and Preliminary Engineering
- Phase II - Detailed Design Engineering and Construction
- Phase III - Operation, Testing, Disposition and Final Report

The project is in the operation and testing phase during this reporting period. All the reactors were operated at long-term operating conditions, i.e. at an effective ammonia/NO_x stoichiometric ratio near 0.81 for 80% NO_x removal. In addition to the long-term base operating conditions, the third sequence of parametric tests was completed for reactors A - J by October 17, 1994, and the fourth parametric sequence was completed by January 18, 1995. The catalyst suppliers, assigned reactors, and the total number of operating hours with exposure to flue gas for each reactor at the end of the third and fourth quarters in 1994 are as follows:

<u>Catalyst supplier</u>	<u>Reactor designation</u>	<u>Operating hours</u>	
		<u>3rd qtr</u>	<u>4th qtr</u>
W R. Grace	A (large)	7616	9291
Nippon Shokubai	B (large)	8505	10156
Siemens	C (large)	8537	10164
W. R. Grace	D (small)	6792	8420
Cormetech	E (small)	6792	8420
Haldor Topsoe	F (small)	6792	8444
Hitachi Zosen	G (small)	3935	5586
Empty*	H (small)	--	--
Cormetech	J (small/low-dust)	2252	3831

* Reactor left empty after Engelhard withdrew from program.

Operation of the pilot facility was relatively routine during the reporting period. The following chronological listing offers a brief history of test facility operation during the period and points out operational highlights on a monthly basis.

July 1994

- Start of third parametric test sequence (June 24, 1994)
- Catalyst sampling of reactors A, C, D, F, G, J
- Electrical failures and repairs from tropical storm Alberto
- Sootblower failure on "A" Air Preheater
- Facility tour and project discussion with a Chinese Delegation for Clean Combustion Technologies

August 1994

- Pressure wash of "A" Air Preheater
- Sootblowers on "A" Air Preheater repaired
- Catalyst sampling of reactors B and E
- Status report and tour provided to plant managers of The Southern Company

September 1994

- Catalyst sampling of reactors A, C, D, F, G
- Reconfiguration of the control system to include O₂ corrections
- Status report and tour provided to representatives from Eglin Air Force Base
- Presentation of paper at DOE's Third Annual Clean Coal Technology Conference

October 1994

- Completion of third parametric test sequence
- Start fourth parametric test sequence (accelerated)
- Failure of bottom sootblower on reactor "B"
- Tube failure of host boiler requiring 3-day forced outage
- Problems noted with rotary air preheater clutches
- Catalyst sampling from reactors B, E, and J
- First bed catalyst replacement on reactor D

November 1994

- Reactor "B" sootblower repaired
- Power elements added to reactor "J" heater
- Replacement of remaining catalyst beds on reactor D

December 1994

- Completion of majority of Fourth Parametric Sequence
- Rotary air preheater clutches repaired
- Reactor "J" heaters repaired

Section 2

INTRODUCTION

The Innovative Clean Coal Technology (ICCT) Program is designed to demonstrate clean coal technologies that are capable of retrofitting or repowering existing facilities to achieve significant reduction in sulfur dioxide (SO_2) and/or nitrogen oxides (NO_x) emissions. The technologies selected for demonstration are capable of being commercialized in the 1990s and are expected to be more cost effective than current technologies.

This ICCT project is funded jointly by the U.S. Department of Energy, the Electric Power Research Institute (EPRI), Ontario Hydro, and by Southern Company Services (SCS) on behalf of the entire Southern electric system. The project's objective is to demonstrate the selective catalytic reduction (SCR) process that removes nitrogen oxides (NO_x) from the flue gas of boilers that burn U.S. high-sulfur coal. The SCR technology involves the injection of ammonia (NH_3) into the flue gas and the subsequent catalytic reduction of NO_x by NH_3 to produce molecular nitrogen (N_2) and water vapor.

A simplified flow diagram of a typical SCR installation with major equipment is shown in Figure 1. Specifically, hot flue gas leaving the economizer section of the boiler is ducted to the SCR reactor. Prior to entering the reactor, NH_3 is injected into the flue gas at a sufficient distance upstream of the reactor to provide for complete mixing of the NH_3 and flue gas. The quantity of NH_3 can be adjusted and it reacts with the NO_x from the flue gas across the catalyst bed. The flue gas leaving the catalytic reactor enters the air preheater where it transfers heat to the incoming combustion air. Provisions are sometimes made for ash removal from the bottom of the SCR reactor since some fallout of fly ash may occur. Duct work is also provided to bypass some flue gas around the economizer during periods when the boiler is operating at reduced load. This is done to maintain the temperature of the flue gas entering the catalytic reactor at the proper reaction temperature of about 700°F . The flue gas leaving the air preheater goes to the electrostatic precipitator (ESP) where fly ash is removed. The ESP is part of the existing plant and is generally unaffected by the SCR system except as higher SO_3 content affects the electrical resistivity of the fly ash or if ammonium bisulfate (NH_4HSO_4) co-precipitates with the fly ash.

Figure 1. Flow Diagram of Typical SCR Installation.

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The SCR technology is in commercial use in Japan and western Europe on gas-, oil-, and low-sulfur, coal-fired power plants. The first utility applications of SCR catalyst technology started in Japan in 1977 for oil- and gas-fired boilers and in 1979 for coal-fired boilers. As of 1986, 90 utility boilers in Japan had been equipped with SCR catalyst technology including 22 coal-fired boilers. These coal-fired boilers represent a combined capacity in excess of 6500 MWe and are typically fired with a low-ash, low-sulfur coal.

In addition to Japanese experience, several countries in western Europe (most notably Germany and Austria) have passed stringent NO_x emission regulations that have all but mandated the installation of SCR. Prior to commercial SCR installations in Germany, utility companies demonstrated several types of SCR facilities in prototype demonstration programs similar to this ICCT project. Over 50 SCR pilot plants were built and operated in western Europe. These pilot plants ranged from 19 to 6200 SCFM and provided the data base that led to commercialization of SCR technology in western Europe.

Previously completed U.S. work with the SCR process on utility boilers consists of three projects which were carried out in the late 1970s and early 1980s. One of these was carried out on a natural gas fired boiler by Southern California Edison. Another project consisted of a pilot test conducted for the EPA at Georgia Power's Plant Mitchell. This pilot plant treated a 1000 ACFM (0.5 MWe) slip stream of flue gas resulting from the combustion of low- to medium-sulfur coal. A third pilot-scale project, carried out at the Public Service Company of Colorado's Arapaho Station treated a 5000 ACFM (2.5 MWe) slip stream of flue gas resulting from the combustion of a U.S. low-sulfur coal.

Although SCR is widely practiced in Japan and Europe, there are numerous technical uncertainties associated with applying SCR to U.S. coals. These uncertainties include:

- (1) potential catalyst deactivation due to poisoning by trace metal species present in U.S. coals that are not present in other fuels.
- (2) performance of the technology and effects on the balance-of-plant equipment in the presence of high amounts of SO₂ and SO₃.
- (3) performance of a wide variety of SCR catalyst compositions, geometries and methods of manufacture under typical high-sulfur coal-fired utility operating conditions.

These uncertainties are being explored by operating a series of small-scale SCR reactors and simultaneously exposing different SCR catalysts to flue gas derived from the combustion of high sulfur U.S. coal.

The first uncertainty above is being handled by evaluating SCR catalyst performance for two years under realistic operating conditions found in U.S. pulverized coal utility boilers. The deactivation rates for the catalysts exposed to flue gas from high sulfur U.S. coal will be documented to determine accurate catalyst life, and thus, accurate process economics.

The second uncertainty above is being explored by performing parametric testing and through the installation/operation of air preheaters downstream of the larger reactors. During parametric testing, operating conditions are adjusted above and below design values to observe deNO_x performance and ammonia slip as functions of the change in operating conditions. Air preheater performance is observed to evaluate effects from SCR operation upon heat transfer, and therefore, upon boiler efficiency.

The third uncertainty is being handled by using honeycomb- and plate-type SCR catalysts from U.S., Japan and Europe of various commercial composition. Results from the tests with these catalysts expands our knowledge of performance on a variety of SCR catalysts under U.S. utility operating conditions with high-sulfur coal.

The intent of this project is to demonstrate commercial catalyst performance, proper operating conditions, and catalyst life for the SCR process. This project is also demonstrating the technical and economic viability of SCR while reducing NO_x emissions by at least 80%.

The project is being conducted at Gulf Power Company's Plant Crist Unit 5, a commercially operating 75 MW unit, located in Pensacola, Florida, on U.S. coals with a sulfur content near 3.0%. Unit 5 is a tangentially-fired, dry bottom boiler, with hot and cold side electrostatic precipitators (ESPs) for particulate control. The SCR process used in this demonstration is designed to treat a slip-stream of flue gas and features multiple reactors installed in parallel. With all reactors in operation, the maximum amount of combustion flue gas that can be treated is 17,400 standard cubic feet per minute (SCFM) which is roughly equivalent to 8.7 MWe.

The SCS facility is a slip-stream SCR test facility consisting of three 2.5 MWe (5000 SCFM) SCR reactors and six 0.20 MWe (400 SCFM) SCR reactors that operate in parallel for side-by-side

comparisons of commercially available SCR catalyst technologies obtained from suppliers throughout the world. Figure 2 presents a simplified process flow diagram for the SCR test facility. The large (2.5 MWe) SCR reactors contain commercially available SCR catalysts as offered by SCR catalyst suppliers. These reactors are coupled with small-scale air preheaters to evaluate the long-term effects of SCR reaction chemistry on air preheater deposit formation and the deposits' effects on an air preheater. The small reactors are used to test additional commercially available catalysts. This demonstration facility size is adequate to develop performance data to evaluate SCR capabilities and costs that are applicable to boilers using high-sulfur U.S. coals.

The demonstration project is organized into three phases: (1) Phase I - Permitting, Environmental Monitoring Plan and Preliminary Engineering; (2) Phase II - Detail Design Engineering and Construction; and (3) Phase III - Operation, Testing, Disposition, and Final Report. The cooperative agreement was signed June 14, 1990, and the project completion date is now projected to be at the end of 1995. The original total estimated project costs were \$15.6 million but project growth increased the expected total cost to \$23 million. The co-funders are SCS (\$10 million), DOE (\$9.4 million), EPRI (\$2.9 million) and Ontario Hydro (\$0.75 million).

Figure 2. Prototype SCR Demonstration Facility-Process Flow Diagram

Section 3

PROJECT DESCRIPTION

Within the three phases of the project, the following tasks are to be conducted to effectively demonstrate the SCR process:

Phase I - Permitting, Environmental Monitoring Plan and Preliminary Engineering

Task 1.1.1 - Prototype Plant Permitting Activities

Task 1.1.2 - Develop Environmental Monitoring Program

Task 1.1.3 - Preliminary Engineering

Task 1.1.4 - Engineering and Construction Contracts Scope Development

Task 1.1.5 - Project Management and Reporting

Phase II - Detail Design Engineering and Construction

Task 1.2.1 - Detailed Design Engineering

Task 1.2.2 - Construction

Task 1.2.3 - Operation Staff Training

Task 1.2.4 - Planning for Detailed Testing

Task 1.2.5 - Start-Up/Shakedown

Task 1.2.6 - Project Management and Reporting

Phase III - Operations, Testing, Disposition and Final Report

Task 1.3.1 - SCR Demonstration Facility Operations and Maintenance

Task 1.3.2 - Process Evaluation

Task 1.3.3 - Environmental Data Management and Reporting

Task 1.3.4 - Economic Evaluation

Task 1.3.5 - Dismantling/Disposition

Task 1.3.6 - Project Management and Reporting

Section 4

PROJECT STATUS

Progress during July - December, 1994, is summarized below for each of the on-going tasks in the Scope of Work.

PHASE III - OPERATIONS, TESTING, DISPOSITION, AND FINAL REPORT

Task 1.3.1 - SCR Demonstration Facility Operations and Maintenance

The catalyst suppliers, assigned reactors, and the total number of operating hours with exposure to flue gas for each reactor at the end of the first and second quarters in 1994 are as follows:

<u>Catalyst supplier</u>	<u>Reactor designation</u>	<u>Operating hours</u>	
		<u>3rd qtr</u>	<u>4th qtr</u>
W. R. Grace	A (large)	7616	9291
Nippon Shokubai	B (large)	8505	10156
Siemens	C (large)	8537	10164
W. R. Grace	D (small)	6792	8420
Cormetech	E (small)	6792	8420
Haldor Topsoe	F (small)	6792	8444
Hitachi Zosen	G (small)	3935	5586
Empty*	H (small)	--	--
Cormetech	J (small/low-dust)	2252	3831

* Reactor left empty after Engelhard withdrew from program (see discussion later in report).

During the third and fourth quarters of 1994, all the reactors were operated in long-term base operating conditions, i.e. at an effective ammonia/NO_x ratio near 0.81 for 80% NO_x removal. In addition to the long-term base operating conditions, the third sequence of parametric tests was completed for reactors A - J by October 17, 1994 and the fourth parametric sequence was completed by January 18, 1995.

Operation of the pilot facility was relatively routine during the reporting period. The following discussion offers a brief history of test facility operation during the period and points out

operational highlights. Following the discussion is a listing of major operational events chronicled on a monthly basis.

Operation of the test facility progressed smoothly during the reporting period allowing for two parametric sequences to be completed. Testing on the third parametric sequence began June 24, 1994 and was completed October 17, 1994. Testing on the fourth parametric sequence began October 19, 1994 and was completed January 18, 1995. Two samplings of each of the test facility catalysts were also performed during the reporting period. Several meetings and technology transfer sessions were held and are listed in the chronological history. During the third quarter, 1994, the host unit boiler was 97% operational. The pilot facility was operational 91% of the time that the host boiler was available. For the fourth quarter, 1994, the host unit boiler was 98% operational. The pilot facility was operational 93% of the time that the host boiler was available.

The first outage scheduled for this reporting period was the July 4th holiday weekend. A short outage was conducted at this time to remove catalyst samples. All catalysts were sampled with the exception of Cormetech Inc. and Nippon Shokubai America, Inc. The sampling of these catalysts was deferred until August when replacement coupons were available. All catalyst samples were sent to the respective suppliers for analysis. The sampling coupons from the Haldor Topsoe catalyst were nearly completely destroyed, leaving only enough catalyst material for a single sampling. Options were evaluated for replacement of the coupons. Erosion did appear very evident for the Grace Synox catalyst, however, catalyst sampling was performed successfully. The other catalyst samples/coupons appeared in good condition. Most catalysts appeared to be relatively free of fouling problems. Catalysts were again sampled in reactors A, C, D, F, and G on September 6 and 7 and all samples were returned for analysis to the manufacturer. Reactors B, E, and J were sampled during October to complete the round of sampling. Reactor D was inspected by the catalyst supplier during October, and the decision was made to replace the existing catalyst because of physical deterioration. The first catalyst bed was replaced with new catalyst prepared by improved production methods late in October. Some of the original catalyst bed coupons were relocated to this new catalyst bed, allowing the project to continue collecting aging information on the original catalysts. Long term aging data was also collected on the newer catalyst since all coupons replaced during the previous samplings on the original first bed were of the improved catalyst type.

Weather during the month of July created several operational problems including electronic and electrical failures from a strong lightening storm (from tropical storm Alberto) . These failures included a Bailey control processor, one of the large reactor heater controls and the air compressor controls. In addition, some small reactor heater elements failed. Repairs and replacements were made on all these items. Furthermore, continuous heavy rains created operational problems from very wet coal for the host boiler. These problems resulted in many rapid load swings, delaying some parametric testing which required steady conditions.

During the month of July the "A" air preheater experienced failure of a sootblowing control valve diaphragm in the pneumatic controller, resulting in loss of effectiveness of the sootblowing system. Within two weeks of operation, the pressure drop rapidly increased to 13" w.c. Because of the increased pressure drop and a cyclic pressure swing that developed in this air heater, a high pressure wash was performed in August to help reduce the pressure drop and eliminate the pressure swing. While the high-pressure wash improved the pressure drop of the air heater, the pressure drop did not fully return to previous levels. The gas-side pressure drops across the air heater at baseline flow (5000 SCFM) averaged about 7" w.c., 3.5" w.c., and under 3" w.c., for "A", "B", and "C" trains, respectively, between sootblowings. An inspection of the rotary air preheaters showed that the clutches on the rotary air preheater variable speed motors had deteriorated due to the much greater-than-normal usage at this facility. Replacement clutches were ordered and were installed in December.

During September some minor repairs were also made. On the "A" air preheater, the lower sootblower nozzles, which were plugged, were cleaned; a thermocouple on the air preheater upper bearing was replaced; and the screen on the sootblowing steam pressure regulator was cleaned. The reactor fans were washed. Ash build-up on the inlet vanes, fan suction housing, and fan wheels had impacted load capacity; capacity was restored after the washing. Oxygen probes and NO_x analyzers and probes were repaired.

Operations during the final quarter of 1994 progressed smoothly without any major unplanned events. The third parametric sequence was completed October 17, 1994. Testing on the fourth parametric sequence began shortly after. Additional manpower was used to supplement the normal testing staff. This allowed acceleration of the testing to insure early completion of the parametric sequence (in preparation for an extended host boiler outage in the Spring of 1995). During October the bottom sootblower on reactor B experienced a part failure and was inoperable until the replacement part arrived in November. No significant increases in pressure

drop were noted due to the inoperability of this sootblower. Problems had been experienced with the flue gas heaters for reactor J preventing the operation of this reactor at high-temperature test conditions. More power elements were added to the reactor J heaters to increase flue gas temperatures during November. Damaged stand-off tubes were also replaced at this time. December operation progressed very smoothly. Routine maintenance was performed during the month such as fan washes and sootblower repairs.

The following chronological history is a synopsis of the major events that occurred during this reporting period.

July 1994

- Start of third parametric test sequence (June 24, 1994)
- Catalyst sampling of reactors A, C, D, F, G, J
- Electrical failures and repairs from tropical storm Alberto
- Sootblower failure on "A" Air Preheater
- Facility tour and project discussion with a Chinese Delegation for Clean Combustion Technologies

August 1994

- Pressure wash of "A" Air Preheater
- Sootblowers on "A" Air Preheater repaired
- Catalyst sampling of reactors B and E
- Status report and tour provided to plant managers of The Southern Company

September 1994

- Catalyst sampling of reactors A, C, D, F, G
- Reconfiguration of the control system to include O₂ corrections
- Status report and tour provided to representatives from Eglin Air Force Base
- Presentation of paper at DOE's Third Annual Clean Coal Technology Conference

October 1994

- Completion of third parametric test sequence
- Start fourth parametric test sequence (accelerated)
- Failure of bottom sootblower on reactor "B"
- Tube failure of host boiler requiring 3-day forced outage
- Problems noted with rotary air preheater clutches
- Catalyst sampling from reactors B, E, and J
- First bed catalyst replacement on reactor D

November 1994

- Reactor "B" sootblower repaired
- Power elements added to reactor "J" heater
- Replacement of remaining catalyst beds on reactor D

December 1994

- Completion of majority of Fourth Parametric Sequence
- Rotary air preheater clutches repaired
- Reactor "J" heaters repaired

• Measurement Accuracy/Repeatability

The majority of manual measurements are made using triplicate samples. This insures the quality of the data and helps to remove operating variability from the results. Since triplicate measurements usually require several hours to complete, they also help to evaluate and insure that steady-state operation has been achieved for the particular test conditions. Each of the triplicate samples are analyzed in duplicate in the laboratory. Thus, six values are acquired for each average reported measured value. Detection limits for ammonia slip measurements are normally approximately 1 ppm with analytical repeatability to within 0.1 ppm. Intermediate ammonia detection limits are somewhat higher, namely 1 to 2 ppm with analytical repeatability to within 1 ppm. SO₂ measurements normally have detection limits of 5 ppm with analytical repeatability to

within 1% of the measured value. The SO₃ detection limits are normally 0.4 ppm with an analytical repeatability to within 0.4% of the measured value.

Task 1.3.2 - Process Evaluation

- Coal Chemistry

Coal samples were analyzed monthly for major components and certain trace elements for comparison with previous project coal analyses and with other world-wide SCR installations. The quarterly averages for July through September and October through December, yearly averages, and project-to-date averages are shown in Table 1.

- Flue Gas Composition

Several flue gas constituents are measured continuously by the gas analyzer system (described previously) at the SCR test facility inlet. Table 2 shows the constituent concentrations in terms of average values, normal high values, and normal low values over the reporting period. These quarterly values were determined using daily averages, daily highs, and daily lows during periods that the host boiler was on-line (operating at greater than 40 MWe).

Table 1. Coal Analysis Data

SCS ID No.						1993	1994	*Project
Test	Method	Units	Units	3rd Qtr. 94	4th Qtr. 94	Average	Average	Average
Moisture, Total	ASTM D 3302	% by Wt.	% by Wt.	11.46	11.86	10.45	11.16	10.84
Ash	ASTM D 3180	% by Wt.	% by Wt.	8.87	9.39	9.62	9.18	9.38
Gross Calorific Value	ASTM D 3180	Btu/lb	Btu/lb	13251	13143	13231	13267	13251
Sulfur, Total	ASTM D 3180	% by Wt.	% by Wt.	2.57	2.49	2.79	2.64	2.71
Sulfur, lb/MMBtu	ASTM D 3180	lb/MMBtu	lb/MMBtu	1.94	1.89	2.11	1.99	2.04
Carbon	ASTM D 3180	% by Wt.	% by Wt.	74.69	74.17	74.67	74.76	74.72
Hydrogen	ASTM D 3180	% by Wt.	% by Wt.	4.99	4.97	5.03	4.97	5.00
Nitrogen	ASTM D 3180	% by Wt.	% by Wt.	1.60	1.59	1.58	1.59	1.58
Oxygen	ASTM D 3180	% by Wt.	% by Wt.	7.29	7.39	6.31	6.86	6.61
Carbon, Fixed	ASTM D 3180	% by Wt.	% by Wt.	53.04	53.52	51.61	53.38	52.57
Volatile Matter	ASTM D 3180	% by Wt.	% by Wt.	38.08	37.09	38.77	37.44	38.05
Aluminum	ASTM D 3682	% by Wt.	% by Wt.	1.02	1.26	1.09	1.12	1.10
Antimony	ASTM D 3683	mg/kg	mg/kg	1.0	0.5	<1.0	<1.0	<1.0
Arsenic	Spec. Chem. Acta. 44B	mg/kg	mg/kg	2.1	4.3	3.4	2.8	3.1
Barium	ASTM D 3683	mg/kg	mg/kg	38	35	53	33	42
Beryllium	ASTM D 3683	mg/kg	mg/kg	2	3	3	3	3
Cadmium	ASTM D 3683	mg/kg	mg/kg	0.24	0.30	<1.00	<1.00	<1.00
Calcium	ASTM D 3682	% by Wt.	% by Wt.	0.22	0.24	0.26	0.22	0.24
Chlorine	ASTM D 4208	mg/kg	mg/kg	2050	2705	1294	2144	1757
Chromium	ASTM D 3683	mg/kg	mg/kg	19	19	19	21	20
Cobalt	ASTM D 3683	mg/kg	mg/kg	8	8	8	7	7
Copper	ASTM D 3683	mg/kg	mg/kg	9	11	9	9	9
Fluorine	ASTM D 3761	mg/kg	mg/kg	42	81	50	61	56
Iron	ASTM D 3682	% by Wt.	% by Wt.	1.00	1.06	1.08	1.12	1.11
Lead	Spec. Chem. Acta. 44B	mg/kg	mg/kg	11	10	12	11	12
Lithium	ASTM D 3683	mg/kg	mg/kg	7	16	7	10	9
Magnesium	ASTM D 3682	% by Wt.	% by Wt.	0.06	0.06	0.05	0.06	0.06
Manganese	ASTM D 3683	mg/kg	mg/kg	22	24	23	25	24
Mercury	ASTM D 3684	mg/kg	mg/kg	0.04	0.05	0.09	0.06	0.07
Molybdenum	ASTM D 3683	mg/kg	mg/kg	8.7	---	8.3	7.1	7.8
Nickel	ASTM D 3683	mg/kg	mg/kg	15	14	15	15	15
Phosphorus	ASTM D 3682	% by Wt.	% by Wt.	0.01	0.01	0.04	0.01	0.02
Potassium	ASTM D 3682	% by Wt.	% by Wt.	0.24	0.13	0.23	0.19	0.21
Selenium	Spec. Chem. Acta. 44B	mg/kg	mg/kg	1.6	1.9	<2.0	<2.0	<2.0
Silica	ASTM D 3682	% by Wt.	% by Wt.	2.22	2.24	2.33	2.25	2.29
Sodium	ASTM D 3682	% by Wt.	% by Wt.	0.06	0.08	0.06	0.06	0.06
Titanium	ASTM D 3682	% by Wt.	% by Wt.	0.06	0.06	0.06	0.06	0.06
Vanadium	ASTM D 3683	mg/kg	mg/kg	41	36	49	40	44
Zinc	ASTM D 3683	mg/kg	mg/kg	91	35	33	48	41

*Project life average for start-up through December 1994.

< Less Than Detection Limit.

TABLE 2. TEST FACILITY GAS CONCENTRATIONS

<u>July - September 1994</u>			
<u>Constituent</u>	<u>Average</u>	<u>High</u>	<u>Low</u>
Unit #5 Load (MW)	58	82	37
Inlet NO _x (ppm)	351	404	285
Inlet O ₂ (%)	5.3	8.2	2.3
Inlet CO ₂ (%)	14.6	17.7	11.5
Inlet CO (ppm)	12.2	97.1	0.6
Inlet SO ₂ (ppm)	1414	1699	1074

<u>October - December 1994</u>			
<u>Constituent</u>	<u>Average</u>	<u>High</u>	<u>Low</u>
Unit #5 Load (MW)	58	81	34
Inlet NO _x (ppm)	353	423	276
Inlet O ₂ (%)	5.3	8.2	2.7
Inlet CO ₂ (%)	14.8	17.7	11.2
Inlet CO (ppm)	19	88	4.4
Inlet SO ₂ (ppm)	1379	1618	1079

- Mass Concentration and Particle Size Distribution

The mass concentration and particle size distribution measurements to confirm all reactors were receiving fly ash similar in concentration and particle size to that of the fly ash in the main plant ductwork were reported in the previous quarterly progress report for April - September, 1993. Mass concentration was measured for each reactor during parametric testing. These were made for profile characterizations rather than reactor to reactor comparisons. Simultaneous measurements were not made during this reporting period. These mass concentration results are shown later under the individual catalyst/reactor performance sections.

- Fly Ash Chemistry and Resistivity

Ash mineral analyses and fly ash resistivity data were reported previously in the April - September, 1993 progress report.

- Ammonia/NO_x Ratio

During long-term baseline operation, the SCR reactors were operated to achieve near 80% NO_x reduction when calculated on a constant oxygen basis. Modifications to the control system were made to include oxygen inleakage corrections when calculating the appropriate ammonia flow rate. This greatly enhanced the ability to operate the SCR reactors very near an actual NH₃-to-NO_x ratio of 0.80 giving roughly 80% NO_x reduction when calculated on a constant oxygen basis. This is assuming, of course, that little or no NO₂ is present, resulting in an effective 1:1 NH₃-to-NO_x stoichiometry. In practice, small amounts (1-2%) of NO₂ present results in a slightly reduced NO_x reduction efficiency. Initial estimates based on literature values indicated that NO₂ concentrations may be as high as 5% of the total NO_x present. However, closer analysis of the monitoring data indicated the actual NO₂ present at the SCR facility is actually closer to 1% of the total NO_x present. In addition to long-term baseline operation, various parametric tests were performed requiring variation in the ammonia-to-NO_x ratio. During these tests, the effective ammonia-to-NO_x ratio was varied from a high of approximately 1.28 to a low of approximately 0.51. These parametric tests were conducted over relatively short periods of time and represent only a small fraction of the total reactor operating hours.

- Ammonia Distribution

Ammonia distribution within the individual SCR reactors is extremely important in controlling ammonia slip and maintaining reactor efficiency. Assuming a perfectly smooth NO_x distribution, it is desirable to maintain an ammonia distribution that is as smooth as possible. The general criteria set for the test facility is to maintain ammonia distribution to within 10% of the average. Ammonia distributions were measured during the Fourth quarter, 1993, downstream of the dummy bed on each reactor at nine equally spaced points on the large reactors and four on the small reactors. Ammonia distribution measurements indicated that all distributions were within the 10% limit with averages comparing favorably with the predicted value. Specialized tests showed that the intentional closing of ammonia injection pipes across one half of the ammonia injection grid resulted in extreme ammonia maldistributions at the entrance to the first catalyst layer.

- Flue Gas Temperature

The SCR facility is equipped with an economizer by-pass duct. This allows for high temperature flue gas extracted upstream of the host unit economizer to be mixed with flue gas extracted downstream of the host unit economizer. By adjusting the relative flows of these two components of the test facility feed gas, the temperature to the test facility can be adjusted. Under normal operation, the flue gas temperature to the test facility is maintained at 650° F. This is possible when the host unit is running at relatively high loads, however, at low unit load, the test facility inlet gas temperature often drops below 650°F even with full use of the economizer by-pass duct. Also, under some circumstances, while the host unit is operating at very high load, the feed gas to the test facility may exceed 650°F even with no economizer by-pass gas being used. The average flue gas temperature to the test facility as well as the daily high and low temperature are shown below for this reporting period. As with the previously shown gas concentration data, the data are computed using daily averages, daily highs, and daily lows, during periods of on-line host boiler operation.

Test Facility Inlet Gas Temperature (° F)

1994

<u>Date</u>	<u>Average</u>	<u>High</u>	<u>Low</u>
Jul.-Sept.	652	676	624
Oct.-Dec.	659	683	623

Each reactor is equipped with a flue gas heater which maintains strict control over the temperature of the flue gas entering the reactors. Under normal operating conditions the flue gas is maintained at 700°F at the entrance to the reactors. This requires that the gas be heated from approximately 650°F to 700°F under normal host unit operating conditions. Of course, heat loss in the system requires some additional flue gas heating over the 50°F temperature difference noted. Under parametric conditions, the flue gas temperature to the reactors is varied approximately from a low of 620°F to a high of 750°F. Under these conditions, the economizer bypass duct flow rate may be adjusted to assist the heaters in obtaining the appropriate temperature. Under high temperature parametric conditions, heat loss through the system is more

apparent, and flue gas temperatures of 780°F just downstream of the heater may be required to give 750°F at the reactor inlet. Lower temperature parametric conditions do not show as extreme a temperature loss between the heaters and the inlet to the reactors. As a result, the heater exit temperature is normally much closer to the reactor inlet gas temperature during low temperature parametric tests and normal operating conditions.

- Air Preheater Performance Data

The three large reactors of the SCR facility are each equipped with an air preheater. Reactor A is equipped with a three-layer Ljungstrom type rotary air preheater supplied by ABB Air Preheater, Inc. of Wellsville, New York. Reactor B is equipped with a two layer rotary air preheater nearly identical to the A preheater, also supplied by ABB. Reactor C is equipped with an ABB Q-pipe which is a heat pipe design utilizing toluene and naphthalene as the working fluids. The original design of the SCR facility included air preheater bypass ducting which allowed the air preheaters to be bypassed during any condition other than normal operating conditions. This was done to insure that the air preheater's long-term fouling characteristics were not skewed by extreme conditions during some of the short term parametric tests. The large reactor fan design requires relatively cool gas (less than 350°F). To accommodate this restriction, the air preheater bypass ducting was equipped with heat exchangers which were designed to cool the flue gas in place of the air preheaters. Unfortunately, the design of these by-pass heat exchangers caused immediate fouling upon use, making them unsatisfactory for the application. Consequently, the SCR facility is forced to use the three large reactor air preheaters at all times when on-line to maintain proper flue gas conditions for the large reactor fans. As a result, the air preheaters are exposed to the harsh conditions created by some of the parametric tests. However, these test periods are very short compared to the overall operating time at standard conditions, and it is assumed that overall fouling characteristics of the air preheaters are not greatly affected by the current operational requirements. Tables 3 and 4 show the average operating parameters for the three air preheaters over the reporting period shown. These values include any parametric test conditions that were performed during the specific time period.

Two series of manual tests on the facility air preheaters were conducted during the reporting period. The first series was conducted during the late-September early-October time frame. The second series was conducted in mid-December. A verbal discussion and tabular display of the results of the first series of tests is shown in appendix A-1. These tests consisted of a series of simultaneous measurements at the inlet and outlet of each of the facility air preheaters to determine sulfur dioxide, sulfur trioxide, hydrogen chloride, and ammonia concentrations.

The second series of air preheater tests conducted during this reporting period examined ash loading, ash mineralogy, and ash resistivity in addition to the concentrations of the species previously mentioned. The results of these tests are shown in Appendix A-2.

TABLE 3

AVERAGE AIR PREHEATER OPERATIONAL PARAMETERS, JUL.-SEP., 1994

<u>PARAMETER</u>	<u>REACTOR A</u>	<u>REACTOR B</u>	<u>REACTOR C</u>
GAS FLOW RATE (SCFM)	4982	5018	5018
AIR FLOW RATE (SCFM)	4687	4437	8035
INLET GAS TEMP. (°F)	675	667	672
EXIT GAS TEMP. (°F)	300	300	300
INLET AIR TEMP. (°F)	94	94	94
EXIT AIR TEMP. (°F)	584	575	422
GAS SIDE PRESS. DROP ("H ₂ O)	7.12	3.99	2.57
AIR SIDE PRESS. DROP ("H ₂ O)	3.21	1.84	NA
AIR/GAS DIFF. PRESS. ("H ₂ O)	0.51	0.50	NA
INLET GAS O ₂ (% WET)	5.52	6.21	6.27
EXIT GAS O ₂ (% WET)	8.21	8.69	NA

TABLE 4

AVERAGE AIR PREHEATER OPERATIONAL PARAMETERS, OCT.-DEC., 1994

<u>PARAMETER</u>	<u>REACTOR A</u>	<u>REACTOR B</u>	<u>REACTOR C</u>
GAS FLOW RATE (SCFM)	4932	5002	4939
AIR FLOW RATE (SCFM)	4009	3772	6834
INLET GAS TEMP. (°F)	675	667	673
EXIT GAS TEMP. (°F)	300	300	317
INLET AIR TEMP. (°F)	79	79	79
EXIT AIR TEMP. (°F)	592	596	423
GAS SIDE PRESS. DROP ("H ₂ O)	7.06	4.69	5.39
AIR SIDE PRESS. DROP ("H ₂ O)	2.99	1.95	NA
AIR/GAS DIFF. PRESS. ("H ₂ O)	0.52	0.51	NA
INLET GAS O ₂ (% WET)	5.45	6.38	6.14
EXIT GAS O ₂ (% WET)	8.53	9.24	NA

- Catalyst-Specific Performance Parameters

The long term NO_x reduction and parametric test results characterizing the performance for reactors A - J for this reporting period are discussed in the following sections. The parametric tests conducted during this reporting period are composed of fourteen reactor operating conditions defined by variations in the flue gas flow rate, temperature, and ammonia-to-NO_x ratio. The test conditions for the third and fourth parametric sequences are shown in Tables 5a and 5b, respectively. The particular measurements (intermediate ammonia, slip ammonia, SO₂, SO₃, HCl, N₂O, and velocity and mass concentration profiles) are also shown in this table at the various test conditions. Although identical test conditions are indicated, the measurements were not taken simultaneously (e.g., ammonia and SO₂ data for the same conditions were not collected during the exact same test run, but rather under similar process conditions at different times).

TABLE 5a. PARAMETRIC TEST CONDITIONS (3rd Parametric Sequence)

Flue gas flow rate Large / Small reactor (KSCFM)	Flue gas temperature (°F)	NH ₃ /NO _x Ratio	Measurements
3.0 / 0.24	620	0.8	slip NH ₃
5.0 / 0.40	620	0.6	slip NH ₃
5.0 / 0.40	620	0.8	intermediate & slip NH ₃
5.0 / 0.40	620	1.0	slip NH ₃
5.0 / 0.40	700	0.6	intermediate & slip NH ₃
5.0 / 0.40	700	0.8	*Intermediate & slip NH ₃ , SO ₂ /SO ₃ , N ₂ O, HCl (gas phase only) velocity & mass concentration profile.
5.0 / 0.40	700	1.0	intermediate & slip NH ₃
5.0 / 0.40	750	0.6	slip NH ₃
5.0 / 0.40	750	0.8	intermediate & slip NH ₃
5.0 / 0.40	750	1.0	slip NH ₃
7.5 / 0.60	620	1.0	intermediate & slip NH ₃
7.5 / 0.60	700	0.6	slip NH ₃
7.5 / 0.60	700	0.8	intermediate & slip NH ₃
7.5 / 0.60	700	1.0	slip NH ₃

*Design conditions.

TABLE 5b. PARAMETRIC TEST CONDITIONS (4th Parametric Sequence)

Flue gas flow rate Large / Small reactor (KSCFM)	Flue gas temperature (°F)	NH ₃ /NO _x Ratio	Measurements
3.0 / 0.24	620	0.8	slip NH ₃
5.0 / 0.40	620	0.6	slip NH ₃
5.0 / 0.40	620	0.8	intermediate & slip NH ₃
5.0 / 0.40	620	1.0	slip NH ₃
5.0 / 0.40	700	0.6	intermediate & slip NH ₃
5.0 / 0.40	700	0.8	*Intermediate & slip NH ₃ , SO ₂ /SO ₃ HCl velocity profile
5.0 / 0.40	700	1.0	intermediate & slip NH ₃
5.0 / 0.40	750	0.6	slip NH ₃
5.0 / 0.40	750	0.8	intermediate & slip NH ₃ , SO ₂ /SO ₃
5.0 / 0.40	750	1.0	slip NH ₃
7.5 / 0.60	620	1.0	intermediate & slip NH ₃
7.5 / 0.60	700	0.6	slip NH ₃
7.5 / 0.60	700	0.8	intermediate & slip NH ₃
7.5 / 0.60	700	1.0	slip NH ₃

*Design conditions.

- Reactor Pressure Drop

Overall reactor pressure drops (inlet to outlet, including dummy layer and all catalysts) are shown in Figure 3 for reactors A - J during July - September, 1994 and in Figure 4 for reactors A - J for October - December, 1994. Both figures show that for the majority of the catalysts, the overall reactor pressure drop remained relatively constant over exposure time. This finding is encouraging and demonstrates that sootblowing and other operational procedures were effective at maintaining catalyst cleanliness. An exception to this finding, however, is the Cormetech low-dust catalyst. Due to the small pitch, particles in the flue gas stream (thought primarily to be from deposition along the duct runs and scoop upstream of the reactor) tended to block the flow channel on the screen above the catalyst. This required frequent cleaning and aggressive sootblowing. These activities are noted by the erratic nature of the pressure drop for the Cormetech low-dust catalyst. An example of this is shown in Figure 4 where cleaning of the catalyst screens resulted in a significant improvement in pressure drop over the late October, 1994 time frame. Also, the Hitachi Zosen catalyst showed relatively high pressure drops during the third quarter, 1994 prior to the catalyst sampling outage in early September. These higher

pressure drops were likely due to particulate buildup on the catalyst screens prior to the outage at which time the screens were manually cleaned.

FIGURE 3

PRESSURE DROP VS. TIME

3rd QUARTER 1994

Pressure (inch. of H₂O)

29

FIGURE 4

PRESSURE DROP VS. TIME

4th QUARTER 1994

- Reactor A

Tables 6a and 6b show the test data for intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the Grace Noxeram catalyst. All of the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in these tables as an average over the operating periods shown, i.e., for July-September and October - December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to- NO_x ratio, 5000 SCFM flow rate, and 700 °F reactor temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 6a and 6b is presented below in three sets of plots: ammonia slip versus each of flow rate, ammonia-to- NO_x ratio, and temperature. Figure 5 shows ammonia slip versus flow rate at roughly 80% NO_x reduction for the fourth parametric sequence. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. The ammonia slip is, however, relatively minor indicating the ability of the catalyst design to withstand significant increases in flow while maintaining ammonia slip limits. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases. This plot demonstrates the ability of an SCR system to follow load variations dictated by the host boiler while maintaining design specifications.

Figures 6a and 6b show ammonia slip versus ammonia-to- NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. These plots show sharp increases in ammonia slip as the ammonia-to- NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to- NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figures 7a and 7b for the third and fourth parametric sequences, respectively. Figure 7b shows

some improvement (decrease) in ammonia slip between 620 and 700°F, likely due to improvements in the kinetic reaction rate with increasing temperature. The same trend is not present in Figure 7a. However, significant measurement variability could account for this difference. Only slight improvements are noted with increasing temperature above 700°F. This may possibly be due to mass transfer limitations that have become controlling at these higher temperatures. In general, these plots demonstrate that in terms of ammonia slip, significant improvements are not realized with temperatures above 700°F. Losses in boiler efficiency would probably outweigh any improvements that may be obtained in ammonia slip by designing an SCR reactor to operate at temperatures near 750°F.

The plot for SO₂ oxidation versus flow rate at design temperature for the combination of all catalyst beds in the reactor is shown in Figure 8. Although the plot shows increasing SO₂ oxidation with increasing flow rate, this trend is not expected. Published rate equations and catalyst supplier information indicate that the general form of the plot should be linear with SO₂ oxidation decreasing with flow rate. In this case, large measurement variability of up to 0.30% SO₂ oxidation is the most probable cause for the uncharacteristic trend.

Figures 9a and 9b show SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor for the third and fourth parametric sequences, respectively. Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be more exponential with respect to temperature. The exact shape of the plots is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The general trend of increasing SO₂ oxidation is expected, however, and the plots provide a good basis for determining the potential for SO₃ formation across the SCR reactor at various operating temperatures.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at this point. For consistency with other figures, the plots of SO₂ oxidation versus flow rate are based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured during the third parametric sequence but were measured during the fourth parametric sequence near design operating conditions (700 °F, 5000 SCFM) at the reactor outlet. The mass concentration profile data are given in Figure 10 in six different units of concentration and mass emission rate. The average mass concentration was 3.87 ± 0.33 gr/dscf; and the average emission rate was 6.54 lb/MBtu.

A nine-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are presented in Figures 11a and 11b. The average gas velocity during the third sequence was 13.2 ± 1.0 ft/sec. The velocity profile was generally flat with a standard deviation of 7.6%. For the fourth sequence the average gas velocity was 12.3 ± 1.1 ft/sec. The velocity profile was again generally flat with a standard deviation of 8.9%.

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 233 ± 11 ppmv and 219 ± 13 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (1.3 ppmv, both measurements were dry at 3% O₂).¹

TABLE 6a. REACTOR A DATA (3rd Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
5000	646	3.631	348	0.786	35.3	68.4
6496	650	3.554	341	1.008	76.1	78.5
4997	705	6.103	335	0.586	19.7	52.7
5002	707	4.051	367	0.785	30.6	70.2
4998	706	7.005	338	1.050	36.8	94.1
6169	704	4.614	299	0.793	39.0	66.3
4984	756	4.428	329	0.767	31.7	67.1

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
3000	630	5.133	365	0.800	1.9
5000	630	5.133	350	0.568	1.5
5000	631	3.953	353	0.793	2.0
5003	623	5.532	278	1.014	3.5
6105	622	5.511	204	1.011	4.2
4996	707	3.265	314	0.592	1.4
5010	708	3.879	347	0.790	2.2
5007	706	6.573	291	0.975	1.6
6087	707	4.409	337	0.591	1.8
5165	703	3.090	315	0.943	2.5
6063	706	3.342	311	1.019	2.7
4991	756	4.963	399	0.561	1.7
4999	756	4.255	376	0.784	1.7
5011	755	5.496	289	0.992	1.8

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
4981	705	2.509	2020	0.802	0.2	17.0	16.8	0.83
4954	750	2.729	1959	0.906	0.2	30.8	30.6	1.56

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED (%)
JUL - SEP	4974	376	0.78	82	77

TABLE 6b. REACTOR A DATA (4th Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
5006	645	3.036	272	0.799	35.1	67.0
6590	649	2.180	272	0.943	78.2	65.5
5000	707	2.767	258	0.600	20.6	52.1
5001	705	3.416	295	0.707	23.1	62.9
5007	706	3.465	258	0.986	34.4	85.3
6100	705	2.966	347	1.000	49.5	85.7
4994	754	3.393	283	0.802	29.1	70.0

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
2995	632	2.769	275	0.804	2.0
4999	647	3.583	363	0.600	2.7
5004	651	3.077	350	0.797	4.5
5009	627	4.731	369	1.000	20.7
6516	652	2.946	295	0.999	6.6
5004	703	3.523	363	0.600	2.5
5004	705	2.894	259	0.799	3.0
5000	703	3.443	348	0.602	2.5
6206	705	3.014	326	0.601	3.0
5998	705	2.966	254	0.803	2.8
6289	704	2.475	307	0.934	1.4
4997	755	3.767	310	0.631	1.8
5001	753	2.823	300	0.799	2.8
4998	756	2.761	326	1.003	7.7

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
5109	702	3.555	1744	0.804	9.2	16.5	7.3	0.49
6622	706	3.490	1705	0.798	4.6	14.0	9.4	0.60
5072	758	3.433	2028	0.803	9.7	38.2	28.5	1.78

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED (%)
OCT- DEC	4945	379	0.79	49	86

FIGURE 5

AMMONIA SLIP VS. FLOW RATE

FIGURE 6a

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

GRACE NXRM: DESIGN FLOW, 620F

FIGURE 6b

AMMONIA SLIP VS. NH3/NOx RATIO

AMMONIA SLIP (ppm)

GRACE NXRM: Design Flow, 620 F

FIGURE 7a

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

GRACE NXRM: DESIGN FLOW, NH₃/NO_x=0.8

FIGURE 7b

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

GRACE NXRM: NH₃/NO_x=0.80, Design Flow

FIGURE 8

SO₂ OXIDATION VS. FLOWRATE

GRACE NXRM: NH₃/NO_x=0.80, 700 F

FIGURE 9a

SO2 OXIDATION VS. TEMPERATURE

SO2 OXIDATION (%)

GRACE NXRM: DESIGN FLOW, NH3/NOx=0.8

FIGURE 9b

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%) GRACE NXRM: Design Flow, NH₃/NOX=0.80

Figure 10. Six presentations of the Reactor A outlet mass concentration/mass emission profile.

REACTOR A
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 13.2 ± 1.0 ft/s

Figure 11a. Reactor A flue gas velocity profile.
Third Parametric Sequence

REACTOR A
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 12.3 ± 1.1 ft/s

Figure 11b. Reactor A flue gas velocity profile.
Fourth Parametric Sequence

- Reactor B

Tables 7a and 7b show the parametric test data on intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the NSKK catalyst. All the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in this table as an average over the operating periods shown, i.e., for July-September and October-December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to-NO_x ratio, 5000 SCFM flow rate, and 700 °F reactor temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 7a and 7b is presented below in three sets of plots: ammonia slip versus each of flow rate, ammonia-to-NO_x ratio, and temperature. Figures 12a and 12b show ammonia slip versus flow rate at roughly 80% NO_x reduction for the third and fourth parametric sequences, respectively. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. The ammonia slip is, however, relatively minor indicating the ability of the catalyst design to withstand significant increases in flow while maintaining ammonia slip limits. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases. These plots demonstrate the ability of an SCR system to follow load variations dictated by the host boiler while maintaining design specifications.

Figures 13a and 13b show ammonia slip versus ammonia-to-NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. These plots show sharp increases in ammonia slip as the ammonia-to-NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to-NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figures 14a and 14b for the third and fourth parametric sequences, respectively. The trend of

Figure 14a is somewhat unclear since most values are at or below the ammonia slip detection limit. (The ammonia slip detection limit is 0.7-0.9 ppmv. Any value below the detection limit is plotted as zero). Figure 14b shows some improvement (decrease) in ammonia slip between 620 and 700°F, likely due to improvements in the kinetic reaction rate with increasing temperature. Only slight improvements are noted with increasing temperature above 700°F. This may possibly be due to mass transfer limitations that have become controlling at these higher temperatures. In general, these plots demonstrate that in terms of ammonia slip, significant improvements are not realized with temperatures above 700°F. Losses in boiler efficiency would probably outweigh any improvements that may be obtained in ammonia slip by designing an SCR reactor to operate at temperatures near 750°F.

The plot for SO₂ oxidation versus flow rate at design temperature for the combination of all catalyst beds in the reactor is shown in Figure 15. Although the plot shows increasing SO₂ oxidation with increasing flow rate, this trend is not expected. Published rate equations and catalyst supplier information indicate that the general form of the plot should be linear with SO₂ oxidation decreasing with flow rate. In this case, large measurement variability of up to 0.39% SO₂ oxidation is the most probable cause for the uncharacteristic trend.

Figures 16a and 16b show SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor for the third and fourth parametric sequences, respectively. Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be exponential with respect to temperature. The exact shape of the plots is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The extremely low oxidation rate of the catalyst further exacerbates this problem. The general trend of increasing SO₂ oxidation is expected, however, and the plots provide a good basis for determining the potential for SO₃ formation across the SCR reactor at various operating temperatures.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. In some cases there was no net increase in sulfur trioxide concentrations across the reactor. In fact, some operating conditions showed a loss in sulfur trioxide across the reactor in addition to the loss that normally occurs without catalyst present. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at

this point. For consistency with other figures, the plots of SO₂ oxidation versus flow rate are based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured during the third parametric sequence but were measured during the fourth parametric sequence near design operating conditions (700 °F, 5000 SCFM) at the reactor outlet. The mass concentration profile data are given in Figure 17 in six different units of concentration and mass emission rate. The average mass concentration was 3.27 ± 0.16 gr/dscf ; and the average emission rate was 5.50 lb/MBtu.

A nine-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are presented in Figures 18a and 18b. The average gas velocity during the third sequence was 13.5 ± 0.3 ft/sec. The velocity profile was generally flat with a standard deviation of 2.2%. For the fourth sequence the average gas velocity was 12.6 ± 0.7 ft/sec. The velocity profile was again generally flat with a standard deviation of 5.6%.

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 238 ± 7 ppmv and 222 ± 13 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (1.3 ppmv, both measurements were dry at 3% O₂).¹

TABLE 7a. REACTOR B DATA (3rd Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
4998	625	6.124	335	0.797	46.4	65.8
7429	628	3.955	374	0.975	131.4	62.3
5002	710	3.330	348	0.576	18.1	52.4
4999	706	3.512	350	0.782	40.7	66.5
5006	706	2.994	461	0.820	98.4	60.7
6780	709	6.498	370	0.769	65.7	59.1
5002	755	3.107	360	0.763	47.9	63.0

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
3003	624	3.058	319	0.800	1.5
5005	625	2.285	311	0.571	0.9
5011	626	6.983	303	0.794	BDL
4998	623	6.334	342	0.977	2.6
6498	625	7.149	352	1.056	8.7
5018	704	5.558	345	0.572	0.9
4998	700	5.055	319	0.775	BDL
5003	704	3.328	340	0.987	3.2
6493	706	5.051	322	0.582	1
6367	707	2.426	292	0.780	1.8
6499	705	5.109	334	1.019	4.3
4998	757	6.061	228	0.916	0.9
5004	757	5.258	389	0.777	0.8
5006	756	4.476	375	0.989	1.7

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
5365	704	3.464	2094	0.802	0.1	4.4	4.3	0.20
5396	755	3.361	2119	1.193	0.2	6.5	6.3	0.30

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED (%)
JULY - SEPT.	5050	370	0.78	63	81

TABLE 7b. REACTOR B DATA (4th Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
4991	632	4.478	241	0.843	33.0	70.6
6910	652	2.960	274	0.997	78.0	71.2
5007	706	2.704	259	0.601	20.9	52.0
4999	704	3.111	285	0.799	24.1	71.5
4997	706	3.764	253	0.999	31.0	87.6
6805	706	1.731	208	0.804	43.4	63.6
5001	755	3.359	207	0.708	19.0	64.3

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
3005	630	2.750	287	0.801	1
4990	651	2.280	321	0.603	BDL
5005	650	2.976	362	0.796	1.5
4992	655	2.983	350	1.001	10.6
7331	635	4.668	375	1.002	21.6
4997	704	5.397	329	0.599	BDL
4983	706	2.333	299	0.803	1.1
4995	705	3.214	363	1.001	10.2
6597	706	3.261	363	0.597	1.4
6794	705	2.885	259	0.801	2.1
6596	706	2.857	331	1.000	6.2
4997	757	3.157	327	0.582	1.0
5004	756	2.677	329	0.799	1.1
4992	756	2.709	318	1.002	2.1

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
5329	704	5.365	2076	0.808	5.6	3.6	-2.0	-0.11
7071	705	4.706	1515	0.798	1.8	2.4	0.6	0.04
5350	756	4.167	1783	0.800	8.9	16.2	7.3	0.41

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED (%)
OCT.-DEC.	4987	377	0.79	48	85

FIGURE 12a

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

NSKK: 700 F, NH₃/NO_x=0.8

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 12b

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

NSKK: $\text{NH}_3/\text{NO}_x=0.80$, 700 F

FIGURE 13a

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

NSKK: DESIGN FLOW, 620F

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 13b

AMMONIA SLIP VS. NH3/NOx RATIO

AMMONIA SLIP (ppm)

NSKK: Design Flow, 620 F

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 14a

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

NSKK: DESIGN FLOW, NH₃/NOX=0.8

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 14b

AMMONIA SLIP VS. TEMPERATURE

NSKK: $\text{NH}_3/\text{NO}_x=0.80$, Design Flow

FIGURE 15

SO₂ OXIDATION VS. FLOWRATE

NSKK: NH₃/NO_x=0.80, 700 F

FIGURE 16a

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%) NSKK: DESIGN FLOW, NH₃/NO_x=0.80

FIGURE 16b

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%) NSKK: Design Flow, NH₃/NOX=0.80

Figure 17. Six presentations of the Reactor B outlet mass concentration/mass emission profile.

REACTOR B
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 13.5 ± 0.3 ft/s

Figure 18a **Reactor B** flue gas velocity profile.
Third Parametric Sequence

REACTOR B
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 12.6 ± 0.7 ft/s

Figure 18b. Reactor B flue gas velocity profile.
Fourth Parametric Sequence

- Reactor C

Tables 8a and 8b show the parametric test data on intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the Siemens catalyst. All the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in this table as an average over the operating periods shown, i.e., for July-September and October-December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to- NO_x ratio, 5000 SCFM flow rate, and 700 °F temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 8a and 8b is presented below in three sets of plots: ammonia slip versus each of flow rate, ammonia-to- NO_x ratio, and temperature. Figures 19a and 19b show ammonia slip versus flow rate at roughly 80% NO_x reduction for the third and fourth parametric sequences, respectively. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. The ammonia slip is, however, relatively minor indicating the ability of the catalyst design to withstand significant increases in flow while maintaining ammonia slip limits. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases. These plots demonstrate the ability of an SCR system to follow load variations dictated by the host boiler while maintaining design specifications.

Figures 20a and 20b show ammonia slip versus ammonia-to- NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. These plots show sharp increases in ammonia slip as the ammonia-to- NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to- NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figures 21a and 21b for the third and fourth parametric sequences, respectively. Figure 21b

shows some improvement (decrease) in ammonia slip between 620 and 700°F, likely due to improvements in the kinetic reaction rate with increasing temperature. The slight increase in ammonia slip with increasing temperatures shown in Figure 21a is likely due to measurement variability and/or differences in the set point for NO_x reduction (83% at 750 °F versus 70% at 700°F) and is not considered significant. In this case, the plot should not be construed as demonstrating increases in ammonia slip with increasing temperature. Also, mass transfer limitations that have become controlling at higher temperatures are likely mitigating the effects of increased temperature on ammonia slip. In general, these plots demonstrate that in terms of ammonia slip, significant improvements are not realized with temperatures above 700°F. Losses in boiler efficiency would probably outweigh any improvements that may be obtained in ammonia slip by designing an SCR reactor to operate at temperatures near 750°F.

The plot for SO₂ oxidation versus flow rate at design temperature for the combination of all catalyst beds in the reactor is shown in Figure 22. In general, decreasing SO₂ oxidation is noted with increasing flow rate. This finding is expected since the reaction rate is predicted to be inversely proportional to flow rate according to published rate data and information provided by catalyst suppliers.

Figures 23a and 23b show SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor for the third and fourth parametric sequences, respectively. Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be more exponential with respect to temperature. The exact shape of the plots is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The general trend of increasing SO₂ oxidation is expected, however, and the plots provide a good basis for determining the potential for SO₃ formation across the SCR reactor at various operating temperatures.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. In some cases there was no net increase in sulfur trioxide concentrations across the reactor. In fact, some operating conditions showed a loss in sulfur trioxide across the reactor in addition to the loss that normally occurs without catalyst present. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at this point. For consistency with other figures, the plots of SO₂ oxidation versus flow rate are

based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured during the third parametric sequence but were measured during the fourth parametric sequence near design operating conditions (700 °F, 5000 SCFM) at the reactor outlet. The mass concentration profile data are given in Figure 24 in six different units of concentration and mass emission rate. The average mass concentration was 3.42 ± 0.24 gr/dscf; and the average emission rate was 5.79 lb/MBtu.

A nine-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are presented in Figures 25a and 25b. The average gas velocity during the third sequence was 14.1 ± 1.6 ft/sec. The velocity profile was somewhat skewed (higher flue gas velocities near the front of the reactor) indicated by a relative standard deviation of 11.3%. For the fourth sequence the average gas velocity was 14.1 ± 1.5 ft/sec. The velocity profile was again generally flat with a standard deviation of 10.6%, however, the flue gas velocity was somewhat lower on the back side of the reactor..

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 233 ± 8 ppmv and 260 ± 7 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (2.0 ppmv, both measurements were dry at 3% O₂).¹

TABLE 8a. REACTOR C DATA (3rd parametric sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
5014	625	4.490	367	0.756	33.1	66.6
7493	652	2.261	321	0.969	74.6	73.6
5005	706	5.858	365	0.544	16.7	50.8
4999	709	2.784	357	0.761	26.9	68.6
5005	708	3.654	366	0.972	61.6	80.4
7007	707	4.644	378	0.761	40.3	65.5
4992	753	4.582	376	0.764	27.5	69.1

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
3003	638	3.757	340	0.800	0.8
5010	641	2.689	325	0.583	1.3
5005	630	4.665	361	0.751	2.5
4998	631	3.801	353	0.997	22.2
7404	629	7.395	384	0.938	18.4
4990	706	2.831	326	0.571	1.1
4998	706	6.357	387	0.702	2.7
4995	706	6.465	313	0.967	13.8
7021	708	6.058	348	0.561	3.4
7073	705	5.037	319	0.772	7.0
7050	705	5.037	376	1.000	15.5
4994	758	2.783	328	0.573	1.5
4997	756	4.676	332	0.827	3.0
5005	757	2.129	318	0.972	10.9

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
5392	704	3.406	2106	0.802	0.1	13.7	13.6	0.64
5411	754	3.305	2127	0.801	0.2	24.3	24.1	1.13

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
JULY - SEPT.	5090	368	0.78	46	86

TABLE 8b. REACTOR C DATA (4th parametric sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
4915	627	4.998	387	0.789	5.5	77.5
6500	627	4.681	385	1.000	99.4	74.2
5000	704	4.889	383	0.601	21.1	54.6
5000	707	4.994	337	0.802	27.7	72.0
4996	706	4.908	341	0.999	56.7	83.3
6396	705	2.678	357	0.803	51.3	65.9
5001	757	4.539	355	0.802	35.1	70.3

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
3004	638	2.984	369	0.799	2.5
4995	352	2.733	375	0.600	2.6
5003	649	3.046	337	0.835	6.5
4998	647	2.737	326	0.999	39.4
6500	627	4.681	377	1.000	38
5008	708	4.419	376	0.601	2.8
4992	708	2.365	341	0.800	5.4
4997	705	2.205	315	1.001	16.3
6479	704	5.219	339	0.600	4.1
6428	704	4.681	330	0.802	7.8
6303	706	3.012	358	1.000	20.2
4997	756	2.873	354	0.602	2.6
4998	755	4.361	318	0.803	4.1
4997	757	4.542	332	1.006	14.8

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
5293	702	3.193	2019	0.803	9.2	12.8	3.6	0.18
6784	704	5.538	1550	0.802	5.0	2.1	-2.9	-0.18
5354	756	4.122	1960	0.802	11.0	35.2	24.2	1.23

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
OCT. - DEC.	4946	338	0.79	50	85

FIGURE 19a

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

SIEMENS: 700 F, NH₃/NO_x=0.8

FIGURE 19b

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

FLOWRATE (% of Design Flow)

SIEMENS: NH₃/NO_x=0.80, 700 F

FIGURE 20a

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

SIEMENS: DESIGN FLOW, 620F

FIGURE 20b

AMMONIA SLIP VS. NH3/NOx RATIO

AMMONIA SLIP (ppm)

SIEMENS: Design Flow, 620 F

FIGURE 21a

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

SIEMENS: DESIGN FLOW, NH₃/NO_x=0.8

FIGURE 21b

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

SIEMENS: NH₃/NO_x=0.80, Design Flow

FIGURE 22

SO₂ OXIDATION VS. FLOWRATE

SIEMENS: NH₃/NO_x=0.80, 700 F

FIGURE 23a

SO2 OXIDATION VS. TEMPERATURE

SO2 OXIDATION (%)

SIEMENS: DESIGN FLOW, NH3:NOx=0.8

FIGURE 23b

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%)

SIEMENS: Design Flow, NH₃/NO_x=0.80

Figure 24. Six presentations of the Reactor C outlet mass concentration/mass emission profile.

REACTOR C
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 14.1 ± 1.6 ft/s

Figure 25a. Reactor C flue gas velocity profile.
Third Parametric Sequence

REACTOR C
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 14.1 ± 1.5 ft/s

Figure 25b. Reactor C flue gas velocity profile.
Fourth Parametric Sequence

- Reactor D

Tables 9a and 9b show the parametric test data on intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the Grace Synox catalyst. All the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in these tables as an average over the operating periods shown, i.e., for July-September and October-December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to- NO_x ratio, 400 SCFM flow rate, and 700 °F reactor temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 9a and 9b is presented below in three sets of plots: ammonia slip versus each of flow rate, ammonia-to- NO_x ratio, and temperature. Figures 26a and 26b show ammonia slip versus flow rate at roughly 80% NO_x reduction for the third and fourth parametric sequences, respectively. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. For this reactor, a fairly significant increase in ammonia slip is noted with flow rate. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases.

Figures 27a and 27b show ammonia slip versus ammonia-to- NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. These plots show sharp increases in ammonia slip as the ammonia-to- NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to- NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figures 28a and 28b for the third and fourth parametric sequences, respectively. Some improvement (decrease) in ammonia slip is noted between 620 and 700°F, likely due to improvements in the kinetic reaction rate with increasing temperature. Only slight improvements

are noted with increasing temperatures above 700° F. This may possibly be due to mass transfer limitations that have become controlling at these higher temperatures. In general, these plots demonstrate that in terms of ammonia slip, significant improvements are not realized with temperatures above 700°F. Losses in boiler efficiency would probably outweigh any improvements that may be obtained in ammonia slip by designing an SCR reactor to operate at temperatures near 750°F.

Figures 29a and 29b show SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor for the third and fourth parametric sequences, respectively. Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be more exponential with respect to temperature. The exact shape of the plots is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The general trend of increasing SO₂ oxidation is expected, however, and the plots provide a good basis for determining the potential for SO₃ formation across the SCR reactor at various operating temperatures.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. In some cases there was no net increase in sulfur trioxide concentrations across the reactor. In fact, some operating conditions showed a loss in sulfur trioxide across the reactor in addition to the loss that normally occurs without catalyst present. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at this point. For consistency with other figures, the plots of SO₂ oxidation versus flow rate are based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured during the third parametric sequence but were measured during the fourth parametric sequence near design operating conditions (700 °F, 5000 SCFM) at the reactor outlet. The mass concentration profile data are given in Figure 30 in six different units of concentration and mass emission rate. The average mass concentration was 4.24 ± 0.40 gr/dscf ; and the average emission rate was 7.62 lb/MBtu.

A three-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are

presented in Figures 31a and 31b. The average gas velocity during the third sequence was 14.1 ± 0.3 ft/sec. The velocity profile was generally flat with a standard deviation of 2.1%. For the fourth sequence the average gas velocity was 13.9 ± 1.5 ft/sec. The velocity profile was again generally flat with a standard deviation of 10.8%. The velocity at the back side of the reactor (15.1 ft/sec) was over 23% higher than at the front of the reactor (12.2 ft/sec).

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 232 ± 4 ppmv and 223 ± 17 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (2.0 ppmv, both measurements were dry at 3% O₂).¹

TABLE 9a. REACTOR D DATA (3rd Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION(%)
394	626	7.014	274	0.890	81.6	59.2
602	624	5.523	242	1.106	133.3	55.5
399	705	5.747	258	0.676	42.9	51.0
401	705	5.706	248	0.935	66.4	66.7
400	707	5.606	240	1.176	103.0	74.7
601	706	8.799	242	1.127	76.4	81.2
402	756	6.212	273	1.085	82.8	78.2

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
240	622	8.839	266	0.800	6.3
400	625	9.419	272	0.716	2.8
400	625	7.996	272	0.844	10.0
400	623	7.163	266	1.106	51.1
601	625	6.147	274	1.052	55.9
400	705	6.610	238	0.701	1.9
401	705	8.918	243	0.897	4.1
400	705	6.626	251	1.226	28.4
583	706	8.195	293	0.647	4.8
599	707	3.007	340	0.802	19.6
600	706	2.955	334	1.001	52.8
400	755	2.850	269	0.602	1.7
400	755	2.761	267	0.795	3.2
403	755	2.965	317	0.992	13.6

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
415	706	3.576	1972	0.801	0.4	7.9	7.5	0.38
421	756	3.916	1857	0.792	0.5	21.8	21.3	1.15

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
JUL. - SEPT.	401	360	0.80	22	92

TABLE 9b. REACTOR D DATA (4th Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION(%)
400	623	5.088	356	0.802	148.5	38.5
598	625	5.407	379	1.044	228.5	44.1
399	704	5.741	376	0.606	66.5	42.9
399	705	5.712	330	0.802	94.3	51.6
400	703	5.780	329	1.000	130.7	60.3
600	705	5.152	342	0.803	108.6	48.6
400	756	3.848	358	0.805	89.7	55.5

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
240	625	4.185	328	0.797	5.0
400	625	3.526	328	0.603	7.6
400	626	3.602	338	0.799	21.7
399	624	4.527	334	1.008	66.2
603	625	3.633	373	0.994	83.3
400	706	3.746	324	0.605	1.9
400	704	6.585	334	0.800	5.5
400	703	5.780	325	1.000	23.7
402	704	3.774	322	0.599	2.8
400	705	3.570	324	0.803	9.2
404	703	3.644	325	1.004	35.5
400	754	4.383	334	0.601	2.5
400	754	4.141	333	0.802	6.2
391	754	4.102	332	1.019	25.7

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
416	704	4.830	1554	0.800	4.2	12.0	7.8	0.50
416	705	3.984	1600	0.803	0.7	0.2	-0.5	-0.03
399	755	4.012	1639	0.806	1.1	10.4	9.3	0.57

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
OCT. - DEC.	400	383	0.79	34	89

FIGURE 26a

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

GRACE SYNOX: 700 F, NH₃/NO_x=0.8

FIGURE 26b

AMMONIA SLIP VS. FLOW RATE

FIGURE 27a

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

GRACE SYNOX: DESIGN FLOW, 620F

FIGURE 27b

AMMONIA SLIP VS. NH3/NOx RATIO

AMMONIA SLIP (ppm)

NH3/NOx RATIO

GRACE SNX: Design Flow, 620 F

FIGURE 28a

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

GRACE SYNOX: DESIGN FLOW, $\text{NH}_3/\text{NO}_x=0.8$

FIGURE 28b

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

GRACE SNX: NH₃/NO_x=0.80, Design Flow

FIGURE 29a

SO2 OXIDATION VS. TEMPERATURE

SO2 OXIDATION (%)

TEMPERATURE (F)

GRACE SNX: DESIGN FLOW, NH3/NOx=0.8

FIGURE 29b

SO2 OXIDATION VS. TEMPERATURE

SO2 OXIDATION (%)

GRACE SNX: Design Flow, NH3/NOX=0.80

Figure 30. Six presentations of the Reactor D outlet mass concentration/mass emission profile.

REACTOR D
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 14.1 ± 0.3 ft/s

Figure 31a. Reactor D flue gas velocity profile.
Third Parametric Sequence

REACTOR D
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 13.9 ± 1.5 ft/s

Figure 31b. Reactor D flue gas velocity profile.
Fourth Parametric Sequence

- Reactor E

Tables 10a and 10b show the parametric test data on intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the Cormetech high-dust catalyst. All the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in these tables as an average over the operating periods shown, i.e., for July-September and October-December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to- NO_x ratio, 400 SCFM flow rate, and 700 °F reactor temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 10a and 10b is presented below in three sets of plots: ammonia slip versus each of flow rate, ammonia-to- NO_x ratio, and temperature. Figures 32a and 32b show ammonia slip versus flow rate at roughly 80% NO_x reduction for the third and fourth parametric sequences, respectively. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. The ammonia slip is, however, relatively minor indicating the ability of the catalyst design to withstand significant increases in flow while maintaining ammonia slip limits. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases. These plots demonstrate the ability of an SCR system to follow load variations dictated by the host boiler while maintaining design specifications.

Figures 33a and 33b show ammonia slip versus ammonia-to- NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. The trend of Figure 33a is unclear since all values are below the ammonia slip detection limit. (The ammonia slip detection limit is 0.7-0.9 ppmv. Any value below the detection limit is plotted as zero). Figure 33b does, however, show a sharp increase in ammonia slip as the ammonia-to- NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to- NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figures 34a and 34b for the third and fourth parametric sequences, respectively. Again, the trend of these figures is unclear since all values are below the ammonia slip detection limit.

The plot for SO₂ oxidation versus flow rate at design temperature for the combination of all catalyst beds in the reactor is shown in Figure 35. The plot is relatively flat showing little change in SO₂ oxidation rate. Published rate equations and catalyst supplier information indicate that the general form of the plot should be linear with SO₂ oxidation decreasing with flow rate. Based on similarities with previous test data the relatively flat profile of this plot indicates that either chemical or physical characteristics of the catalyst and reactor are masking this linear effect.

Figures 36a and 36b show SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor. Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be more exponential with respect to temperature. The exact shape of the plots is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The general trend of increasing SO₂ oxidation is expected, however, and the plots provide a good basis for determining the potential for SO₃ formation across the SCR reactor at various operating temperatures.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. In some cases there was no net increase in sulfur trioxide concentrations across the reactor. In fact, some operating conditions showed a loss in sulfur trioxide across the reactor in addition to the loss that normally occurs without catalyst present. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at this point. For consistency with other figures, the plots of SO₂ oxidation versus flow rate are based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured during the third parametric sequence but were measured during the fourth parametric sequence near design operating conditions (700 °F, 5000 SCFM) at the reactor outlet. The mass concentration profile data are given in Figure 37 in six different units

of concentration and mass emission rate. The average mass concentration was 4.24 ± 0.25 gr/dscf; and the average emission rate was 7.25 lb/MBtu.

A three-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are presented in Figures 18a and 18b. The average gas velocity during the third sequence was 13.5 ± 1.1 ft/sec. The flue gas velocity increased 18% from the front to the back of the reactor (12.3 to 14.5 ft/sec). This is indicated by a high standard deviation of 8.1%. For the fourth sequence the average gas velocity was 15.9 ± 1.2 ft/sec. The standard deviation was 7.6%. The velocity at the back side of the reactor (17.1 ft/sec) was over 16% higher than at the front of the reactor (14.7 ft/sec).

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 226 ± 4 ppmv and 233 ± 5 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (1.8 ppmv, both measurements were dry at 3% O₂).¹

TABLE 10a. REACTOR E DATA (3rd parametric sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
387	624	4.947	250	0.874	156.1	24.9
603	626	5.268	300	1.013	49.6	84.8
401	707	7.135	314	0.645	7.6	62.0
400	704	7.673	300	0.924	12.3	88.3
401	706	5.496	367	0.920	50.0	78.4
600	706	7.996	331	0.881	41.8	75.5
400	757	7.147	278	0.990	11.9	94.7

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
243	625	10.244	183	0.800	BDL
400	625	7.493	225	0.555	BDL
401	623	7.752	217	0.774	BDL
403	626	8.061	219	1.064	BDL
598	625	3.099	306	1.002	24.5
400	705	8.367	284	0.600	BDL
403	705	8.367	275	0.904	BDL
396	704	8.251	196	1.242	1.6
602	704	6.180	281	0.668	BDL
602	702	9.402	293	0.904	0.7
598	705	8.000	272	1.039	7.6
400	755	2.447	313	0.604	BDL
401	755	2.620	303	0.799	0.6
400	755	7.180	251	0.994	BDL

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
436	706	3.924	2088	0.806	1.8	8.3	6.5	0.31
434	755	3.763	2124	0.806	0.4	13.2	12.8	0.60

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
JULY - SEPT.	406	359	0.80	42	86

TABLE 10b. REACTOR E DATA (4th parametric sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
400	644	2.377	385	0.797	46.4	67.7
600	625	5.589	383	0.999	143.8	62.4
400	706	5.059	349	0.599	14.7	55.7
400	706	4.848	341	0.798	20.9	73.6
401	705	3.752	325	0.998	42.3	86.8
602	706	3.549	322	0.805	52.9	64.1
391	755	2.587	332	0.809	25.6	73.2

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
250	625	4.892	388	0.788	BDL
399	625	4.879	334	0.593	BDL
400	624	4.736	316	0.804	BDL
400	624	5.633	380	1.003	10.6
601	625	5.381	378	1.000	49.3
400	706	2.936	356	0.600	BDL
400	706	3.272	363	0.807	BDL
398	706	3.055	356	1.004	1.5
599	710	2.417	346	0.602	1.0
599	704	3.394	348	0.804	1.7
595	705	3.359	346	1.005	5.5
401	753	5.294	339	0.598	BDL
400	753	2.587	334	0.800	BDL
400	753	2.587	356	1.000	BDL
400	625	4.953	360	0.600	BDL

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
408	704	3.283	1751	0.802	2.8	9.2	6.4	0.36
624	704	4.101	1678	0.804	0.3	5.7	5.4	0.32
408	749	3.377	1720	0.807	1.2	10.5	9.3	0.54

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
OCT. - DEC.	400	386	0.79	41	88

FIGURE 32a

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

CORM. HD: 700 F, NH₃/NO_x=0.8

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 32b

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

CORM HD: $\text{NH}_3/\text{NO}_x=0.80$, 700 F

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 33a

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

CORM HD: DESIGN FLOW, 620F

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 33b

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

CORM HD: Design Flow, 620 F

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 34a

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

CORM HD: DESIGN FLOW, NH₃/NO_x=0.8

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 34b

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

TEMPERATURE (F)

CORM HD: $\text{NH}_3/\text{NO}_x=0.80$, Design Flow

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 35

SO₂ OXIDATION VS. FLOWRATE

CORM HD: NH₃/NO_x=0.80, 700 F

FIGURE 36a

SO2 OXIDATION VS. TEMPERATURE

SO2 OXIDATION (%)

CORM HD: DESIGN FLOW, NH3/NOx=0.8

FIGURE 36b

SO2 OXIDATION VS. TEMPERATURE

SO2 OXIDATION (%)

CORM HD: Design Flow, NH3/NOX=0.80

Mass Concentration Profile
gr/scf

Average = 1.75 ± 0.15 gr/scf

Mass Concentration Profile
gr/dscf

Average = 4.25 ± 0.25 gr/dscf

Mass Concentration Profile
g/acm

Average = 4.00 ± 0.35 g/acm

Mass Concentration Profile
g/dscm

Average = 9.73 ± 0.56 g/dscm

Mass Concentration Profile
lb/MBtu

Average = 7.25 ± 0.36 lb/MBtu

Mass Concentration Profile
gr/scf (wet)

Average = 3.96 ± 0.30 gr/scf (wet)

Figure 37. Six presentations of the Reactor E outlet mass concentration/mass emission profile.

REACTOR E
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 13.5 ± 1.1 ft/s

Figure 38a. Reactor E flue gas velocity profile.
Third Parametric Sequence

REACTOR E
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 15.9 ± 1.2 ft/s

Figure 38b. . Reactor E flue gas velocity profile.
Fourth Parametric Sequence

- Reactor F

Tables 11a and 11b show the parametric test data on intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the Haldor Topsoe catalyst. All the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in these tables as an average over the operating periods shown, i.e., for July-September and October-December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to- NO_x ratio, 400 SCFM flow rate, and 700 °F reactor temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 11a and 11b is presented below in three sets of plots: ammonia slip versus each of flow rate, ammonia-to- NO_x ratio, and temperature. Figures 39a and 39b show ammonia slip versus flow rate at roughly 80% NO_x reduction for the third and fourth parametric sequences, respectively. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. The ammonia slip is, however, relatively minor indicating the ability of the catalyst design to withstand significant increases in flow while maintaining ammonia slip limits. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases. These plots demonstrate the ability of an SCR system to follow load variations dictated by the host boiler while maintaining design specifications.

Figures 40a and 40b show ammonia slip versus ammonia-to- NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. These plots show sharp increases in ammonia slip as the ammonia-to- NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to- NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figures 41a and 41b for the third and fourth parametric sequences, respectively. Some

improvement (decrease) in ammonia slip is noted between 620 and 700°F, likely due to improvements in the kinetic reaction rate with increasing temperature. The slight increase shown between the 700 and 750°F points for Figure 41a is likely due to measurement variability and is not considered significant. In this case, the plot should not be construed as demonstrating increases in ammonia slip with increasing temperature above 700°F. It is expected that the 700 and 750°F values are roughly equivalent which may be due in part to mass transfer limitations that have become controlling at these higher temperatures. In general, these plots demonstrate that in terms of ammonia slip, significant improvements are not realized with temperatures above 700°F. Losses in boiler efficiency would probably outweigh any improvements that may be obtained in ammonia slip by designing an SCR reactor to operate at temperatures near 750°F.

The plot for SO₂ oxidation versus flow rate at design temperature for the combination of all catalyst beds in the reactor is shown in Figure 42. The plot is relatively flat showing little change in SO₂ oxidation rate. Published rate equations and catalyst supplier information indicate that the general form of the plot should be linear with SO₂ oxidation decreasing with flow rate. Based on similarities with previous test data the relatively flat profile of this plot indicates that either chemical or physical characteristics of the catalyst and reactor are masking this linear effect.

Figures 43a and 43b show SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor for third and fourth parametric sequences, respectively. Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be exponential with respect to temperature. The exact shape of the plots is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The extremely low oxidation rate of the catalyst further exacerbates this problem. The plot is valuable in the context of showing that this particular catalyst has very low SO₂ oxidation potential.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. In some cases there was no net increase in sulfur trioxide concentrations across the reactor. In fact, some operating conditions showed a loss in sulfur trioxide across the reactor in addition to the loss that normally occurs without catalyst present. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at this

point. For consistency with other figures, the plots of SO₂ oxidation versus flow rate are based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured during the third parametric sequence but were measured during the fourth parametric sequence near design operating conditions (700 °F, 5000 SCFM) at the reactor outlet. The mass concentration profile data are given in Figure 44 in six different units of concentration and mass emission rate. The average mass concentration was 4.34 ± 0.17 gr/dscf; and the average emission rate was 7.32 lb/MBtu.

A three-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are presented in Figures 45a and 45b. The average gas velocity during the third sequence was 14.0 ± 1.1 ft/sec. The flue gas velocity increased 18% from the front to the back of the reactor (12.8 to 15.1 ft/sec). This is indicated by a high standard deviation of 7.8%. For the fourth sequence the average gas velocity was 13.3 ± 0.2 ft/sec. The velocity profile was generally flat with a standard deviation of 1.5%.

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 241 ± 13 ppmv and 250 ± 9 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (2.0 ppmv, both measurements were dry at 3% O₂).¹

TABLE 11a. REACTOR F DATA (3rd Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
402	624	1.876	300	1.276	106.8	92.1
580	627	2.468	327	0.926	180.2	37.6
399	706	1.883	319	0.510	51.3	35.0
401	706	3.573	316	0.753	82.6	49.2
399	712	2.586	289	0.927	113.2	53.5
599	706	1.803	314	0.757	119.3	37.7
400	757	1.968	308	0.753	70.0	52.6

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
241	623	4.321	355	0.800	1.5
400	627	2.364	313	0.599	0.8
402	627	2.994	329	0.796	2.9
400	624	4.507	289	1.070	66.3
600	625	5.672	349	0.934	70.4
402	704	7.205	359	0.541	1.5
400	706	2.702	322	0.715	0.9
402	706	2.886	344	0.998	16.0
596	705	3.669	282	0.592	3.4
592	705	2.333	332	0.798	8.8
600	705	2.264	327	1.003	53.9
400	747	5.828	339	0.559	2.2
400	753	4.688	256	0.737	2.5
400	755	4.115	344	0.915	15.9

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
414	705	3.016	2045	0.793	0.3	1.6	1.3	0.06
412	756	2.891	1976	0.808	0.9	3.1	2.2	0.11

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
JULY - SEPT.	401	366	0.76	35	0.88

TABLE 11b. REACTOR F DATA (4th Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
400	625	3.437	326	0.803	82.4	55.0
599	640	3.403	331	1.005	156.1	53.4
400	707	4.696	356	0.598	58.6	43.4
400	707	4.514	346	0.799	68.4	60.2
402	705	2.289	337	0.994	96.2	70.9
600	704	1.974	394	0.788	136.0	44.2
400	755	3.119	363	0.800	68.3	61.2

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
240	625	5.499	383	0.800	BDL
402	625	4.758	380	0.603	1.1
400	625	4.333	403	0.797	2.6
400	624	5.044	381	1.002	9.9
595	626	4.782	321	1.000	27.1
400	704	3.754	340	0.597	BDL
400	705	3.696	330	0.800	0.90
400	706	2.635	334	1.003	11.7
600	706	4.660	312	0.611	2.5
600	705	4.811	331	0.790	3.8
595	707	4.976	338	1.013	20
400	756	2.979	350	0.604	1.0
399	755	3.119	348	0.808	0.9
399	756	5.053	339	1.024	2.3
600	706	2.903	356	0.602	3.1

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
432	706	4.236	1784	0.804	0.7	0.9	0.2	0.01
631	705	5.616	1554	0.800	1.2	0.2	-1.0	-0.07
431	758	3.994	1779	0.804	0.7	0.7	0.0	0.00

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
OCT. - DEC.	401	382	0.79	46	86

FIGURE 39a

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

HALDOR: 700 F, NH3/NOx=0.8

FIGURE 39b

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

HALDOR: $\text{NH}_3/\text{NO}_x=0.80$, 700 F

FIGURE 40a

AMMONIA SLIP VS. NH3/NOx RATIO

AMMONIA SLIP (ppm)

NH3/NOx RATIO

HALDOR: DESIGN FLOW, 620F

FIGURE 40b

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

HALDOR: Design Flow, 620 F

FIGURE 41a

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

HALDOR: DESIGN FLOW, $\text{NH}_3/\text{NO}_x=0.8$

FIGURE 41b

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

HALDOR: NH₃/NO_x=0.80, Design Flow

FIGURE 42

SO2 OXIDATION VS. FLOWRATE

HALDOR: NH3/NOx=0.80, 700 F

FIGURE 43a

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%) HALDOR: DESIGN FLOW, NH₃/NO_x=0.8

FIGURE 43b

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%)

HALDOR: Design Flow, NH₃/NO_x=0.80

Mass Concentration Profile
gr/acf

Average = 1.70 ± 0.08 gr/acf

Mass Concentration Profile
gr/dscf

Average = 4.34 ± 0.17 gr/dscf

Mass Concentration Profile
g/acm

Average = 3.88 ± 0.18 g/acm

Mass Concentration Profile
g/dscm

Average = 9.94 ± 0.38 g/dscm

Mass Concentration Profile
lb/MBtu

Average = 7.32 ± 0.17 lb/MBtu

Mass Concentration Profile
gr/scf (wet)

Average = 3.84 ± 0.06 gr/scf (wet)

Figure 44. Six presentations of the Reactor F outlet mass concentration/mass emission profile.

REACTOR F
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 14.0 ± 1.1 ft/s

Figure 45a. Reactor F flue gas velocity profile.
Third Parametric Sequence

REACTOR F
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 13.3 ± 0.2 ft/s

Figure 45b. Reactor F flue gas velocity profile.
Fourth Parametric Sequence

- Reactor G

Table 12a and 12b show the parametric test data on intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the Hitachi Zosen catalyst. All the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in these tables as an average over the operating periods shown, i.e., for July-September and October-December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to-NO_x ratio, 400 SCFM flow rate, and 700 °F reactor temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 12a and 12b is presented below in three set of plots: ammonia slip versus each of flow rate, ammonia-to-NO_x ratio, and temperature. Figures 46a and 46b show ammonia slip versus flow rate at roughly 80% NO_x reduction for the third and fourth parametric sequences, respectively. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. The ammonia slip is, however, relatively minor indicating the ability of the catalyst design to withstand significant increases in flow while maintaining ammonia slip limits. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases. These plots demonstrate the ability of an SCR system to follow load variations dictated by the host boiler while maintaining design specifications.

Figures 47a and 47b show ammonia slip versus ammonia-to-NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. These plots show sharp increases in ammonia slip as the ammonia-to-NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to-NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figures 48a and 48b for the third and fourth parametric sequences, respectively. Some improvement (decrease) in ammonia slip is generally noted between 620 and 700°F, likely due to improvements in the kinetic reaction rate with increasing temperature. The observed slight increase in ammonia slip between points 620 °F and 700 °F on Figure 48a is likely due to a difference in the set-point for NO_x reduction (85% at 620 °F versus 80% at 700 °F) and/or measurement variability. Also, the uncharacteristic increase in ammonia slip between points 700°F and 750 °F on Figure 48b is likely due to measurement variability and is not considered significant. In this case, it is expected that the 700 °F and 750 °F values are roughly equivalent which may be due in part to mass transfer limitations which have become controlling at these higher temperatures. In general, these plots demonstrate that in terms of ammonia slip, significant improvements are not realized with temperatures above 700°F. Losses in boiler efficiency would probably outweigh any improvements that may be obtained in ammonia slip by designing an SCR reactor to operate at temperatures near 750°F.

The plot for SO₂ oxidation versus flow rate at design temperature for the combination of all catalyst beds in the reactor is shown in Figure 49. In general, decreasing SO₂ oxidation is noted with increasing flow rate. This finding is expected since the reaction rate is predicted to be inversely proportional to flow rate according to published rate data and information provided by catalyst suppliers.

Figures 50a and 50b show SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor. Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be more exponential with respect to temperature. The exact shape of the plots is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The general trend of increasing SO₂ oxidation is expected, however, and the plots provide a good basis for determining the potential for SO₃ formation across the SCR reactor at various operating temperatures.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at this point. For consistency with other figures, the plots

of SO₂ oxidation versus flow rate are based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured during the third parametric sequence but were measured during the fourth parametric sequence near design operating conditions (700 °F, 5000 SCFM) at the reactor outlet. The mass concentration profile data are given in Figure 51 in six different units of concentration and mass emission rate. The average mass concentration was 3.31 ± 0.36 gr/dscf; and the average emission rate was 5.55 lb/MBtu.

A three-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are presented in Figures 52a and 52b. The average gas velocity during the third sequence was 18.0 ± 1.5 ft/sec. The flue gas velocity increased 19% from the front to the back of the reactor (16.4 to 19.5 ft/sec). This is indicated by a high standard deviation of 8.3%. For the fourth sequence the average gas velocity was 14.2 ± 0.5 ft/sec. The standard deviation was 3.5%.

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 225 ± 5 ppmv and 256 ± 8 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (2.3 ppmv, both measurements were dry at 3% O₂).¹

TABLE 12a. REACTOR G DATA (3rd Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
402	624	6.311	263	0.821	45.8	64.7
596	625	6.737	192	1.039	79.2	62.6
397	707	5.581	332	0.613	18.2	55.8
361	706	5.316	344	0.853	32.2	76.0
394	706	4.667	302	1.053	70.5	82.0
600	703	6.357	325	0.810	61.3	64.1
403	755	5.617	264	0.902	34.4	77.1

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
241	626	8.349	283	0.800	BDL
404	625	7.021	294	0.631	BDL
400	625	8.739	309	0.851	1.4
401	625	3.573	340	1.002	83.6
602	628	2.251	309	0.964	41.9
397	707	2.518	349	0.603	0.7
400	707	2.480	342	0.801	2.1
400	704	7.496	310	1.072	39.5
603	705	2.300	277	0.601	1.2
599	705	2.190	275	0.791	2.9
599	705	3.723	285	1.031	36.7
400	755	2.590	331	0.598	1.2
400	755	2.436	324	0.803	2.1
399	741	5.725	271	1.142	25.5

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
402	706	2.240	2009	0.799	0.3	2.1	1.8	0.09
401	756	2.699	1855	0.815	0.4	16.0	15.6	0.84

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
JULY - SEP.	401	359	0.79	47	84

TABLE 12b. REACTOR G DATA (4th Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
397	626	3.702	252	0.800	53.3	58.9
601	624	3.154	252	1.000	110.9	56.0
391	705	3.384	295	0.546	31.5	44.0
400	705	3.270	288	0.791	48.0	62.5
406	704	2.458	339	1.018	125.3	64.8
601	703	2.908	360	0.796	107.9	49.6
400	756	2.840	356	0.805	86.8	56.1

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
219	622	4.04	276	0.856	BDL
404	622	3.303	279	0.600	BDL
403	625	3.152	308	0.793	2.9
400	625	3.035	297	1.003	17.8
601	624	3.079	255	0.991	11.8
400	701	3.553	304	0.606	0.8
400	706	6.198	318	0.833	1.5
401	706	5.683	309	0.971	8.3
600	706	3.67	350	0.602	3.2
601	706	3.418	343	0.795	5.4
600	705	3.38	348	1.002	14.7
400	756	4.747	316	0.604	1.2
400	756	4.923	321	0.807	2.6
400	755	4.033	352	1.000	7.8

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
467	705	5.646	1648	0.801	0.4	3.0	2.6	0.16
797	705	7.768	1642	0.800	2.0	2.9	0.9	0.05
493	757	6.722	1799	0.804	0.5	10.8	10.3	0.57

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
OCT. - DEC.	402	391	0.79	44	85

FIGURE 46a

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

HITACHI: 700 F, NH₃/NO_x=0.8

FIGURE 46b

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

HITACHI: $\text{NH}_3/\text{NO}_x=0.80$, 700 F

FIGURE 47a

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

HITACHI: DESIGN FLOW, 620F

(BDL) Below lower detection limit of 0.7-0.9 pp

FIGURE 47b

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

HITACHI: Design Flow, 620 F

(BDL) Below lower detection limit of 0.7-0.9 ppm

FIGURE 48a

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

TEMPERATURE (F)

HITACHI: DESIGN FLOW, NH₃/NO_x=0.8

FIGURE 48b

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

HITACHI: $\text{NH}_3/\text{NO}_x=0.80$, Design Flow

FIGURE 49

SO₂ OXIDATION VS. FLOWRATE

HITACHI: NH₃/NO_x=0.80, 700 F

FIGURE 50a

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%) HITACHI: DESIGN FLOW, NH₃/NO_x=0.8

FIGURE 50b

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%)

HITACHI: Design Flow, NH₃/NO_x=0.80

Figure 51. Six presentations of the Reactor G outlet mass concentration/mass emission profile.

REACTOR G
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 18.0 ± 1.5 ft/s

Figure 52a. Reactor G flue gas velocity profile.
Third Parametric Sequence

REACTOR G
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 14.2 ± 0.5 ft/s

Figure 52b. Reactor G flue gas velocity profile.
Fourth Parametric Sequence

- Reactor J

Tables 13a and 13b show the test data for intermediate ammonia, slip ammonia, and sulfur dioxide oxidation collected during this reporting period for the Cormetech low-dust catalyst. All the ammonia data are corrected to reactor inlet oxygen concentration. The long term NO_x reduction is also given in this table as an average over the operating periods shown, i.e., for July- September and October - December of 1994. The long term NO_x reduction data indicates the average performance of the catalyst at or near the design operating conditions of 0.8 ammonia-to- NO_x ratio, 5000 SCFM flow rate, and 700 °F reactor temperature.

The intermediate ammonia measurements were made after the first catalyst bed and at conditions thought to give the best kinetic information. The NO_x removals reported with the intermediate ammonia measurements are computed from the measured ammonia concentration using standard material balance techniques.

The ammonia slip data given in Tables 13a and 13b is presented below in three set of plots: ammonia slip versus each of flow rate, ammonia-to- NO_x ratio, and temperature. Figures 53a and 53b show ammonia slip versus flow rate at roughly 80% NO_x reduction for the third and fourth parametric sequences, respectively. As expected, the trend shows increasing ammonia slip with increasing reactor flow rate. The ammonia slip is, however, relatively minor indicating the ability of the catalyst design to withstand significant increases in flow while maintaining ammonia slip limits. Since a portion of the overall reaction rate is due to mass transfer limitations, improvements in bulk mass transfer coefficients are likely mitigating the effect of increased flow on slip ammonia increases. These plots demonstrate the ability of an SCR system to follow load variations dictated by the host boiler while maintaining design specifications.

Figures 54a and 54b show ammonia slip versus ammonia-to- NO_x ratio at low temperature and design flow rate for the third and fourth parametric sequences, respectively. These plots show sharp increases in ammonia slip as the ammonia-to- NO_x ratio approaches 1.0. This finding is in keeping with published data of this type. At ammonia-to- NO_x ratios near 1.0, non-idealities in the reactor system force the catalyst to slip ammonia since areas are present in the reactor where NO_x is the limiting reagent.

Ammonia slip versus temperature for design flow and roughly 80% NO_x reduction is plotted in Figure 55 for the fourth parametric sequence (this plot was not available for the third parametric sequence). Some improvement (decrease) in ammonia slip is noted between 620 and 680 °F, likely due to improvements in the kinetic reaction rate with increasing temperature. The slight increase shown between the 680 and 760 °F points is likely due to measurement variability and is not considered significant. In this case, the plot should not be construed as demonstrating increases in ammonia slip with increasing temperatures above 680 °F. It is expected that the 680 and 760 °F values are roughly equivalent which may be due in part to mass transfer limitations that have become controlling at these higher temperatures. In general, the plot demonstrates that in terms of ammonia slip, significant improvements are not realized with temperatures above 700°F. Losses in boiler efficiency would probably outweigh any improvements that may be obtained in ammonia slip by designing an SCR reactor to operate at temperatures near 750°F.

The plot for SO₂ oxidation versus flow rate at design temperature for the combination of all catalyst beds in the reactor is shown in Figure 56. Although the plot shows increasing SO₂ oxidation with increasing flow rate, this trend is not expected. Published rate equations and catalyst supplier information indicate that the general form of the plot should be linear with SO₂ oxidation decreasing with flow rate. In this case, the uncharacteristic profile indicates that either chemical or physical characteristics of the catalyst and reactor are masking this linear effect.

Figure 57 shows SO₂ oxidation versus temperature at design flow rate for the combination of all catalyst beds in the reactor for the fourth parametric sequence (this plot was not available for the third parametric sequence). Published information describing the effects of temperature on SO₂ oxidation and information obtained from the catalyst suppliers indicate that increases in SO₂ oxidation are expected to be more exponential with respect to temperature. The exact shape of the plot is somewhat unclear since fairly large measurement variability exists in the test facility and other phenomena such as SO₃ deposition occur in the test facility reactors. The general trend of increasing SO₂ oxidation is expected, however, and the plot provides a good basis for determining the potential for SO₃ formation across the SCR reactor at various operating temperatures.

The SO₂ oxidation data are corrected to reactor outlet oxygen concentrations. The value for sulfur trioxide produced in the reactor is based on the measured inlet and outlet sulfur trioxide concentrations. (Tables showing SO₂ oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO₃ is measured at this point. For consistency with other figures, the plots

of SO₂ oxidation versus flow rate are based on reactor inlet flow rates. In practice, differences between inlet and outlet flow rates are slight and do not greatly affect the overall analysis.)

Mass concentrations were not measured on this reactor due to the extremely low mass loading downstream of the host unit ESP. A three-point flue gas velocity profile was conducted at the design operating conditions at the reactor inlet for both the third and fourth parametric sequences. Flue gas velocity profiles are presented in Figures 58a and 58b. The average gas velocity during the third sequence was 16.7 ± 1.0 ft/sec, with a relative standard deviation of 6.0%. For the fourth sequence the average gas velocity was 14.2 ± 0.4 ft/sec. The velocity profile was generally flat with a standard deviation of 2.8%.

HCl concentrations were measured at the design operating condition at the reactor outlet during both the third and fourth parametric sequences. The resulting average HCl concentrations (at 3% O₂, dry) were 234 ± 5 ppmv and 244 ± 2 ppmv respectively. The N₂O concentrations were also measured during the fourth parametric sequence at the reactor inlet (1.2 ppmv) and at the reactor outlet (2.5 ppmv, both measurements were dry at 3% O₂).¹

TABLE 13a. REACTOR J DATA (3rd Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
403	625	4.427	290	0.752	29.6	65.0
597	628	3.917	283	0.972	67.0	73.5
401	707	3.702	305	0.595	15.4	54.5
404	706	3.686	309	0.794	25.6	71.1
391	706	3.745	310	1.018	39.8	88.9
605	693	3.294	313	0.795	43.1	65.8

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
240	623	5.534	307	0.800	0.9
402	623	5.534	320	0.604	1.5
400	623	3.775	299	0.766	2.7
400	625	7.436	331	0.940	3.5
596	625	6.061	323	0.933	16.6
375	707	3.835	301	0.580	0.7
401	708	3.039	308	0.596	1.2
395	706	3.881	322	1.001	3.6
594	695	3.488	300	0.540	1.8
601	688	1.715	294	0.740	3.9
600	691	1.882	302	0.931	10.6

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS. SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
413	705	3.381	2078	0.798	0.6	8.4	7.8	0.36

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
JULY - SEP.	398	386	0.76	106	71

TABLE 13b. REACTOR J DATA (4th Parametric Sequence)

INTERMEDIATE AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	INT. NH ₃ (ppmv)	INT. NO _x REDUCTION (%)
400	624	5.470	332	0.802	16.7	75.2
594	625	5.194	342	1.010	108.5	69.3
400	707	3.663	330	0.597	4.3	58.4
400	707	4.022	335	0.805	9.3	77.7
404	708	3.736	333	1.000	25.1	92.4
600	703	3.213	319	0.804	27.7	71.7
403	756	6.328	257	0.810	37.7	66.3

SLIP AMMONIA PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP. (°F)	INLET O ₂ (%)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	SLIP NH ₃ (ppmv)
239	625	3.490	289	0.815	1.1
400	625	3.306	310	0.603	0.7
402	625	3.954	332	0.796	1.6
403	625	4.036	320	0.995	6.8
601	624	3.250	310	1.004	18.3
399	646	7.202	330	0.799	0.5
399	666	6.783	320	0.799	0.8
400	705	5.236	305	0.852	1.7
601	686	4.509	299	0.602	1.3
599	674	3.324	320	0.788	4.3
599	676	3.267	302	0.994	22.1
401	756	5.993	224	0.603	2.2
401	758	6.328	257	0.811	3.4
397	754	6.272	226	1.001	8.3

SULFUR DIOXIDE OXIDATION PARAMETRIC TEST DATA

FLOW RATE (SCFM)	TEMP (°F)	OUTLET O ₂ (%)	INLET SO ₂ (ppmv)	NH ₃ /NO _x RATIO	MEAS SO ₃ IN (ppmv)	SO ₃ OUT (ppmv)	SO ₃ formed (ppmv)	OXID. RATE (%)
498	704	7.678	1720	0.807	0.6	2.5	1.9	0.11
711	703	7.575	1666	0.783	1.3	5.2	3.9	0.23
494	756	7.751	1769	0.803	0.8	8.6	7.8	0.44

LONG TERM NO_x REDUCTION

TIME PERIOD	FLOW RATE (SCFM)	INLET NO _x (ppmv)	NH ₃ /NO _x RATIO	OUTLET NO _x (ppmv)	NO _x RED. (%)
OCT. - DEC.	404	398	0.76	69	0.79

FIGURE 53a

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

FLOW RATE (% of design)

CORM LD: 700 F, NH3/NOx=0.8

FIGURE 53b

AMMONIA SLIP VS. FLOW RATE

AMMONIA SLIP (ppm)

CORM LD: NH3/NOx=0.80, 700 F

FIGURE 54a

AMMONIA SLIP VS. NH₃/NO_x RATIO

AMMONIA SLIP (ppm)

CORM LD: DESIGN FLOW, 620F

FIGURE 54b

AMMONIA SLIP VS. NH3/NOx RATIO

AMMONIA SLIP (ppm)

NH3/NOx RATIO

CORM LD: Design Flow, 620 F

FIGURE 55

AMMONIA SLIP VS. TEMPERATURE

AMMONIA SLIP (ppm)

CORM LD: $\text{NH}_3/\text{NO}_x=0.80$, Design Flow

FIGURE 56

SO₂ OXIDATION VS. FLOWRATE

CORM LD: NH₃/NO_x=0.80, 700 F

FIGURE 57

SO₂ OXIDATION VS. TEMPERATURE

SO₂ OXIDATION (%)

CORM LD: Design Flow, NH₃/NOX=0.80

REACTOR J
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 16.7 ± 1.0 ft/s

Figure 58a. Reactor J flue gas velocity profile.
Third Parametric Sequence

REACTOR J
CATALYST LAYER 1 INLET

Velocity Profile
ft/s

Average = 14.2 ± 0.4 ft/s

Figure 58b. Reactor J flue gas velocity profile.
Fourth Parametric Sequence

Section 5

PROJECT MANAGEMENT AND REPORTING

The following major management and reporting activities occurred during this reporting period:

Intermediate NO_x analysis system was returned to Lear Siegler Measurement Controls Corporation for refund due to unacceptable system performance.

Project status meeting was held December 6 and 7, 1994

Facility tour and project discussion provided to Chinese Delegation for Clean Combustion Technologies

Status report and tour provided to plant managers of The Southern Company

Status report and tour provided to representatives from Eglin Air Force Base

Paper presented at the DOE Third Annual Clean Coal Technology Conference

Section 6

PLANNED ACTIVITIES

During the first two quarters of 1995, the following activities are planned:

Complete the fifth and final set of parametric tests on all operating reactors/catalysts, while continuing to operate at long term conditions for the reactors/catalysts not undergoing parametric testing.

Remove catalyst samples and submit for laboratory analysis.

Maintain and repair equipment as needed to continue satisfactory operation. Monitor and clean air heaters as needed.

Continue to pursue technology transfer objectives by presenting technical information at appropriate forums.

Prepare for and conduct maintenance activities during the scheduled host unit outage (planned for February through mid-April, 1995).

Perform major maintenance and inspection of test facility air preheaters.

Make necessary preparations for facility dismantling and disposition upon completion of the operating phase of the project.

Evaluate commercially available ammonia monitors for their applicability to SCR technology.

REFERENCES

1. Testing and Analytical Services for the Innovative Clean Coal Technology Demonstration of Selective Catalytic Reduction (SCR) Technology for the Control of Nitrogen Oxide (NO_x) Emissions from High Sulfur Coal, Interim Report for Task 4, Parts 1 - 7 (Reactors A -G), Long-Term Parametric Tests, Draft SRI report to SCS.

APPENDIX A-1

Testing and Analytical Services for the Innovative Clean Coal Technology Demonstration of Selective Catalytic Reduction (SCR) Technology for the Control of Nitrogen Oxide (NO_x) Emissions from High Sulfur Coal, Final Report, Task 4: Air Heater Tests, Second Parametric Series, SRI report to SCS, September 10, 1995.

**TESTING AND ANALYTICAL SERVICES FOR THE INNOVATIVE CLEAN COAL
TECHNOLOGY DEMONSTRATION OF SELECTIVE CATALYTIC REDUCTION
(SCR) TECHNOLOGY FOR THE CONTROL OF NITROGEN OXIDE (NO_x)
EMISSIONS FROM HIGH SULFUR COAL**

Final Report for Task 4

**Air Heater Tests
Reactors A, B, C
Second Parametric Series**

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September 10, 1995

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Section 1

INTRODUCTION

This report is the eighth in a series of reports describing the results of testing and analytical services for the Innovative Clean Coal Technology Demonstration of Selective Catalytic Reduction (SCR) Technology for the control of nitrogen oxide (NO_x) emissions from high-sulfur, coal-fired boilers. The test results for the second sequence of air heater tests are summarized in this report. The air heater evaluations were conducted at the beginning (June 1994) and end (October 1994) of the second sequence of parametric testing under Task 4: Long-Term Parametric Tests. The tests in June 1994 (SO_2 , SO_3 , and particulate mass concentrations) were specifically conducted to establish a set of baseline performance values. (The air heaters had been washed and a partial replacement of baskets had occurred on the two rotary air heaters (A and B) during the May/June 1994 outage.)

The SCR test facility is located at Gulf Power Company's Plant Crist Unit 5 in Pensacola, Florida. The test facility includes three large SCR reactors, each designed to treat 5000 wscfm of flue gas, and six small reactors, each processing 400 wscfm of flue gas. An air heater capable of removing sufficient heat to reduce the flue gas temperature from a range of 600 to 750 °F down to 300 °F was included in the design of each of the three large reactors. The three large reactors are designated as reactors A, B, and C. Reactors A and B incorporate Ljungstrom-type air heaters and Reactor C's air heater incorporates a heat pipe design.

The original design of the SCR test facility also included bypass heat exchangers on each of the three large reactors. These units were intended for use during parametric testing of the reactors (Task 4: Long Term Parametric Tests) so that flue gas containing higher concentrations of slip ammonia could be diverted around the air heaters. However, the bypass heat exchangers did not function as planned and the practice of bypassing the air heaters on Reactors A, B and C during parametric testing was abandoned. Thus, the air heater test data presented in this report include the effects of day-long periods of exposure to ammonia concentrations normally ranging from a few parts per million by volume ppm(v) to 20 ppm(v), although brief excursions approached 100 ppm(v).

The air heater testing included the determinations of particulate mass concentration (outlet of Reactor A and B air heaters) and measurements of the concentrations of sulfur dioxide, sulfur trioxide, hydrogen chloride and ammonia (inlet and outlet of Reactor A, B and C air heaters). All tests were conducted with manual sampling methods. Ammonia samples were segregated into solid and gas-phase fractions to characterize the gas/solid phase partitioning of ammonia across the air heaters. In general, simultaneous tests were performed at the inlet and outlet of each of the three air heaters.

This report is divided into several sections. Section 2 describes the test methods used for the air heater testing. Section 3 reviews all of the test results. The test data are briefly summarized in Section 4. Tables containing original data summaries that were produced for the air heater testing are contained in Appendix A.

Section 2

TEST METHODS

A variety of test methods were used to characterize air heater performance. The following subsections briefly describe the test methods for ammonia (NH_3), sulfur dioxide (SO_2), sulfur trioxide (SO_3), hydrogen chloride (HCl), and particulate mass concentration. Figure 2-1 shows a sketch of a large reactor and its air heater (not to scale). The test port locations for air heater inlet and outlet measurements are indicated on the diagram. Test ports (three horizontal ports) downstream of the third catalyst layer (the normal reactor outlet test location) were used to measure concentrations of air heater inlet gas constituents. Three test ports (horizontal) were installed in a transition piece in the outlet ducting of the Reactor A and B air heaters that were suitable for particulate and gas phase flue gas constituent testing. Test ports at this same location in the Reactor C air heater outlet were not installed. However, a single test port (horizontal) in a section of ducting at the inlet transition to the cyclone on Reactor C (downstream of the reactor bypass duct) was suitable for testing gas phase flue gas constituents (Reactor C air heater outlet). Turbulent flow at this location precluded mass concentration tests, however.

Air heater tests were performed with the reactors operating at Test Condition 22, the normal baseline or long-term operating condition. These operating conditions included a flue gas temperature of 700 °F, an NH_3/NO_x ratio of 0.8, and a flue gas flow rate of 5000 wscfm (100% of design flow rate). During measurements of air heater inlet and outlet ammonia concentrations only, additional tests were performed at Test Condition 24. The operating parameters for these tests were a flue gas temperature of 700 °F, an NH_3/NO_x ratio of 1.0, and a flue gas flow rate of 5000 wscfm.

AMMONIA

Ammonia concentrations were measured simultaneously at the air heater inlet (downstream of the third catalyst layer) and at the air heater outlet on each of the large reactors. At each site and at each test condition, three independent tests were performed to determine an average ammonia concentration. Sampling ports located downstream of the third catalyst layer were used to measure air heater inlet ammonia concentration. Flue gas was sampled at three equally-spaced points in each of the three test ports (a total of nine traverse points) to determine an average inlet ammonia concentration for each test. At the air heater outlet sampling location on Reactors A and B the probe also sampled at three equally-spaced points in each of the three test ports (a total of nine traverse points). At the single Reactor C outlet test port, the ammonia probe traversed three, equally-spaced, points (front to rear) during each test.

Figure 2-1. Schematic drawing of SCR reactor and air heater cross section (side view).

Figure 2-2. Schematic diagram of the ammonia sampling train.

A schematic drawing of the ammonia sampling train is shown in Figure 2-2. The flue gas sample is drawn through a glass-lined probe and a heated filter to remove particulate. The filter is maintained at the nominal flue gas temperature. The gas sample passes through a length of PTFE tubing to a set of three impingers in an ice bath. The first two impingers contain a 0.1 normal solution of sulfuric acid. The third impinger serves as a trap to prevent the solutions from accidentally being drawn into the pump. A second glass wool plug is placed in the line between the last two impingers to collect any ammonia aerosols that may escape the second impinger. The remainder of the train consists of a silica gel column to remove the last traces of water from the flue gas sample, a leak-free pump, and a dry gas meter to measure the volume of the sample.

The samples were segregated during sample collection into a solid-phase sample and a gas-phase sample. The solid-phase sample consisted of the heated filter, all of the collected particulate, and the probe-wash liquid. The gas-phase sample consisted of the impinger liquids and the wash and rinse liquids. The two samples were analyzed separately to characterize the ammonia partitioning between the gas and solid phases.

At the outset of the Task 4 parametric testing, modified Greenberg-Smith type impingers were used for ammonia sampling. However, 100 ml gas sampling impingers, each containing about 50 ml of solution, were used for the air heater ammonia testing to reduce the detection limit to less than 1 ppm(v) for a reasonable sample volume, about 3 ft³ of gas. The lower detection limit was needed for much of the air heater ammonia testing because ammonia concentrations are very low at the reactor exit when operating at the reactor design condition with an NH₃/NO_x ratio of 0.8.

The impinger solutions are made alkaline in the laboratory (converting the NH₄⁺ ion to free NH₃ in solution). The concentration of ammonia is then determined with an ammonia ion specific electrode, Orion Model 920A. As mentioned above, three individual measurements of ammonia concentration are made for each test condition. Two independent determinations of the ammonia concentration are then conducted on each sample.

SULFUR DIOXIDE AND SULFUR TRIOXIDE

During the air heater evaluation, SO₂ and SO₃ concentrations were measured simultaneously at the reactor outlet downstream of the third catalyst layer (air heater inlet) and the air heater outlet. Sulfur dioxide (SO₂) and sulfur trioxide (SO₃) were collected in a controlled condensation

sampling train. All tests were conducted using single-point sampling in either the right-hand port (air heater inlet test location) or middle port (air heater outlet test location).

Figure 2-3. Schematic diagram of the controlled condensation sampling train for SO_2 and SO_3 .

A schematic drawing of the SO_2/SO_3 sampling train is shown in Figure 2-3. The flue gas sample is drawn through a heated, quartz-lined probe maintained above 550°F . The sample then passes through a quartz filter housed in a heated quartz filter holder, also maintained at 550°F . The next element in the train is the SO_3 condenser. The condenser is a length of quartz tubing packed with quartz wool and maintained between 120°F and 130°F in a heated water bath. The sample next passes through a length of PTFE tubing to a set of three impingers in an ice bath. The first two impingers contain a 3% solution of hydrogen peroxide to oxidize SO_2 . The third impinger serves as a trap to prevent the solutions from accidentally being drawn into the pump. The remainder of the train consists of a silica gel column to remove the last traces of water from the sample, a leak-free pump, and a dry gas meter to measure the volume of the sample.

The SO_3 is collected in the condensing element and the SO_2 is collected in the bubblers by oxidation with the hydrogen peroxide, converting it to H_2SO_4 in solution. In the condenser the SO_3 present begins a hydration reaction with the water vapor present making H_2SO_4 . The excess water vapor also condenses to produce a condensate of concentrated aqueous H_2SO_4 . Thus, two solutions of H_2SO_4 are collected; one a very concentrated solution of limited amount containing the original SO_3 and the other a relatively weak solution in far greater amount containing the original SO_2 . The concentrations of the sulfate ion are determined by ion chromatography using a DIONEX Model DX-100 Ion Chromatograph.

HYDROGEN CHLORIDE

Figure 2-4. Schematic diagram of the chloride sampling train.

A schematic sketch of the chloride sampling train is shown in Figure 2-4. The flue gas sample is drawn through a heated, quartz-lined probe maintained above 550 °F. The sample then passes through a quartz filter housed in a heated quartz filter holder, also maintained at 550 °F. The sample next passes through a length of PTFE tubing to a set of three impingers in an ice bath. The first two impingers contain type 1 de-ionized water for removal of HCl vapor. The third impinger serves as a trap to prevent the solutions from accidentally being drawn into the pump. The remainder of the train consists of a silica gel column to remove the last traces of water from the sample, a leak-free pump, and a dry gas meter to measure the volume of the sample.

The chloride ion concentration is determined by ion chromatography using a DIONEX Model DX-100 Ion Chromatograph. Hydrogen chloride concentrations were determined by single-point sampling (at the mid-point of the duct) at the air heater inlet (downstream of the third catalyst layer, right-hand port) and at the air heater outlet (middle port). Inlet and outlet tests were conducted simultaneously.

MASS CONCENTRATION

Mass concentration was measured using a sampling train similar to that defined in the EPA Reference Test Method 17. A schematic drawing of the train used for mass concentration sampling is shown below in Figure 2-5.

Figure 2-5. Schematic drawing of the mass concentration sampling train.

This train consists of a filter holder and nozzle that is designed to operate in the flue gas stream, followed by a heated sampling probe, a condenser, a drying column, a gas meter, a pump, and finally a flow control mechanism, usually a calibrated orifice. An S-type pitot and thermocouple located near the nozzle provide a means for sampling isokinetically during each test. The glass fiber thimbles are desiccated before and after sampling and then weighed on an electronic microbalance.

Particulate mass concentrations were measured simultaneously upstream of catalyst layer 4 (air heater inlet) and at each air heater outlet (except Reactor C). At the air heater inlet, the three sample ports immediately above the access door at the fourth catalyst layer were used to obtain the sample. During each test particulate was sampled at three, equally-spaced, positions within the three test ports (a total of nine traverse points). At the air heater outlets on reactors A and B, three ports are available for mass sampling. During each test particulate was sampled at three, equally-

spaced, positions within the three test ports (a total of nine traverse points). Three runs were made at each test site to give a meaningful statistical average.

.SAMPLING QUALITY ASSURANCE

The measures adopted to ensure that meaningful results were obtained during the various testing procedures can be divided into three categories; equipment maintenance and calibrations, operating techniques, and analytical techniques. New equipment was obtained for use in the SCR testing program and preventive maintenance and calibrations are performed at regular intervals. Due to the dynamic nature of the process, each measurement requires three replicate samples. The replicates are averaged to yield a representative value. Variability gives a means to discern any anomalies not revealed by other quality control checks.

The sample trains are leak-checked by drawing a vacuum of 15 in. Hg before and after each sampling run. No in-leakage is tolerated. If any loss of pressure is observed within one minute, the source of the leakage is found and eliminated prior to testing. During each run the oxygen level of the gas exiting the dry gas meter is measured to detect air in-leakage that could dilute the samples.

Ammonia samples are analyzed with an ion-specific electrode. The instrument is calibrated using 0.1 µg/ml, 0.5 µg/ml, 1.0 µg/ml, 5.0 µg/ml and 10 µg/ml standards. At the conclusion of each analytical session, a sample spiked with a known amount of ammonia is analyzed and the result compared with the predicted concentration. A blank sample is analyzed to detect zero drift and a mid-range standard is also analyzed to detect calibration drift.

Both the sulfate (SO_2 & SO_3) samples and the chloride (HCl) samples are analyzed by means of ion chromatography. This instrument is calibrated using a minimum of three points on the calibration curve. As with the ammonia analysis, spiked samples, blanks, and standards are analyzed to ensure that calibration drift has not occurred.

While gas-phase flue gas constituents are being sampled, both field blanks and sample blanks are run as quality control checks. The field blank consists of a container of type 1 de-ionized water that is exposed to ambient air at the sampling site. Sample blanks are obtained by passing ambient air through the probe and through the impingers filled with the appropriate solution. These blanks would detect sample contamination should it occur.

Section 3

AIR HEATER TEST RESULTS

AMMONIA CONCENTRATIONS

Concentrations of ammonia were measured simultaneously at each of the three air heater inlet and outlet test locations with the reactors operating at Test Condition 22, the baseline operating condition ($\text{NH}_3/\text{NO}_x = 0.8$), and at Test Condition 24 ($\text{NH}_3/\text{NO}_x = 1.0$). The ammonia testing protocol, designed to differentiate between gas-phase and solid-phase ammonia, as described in Section 2, was used.

The test data and estimated solid-phase ammonia concentrations on a mass of ammonia per mass of ash basis are presented in Table 3-1. The mass-basis ammonia concentrations shown in the table for the ash entering and exiting the air heater were derived both from solid-phase ammonia measurements conducted simultaneously with the gas-phase measurements and mass concentration measurements made earlier at the same location. The ammonia partitioning between the gas and solid phases shown in the table are similar for all three air heaters. These data show that ammonia partitioning at the inlet to the air heater is roughly equal (on a flue gas volumetric basis or ammonia mass basis) between the gas and solid phases and that the ammonia shifts heavily to the solid phase as it cools while passing through the air heater.

As expected, the data in Table 3-1 show a significant increase in ammonia concentration in both the gas and solid phase (except the gas phase at the air heater outlets) during operation at the higher NH_3/NO_x ratio at Test Condition 24. For the gas phase at the air heater inlets, the range of concentrations at Test Condition 24 was 1.2 to 7.3 ppm(v) dry @ 3 % O_2 , while at Test Condition 22 the range of concentrations was 0.4 to 1.3 ppm(v) dry @ 3 % O_2 . For the solid phase at the air heater inlets the range of ammonia concentrations at Test Condition 24 was 1.4 to 6.5 ppm(v) dry @ 3 % O_2 , (188 to 887 $\mu\text{g/g}$ of ash), while at Test Condition 22 the range of ammonia concentrations was 0.4 to 2.0 ppm(v) dry @ 3 % O_2 (51 to 270 $\mu\text{g/g}$ of ash). The partitioning shifts heavily toward the solid phase at the air heater outlets. As expected, a significant increase in total ammonia concentration was measured during operation at the higher NH_3/NO_x ratio at Test Condition 24.

Each ammonia sampling train was used to run a blank sample by sampling ambient air before each set of tests was run to demonstrate the integrity of the equipment. The original data summaries from these blank ammonia concentration tests can be found in Table A-1 in Appendix A. The original data summaries for the actual ammonia concentration tests at Test Conditions 22 and 24 can be found in Table A-2 in Appendix A.

SO_2 and SO_3 CONCENTRATIONS

Concentrations of sulfur dioxide and sulfur trioxide were measured simultaneously at the air heater inlet and outlet test locations of Reactors A, B, and C during operation at Test Condition 22. Tests were conducted both at the beginning (baseline performance) and the end of the second parametric test sequence under Task 4 (June and October 1994). Concentrations of sulfur dioxide and sulfur

Table 3-1. SCR Reactor Air Preheater Tests, September and October, 1994: Ammonia Concentrations

Reactor	Date	$\frac{\text{NH}_3}{\text{NO}_x}$	Air Preheater Location	Gas-Phase NH_3 , ppm(v), @ 3% O_2 , dry	Solid-Phase NH_3 , Equivalent ppm(v), @ 3% O_2 , dry	Estimated Solid-Phase NH_3 , $\mu\text{g/g}$	Estimated Upper Limit Solid-Phase NH_3 , $\mu\text{g/g}$	Estimated Lower Limit Solid-Phase NH_3 , $\mu\text{g/g}$
A	13-Oct-94	0.8	Inlet	0.4 ± 0.1	0.7 ± 0.2	87	119	58
			Outlet	<0.6	1.4 ± 0.2	191	222	163
A	13-Oct-94	1.0	Inlet	1.2 ± 0.3	1.4 ± 0.2	188	226	152
			Outlet	<0.6	1.7 ± 0.1	233	252	215
B	12-Oct-94	0.8	Inlet	0.6 ± 0.1	0.4 ± 0.1	51	61	41
			Outlet	<0.5	0.8 ± 0.1	119	134	104
B	12-Oct-94	1.0	Inlet	7.3 ± 6.3	4.9 ± 3.7	692	1233	170
			Outlet	<0.5	6.5 ± 5.5	923	1731	141
C	29-Sep-94	0.8	Inlet	1.3 ± 0.4	2.0 ± 0.2	270	314	228
			Outlet	<0.5	2.4 ± 0.2	324	359	291
C	30-Sep-94	1.0	Inlet	3.6 ± 0.5	6.5 ± 0.8	887	1028	755
			Outlet	<0.5	7.2 ± 3.5	990	1523	491

trioxide were also measured in October 1994 at the split inlet upstream of the three large reactors. The test data are summarized in Table 3-2 (June 1994) and Table 3-3 (October 1994).

In June 1994 SO_3 concentrations at the air heater inlets ranged from 10 to 19 ppm(v) dry @ 3% O_2 , while SO_3 concentrations at the air heater outlets ranged from 10 to 16 ppm(v) dry @ 3% O_2 . Reductions in SO_3 concentration across the air heaters ranged from 0% on Reactor B to 11% on Reactor A to 32% on Reactor C. Within the tolerance of the standard deviations given for average SO_2 concentrations in Table 3-3, there was only a slight increase in SO_2 concentration across the individual air heaters. The reason for this slight increase in concentration is not known. Air heater inlet SO_2 concentrations averaged 2038 ± 191 ppm(v) dry @ 3% O_2 , while the air heater outlet SO_2 concentrations averaged 2143 ± 179 ppm(v) dry @ 3% O_2 . Table A-3 in Appendix A contains the original data summaries for these tests.

In October 1994 SO_2 and SO_3 concentrations were measured at the split inlet upstream of the three large reactors. The average SO_2 concentration was 1880 ± 11 ppm(v) dry @ 3% O_2 and the average SO_3 concentration was 1.3 ± 0.01 ppm(v) dry @ 3% O_2 . Table A-4 in Appendix A contains the original data summaries for these tests.

During the October 1994 tests SO_3 concentrations at the air heater inlets ranged from 3.8 to 21.7 ppm(v) dry @ 3% O_2 , while SO_3 concentrations at the air heater outlets ranged from 7.3 to 15.6 ppm(v) dry @ 3% O_2 . Changes in SO_3 concentrations across the air heaters ranged from factors of 0.72 on Reactor A to 2.52 on Reactor B to 1.78 on Reactor C. Within the tolerance of the standard deviations given for average SO_2 concentrations in Table 3-3, there were measurable reductions in SO_2 concentrations across the individual air heaters. The reason for these rather large decreases in SO_2 concentration is not known. SO_2 concentrations changed by factors of 0.75 (Reactor A), 0.85 (Reactor B), and 0.76 (Reactor C). Overall, air heater inlet SO_2 concentrations averaged $1,957 \pm 71$ ppm(v) dry @ 3% O_2 , while the air heater outlet SO_2 concentrations averaged $1,539 \pm 165$ ppm(v) dry @ 3% O_2 . Table A-5 in Appendix A contains the original data summaries for these tests.

HCl CONCENTRATION

Measurements of the concentration of hydrogen chloride were conducted simultaneously at the inlet and outlet of each of the three large reactor air heaters in October 1994. Three independent tests were performed at each test location. Single point sampling was used. The test results are presented in Table 3-4 as the average concentration and the standard deviation. Air heater inlet HCl concentrations fell within the range of 92.8 to 101 ppm(v) dry @ 3% O_2 . Air heater outlet HCl concentrations fell within the range of 81.1 to 93.1 ppm(v) dry @ 3% O_2 . The decrease in HCl concentration across the air heaters ranged from 7.8% on Reactor B to 14.9% on Reactor C. The specific cause for this reduction in HCl concentration across the reactor air heaters is not known at this time. The original data summaries for these HCl tests are presented in Table A-6 in Appendix A.

PARTICULATE MASS CONCENTRATION

Particulate mass concentrations were measured only at the outlet of the air heaters on Reactors A and B during the baseline performance tests in June 1994. No outlet measurement was possible on

Table 3-2. SCR Reactor Air Heater Tests: SO₂ and SO₃ Concentrations (June 1994)

Reactor	SO ₃		SO ₂	
	Inlet	Outlet	Inlet	Outlet
	ppm(v), dry @ 3% O ₂	ppm(v), dry @ 3% O ₂	ppm(v), dry @ 3% O ₂	ppm(v), dry @ 3% O ₂
A	18.3 ± 3.5	16.0 ± 1.4	2187 ± 55	2294 ± 24
B	10.0 ± 5.1	10.0 ± 1.4	2104 ± 458	2190 ± 27
C	18.8 ± 3.1	12.6 ± 0.7	1822 ± 33	1945 ± 24

Table 3-3. SCR Reactor Air Heater Tests: SO₂ and SO₃ Concentrations (October 1994)

Reactor	SO ₃		SO ₂	
	Inlet	Outlet	Inlet	Outlet
	ppm(v), dry @ 3% O ₂	ppm(v), dry @ 3% O ₂	ppm(v), dry @ 3% O ₂	ppm(v), dry @ 3% O ₂
A	21.7 ± 2.3	15.6 ± 3.1	1890 ± 67	1413 ± 48
B	3.8 ± 1.2	9.6 ± 1.8	2032 ± 31	1726 ± 92
C	4.1 ± 0.8	7.3 ± 0.5	1949 ± 14	1479 ± 46

Table 3-4. SCR Reactor Air Heater Tests: HCl Concentrations

Reactor	HCl	
	Inlet	Outlet
	ppm(v), dry @ 3% O ₂	ppm(v), dry @ 3% O ₂
A	92.8 ± 1.9	81.1 ± 1.0
B	101 ± 5.0	93.1 ± 4.1
C	99.8 ± 4.0	84.9 ± 0.8

Table 3-5. SCR Reactor Air Heater Tests: Outlet Mass Concentrations

Reactor	Air Heater Outlet
	gr/dscf
A	2.48 ± 0.12
B	2.34 ± 0.04
C	Not Tested

the Reactor C air heater because sampling ports in a location suitable for mass concentration measurements could not be installed on that reactor.

Table 3-5 presents the mass concentration data for the air heater tests. The average air heater outlet mass concentration was 2.48 ± 0.12 gr/dscf on Reactor A and 2.34 ± 0.04 gr/dscf on Reactor B. The original data summaries for the mass concentration tests can be found in Table A-7 in Appendix A.

Section 4

SUMMARY

This report is the eighth in a series of reports describing the results of testing and analytical services for the Innovative Clean Coal Technology Demonstration of Selective Catalytic Reduction (SCR) Technology for the control of nitrogen oxide (NO_x) emissions from high-sulfur, coal-fired boilers. The test results for the second sequence of air heater tests are summarized in this report. The air heater evaluations were conducted at the beginning (June 1994) and end (October 1994) of the second sequence of parametric testing under Task 4: Long-Term Parametric Tests. The tests in June 1994 (SO_2 , SO_3 , and particulate mass concentrations) were specifically conducted to establish a set of baseline performance values. (The air heaters had been washed and a partial replacement of baskets had occurred on the two rotary air heaters (A and B) during the May/June 1994 outage.)

The SCR test facility is located at Gulf Power Company's Plant Crist Unit 5 in Pensacola, Florida. The test facility includes three large SCR reactors, each designed to treat 5000 wscfm of flue gas, and six small reactors, each processing 400 wscfm of flue gas. An air heater capable of removing sufficient heat to reduce the flue gas temperature from a range of 600 to 750 °F down to 300 °F was included in the design of each of the three large reactors. The three large reactors are designated as reactors A, B, and C. Reactors A and B incorporate Ljungstrom-type air heaters and Reactor C incorporates a heat pipe design.

The air heater testing included the determinations of particulate mass concentration and measurements of the concentrations of sulfur dioxide, sulfur trioxide, hydrogen chloride and ammonia with manual sampling methods. Ammonia samples were segregated into solid and gas-phase fractions to characterize the gas/solid phase partitioning of ammonia across the air heaters. Tests were performed at the inlet and outlet of each of the three air heaters (except for mass concentration measurements at the inlet of each reactor air heater and the outlet of the Reactor C air heater).

AMMONIA CONCENTRATIONS

At the air heater inlets, during measurements conducted in October 1994, the ammonia present was roughly divided equally between gas phase and solid phase. At the air heater outlets, the gas phase ammonia concentrations were below the detection limit, indicating that nearly all of the ammonia present had partitioned to the solid phase.

As expected, there was a measurable increase in ammonia concentration in both the gas and solid phases at the air heater inlets during operation at the higher NH_3/NO_x ratio at Test Condition 24 compared to Test Condition 22. At both parametric operating conditions, slip ammonia partitioned mostly to the solid phase at the air heater exit after being cooled while passing through the air heater.

SO₂ and SO₃ CONCENTRATIONS

In June 1994 (baseline performance) SO₃ inlet concentrations ranged from 10 to 19 ppm(v) dry @ 3% O₂, while SO₃ concentrations at the reactor outlets ranged from 10 to 16 ppm(v) dry @ 3% O₂. Reductions in SO₃ concentration across the air heaters ranged from 0% on Reactor B to 11% on Reactor A to 32% on Reactor C. Within the tolerance of the standard deviations given for average SO₂ concentrations, there was only a slight increase in SO₂ concentration across the individual air heaters. The reason for this slight increase in concentration is not known. Air heater inlet SO₂ concentrations averaged 2038 ± 191 ppm(v) dry @ 3% O₂, while the air heater outlet SO₂ concentrations averaged 2143 ± 179 ppm(v) dry @ 3% O₂.

In October 1994 SO₂ and SO₃ concentrations were measured at the split inlet upstream of the three large reactors. The average SO₂ concentration was 1880 ± 11 ppm(v) dry @ 3% O₂ and the average SO₃ concentration was 1.3 ± 0.01 ppm(v) dry @ 3% O₂.

During the October 1994 tests SO₃ concentrations at the air heater inlets ranged from 3.8 to 21.7 ppm(v) dry @ 3% O₂, while SO₃ concentrations at the air heater outlets ranged from 7.3 to 15.6 ppm(v) dry @ 3% O₂. Changes in SO₃ concentrations across the air heaters ranged from factors of 0.72 on Reactor A to 2.52 on Reactor B to 1.78 on Reactor C. Within the tolerance of the standard deviations given for the average SO₂ concentrations, there were measurable reductions in SO₂ concentrations across the individual air heaters. The reason for these rather large decreases in SO₂ concentration is not known. SO₂ concentrations changed by factors of 0.75 (Reactor A), 0.85 (Reactor B), and 0.76 (Reactor C). Overall, air heater inlet SO₂ concentrations averaged $1,957 \pm 71$ ppm(v) dry @ 3% O₂, while the air heater outlet SO₂ concentrations averaged $1,539 \pm 165$ ppm(v) dry @ 3% O₂.

HCl CONCENTRATIONS

Air heater inlet HCl concentrations, measured in October 1994, fell within the range of 92.8 to 101 ppm(v) dry @ 3% O₂. Air heater outlet HCl concentrations fell within the range of 81.1 to 93.1 ppm(v) dry @ 3% O₂. The decrease in HCl concentration across the air heaters ranged from 7.8% on Reactor B to 14.9% on Reactor C. The specific cause for this reduction in HCl concentration across the reactor air heaters is not known at this time.

MASS CONCENTRATIONS

The average air heater outlet mass concentrations, measured during baseline performance tests in June 1994, were 2.48 ± 0.12 gr/dscf for the Reactor A air heater and 2.34 ± 0.04 gr/dscf for the Reactor B air heater.

APPENDIX A
ORIGINAL DATA SUMMARIES

Table A-1

Well ID	Site	Gas	Number				NH ₃ Concentration		Analytical					Dry Gas Meter								
				Time, Begin	Time, End	Date	Average	σ	NH ₃	Dil	Vol.	NH ₃	NH ₃	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor
						mg/ml		ml	μM	ppm, dry	STD I, dry	°K	In. Hg	°F	°F	ft ³	ft ³					
093	AAI	NH ₃	01	0950	1003	13-Oct	< 0.48		0.014 0.010	1	234	1.67 1.67	0.5 0.5	78.05	297	29.98	75	76	631.700	634.700	Stack 1	0.998
093	AAO	NH ₃	01	0933	0944	13-Oct	< 0.75		0.000 0.000	1	366	2.61 2.61	0.8 0.8	77.86	295	29.98	72	72	530.200	533.200	SRI 3	0.989
093	BAI	NH ₃	01	0926	0941	12-Oct	< 0.47		0.032 0.043	1	232	1.66 1.66	0.5 0.5	78.41	296	29.95	72	73	589.700	592.700	Stack 1	0.998
093	BAO	NH ₃	01	0923	0934	12-Oct	< 0.54		0.010 0.009	1	301	2.15 2.15	0.5 0.5	89.08	292	29.95	66	67	485.900	489.300	SRI 3	0.989
091	CAI	NH ₃	01	0939	0955	29-Sep	< 0.37		0.022 0.016	1	238	1.70 1.70	0.4 0.4	103.33	301	30.04	82	82	435.100	439.100	Stack 1	1.001
091	CAO	NH ₃	01	0957	1012	29-Sep	< 0.60		0.073 0.076	1	287	2.05 2.05	0.6 0.6	76.86	300	30.04	80	80	387.800	390.800	SRI 3	0.989
091	CAO	NH ₃	05	0859	0911	30-Sep	< 0.64		0.009 0.007	1	311	2.22 2.22	0.6 0.6	77.65	297	30.04	73	76	410.700	413.700	SRI 3	0.989
091	CAI	NH ₃	05	0856	0612	30-Sep	< 0.30		0.028 0.022	1	191	1.36 1.36	0.3 0.3	103.53	300	30.04	81	81	460.200	464.200	Stack 1	1.001

Table A-2 (Reference Table 3-1)

Week of Year	Series	Object	Number				NH ₃ Concentration		Analytical					Reactor Conditions					Dry Gas Meter									
							ppm (v), dry, @ 3% O ₂		NH ₃	Dil	Vol.	NH ₃	NH ₃	Condition Number	Flow	Temp.	NH ₃ / NO _x	Unit & Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter LD	Corr. Factor
				Time, Begin	Time, End	Date	Average	σ	μ g/ml		ml	μ M	ppm(v), dry, 3% O ₂		scfm	° F		MW	%	STD L, dry	° K	In. Hg	° F	° F	ft ³	ft ³		
093	AAI	NHG	02	1043	1120	13-Oct-94	< 0.3		0.089	1	334	2.4	0.3	22	5000	705	0.8	79	2.8	156.25	297	29.98	77	73	635.000	641.000	Stack 1	0.998
									0.097			2.4	0.3															
093	AAI	NHG	03	1135	1215	13-Oct-94	0.5 ± 0.004		0.179		304	3.9	0.5	22	5000	705	0.8	79	2.6	157.13	295	29.98	73	71	641.200	647.200	Stack 1	0.998
									0.177			3.8	0.5															
093	AAI	NHG	04	1237	1316	13-Oct-94	0.4 ± 0.004		0.118		305	2.6	0.4	22	5000	705	0.8	76	2.6	156.98	296	29.98	72	73	647.400	653.400	Stack 1	0.998
									0.116			2.5	0.4															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							0.4 ± 0.11		Testing Interval Averages									78	2.7									
									σ									1.7	0.1									
093	AAI	NHS	02	1043	1120	13-Oct-94	0.4 ± 0.02		0.196	1	208	2.9	0.4	22	5000	705	0.8	79	2.8	156.25	297	29.98	77	73	635.000	641.000	Stack 1	0.998
									0.208			3.1	0.4															
093	AAI	NHS	03	1135	1215	13-Oct-94	0.8 ± 0.005		0.363		215	5.6	0.8	22	5000	705	0.8	79	2.6	157.13	295	29.98	73	71	641.200	647.200	Stack 1	0.998
									0.366			5.6	0.8															
093	AAI	NHS	04	1237	1316	13-Oct-94	0.8 ± 0.01		0.348		216	5.4	0.7	22	5000	705	0.8	76	2.6	156.98	296	29.98	72	73	647.400	653.400	Stack 1	0.998
									0.353			5.4	0.8															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							0.7 ± 0.20		Testing Interval Averages									78	2.7									
									σ									1.7	0.1									
093	AAO	NHG	02	1043	1112	13-Oct-94	< 0.6		0.000	1	380	2.7	0.6	22	5000	705	0.8	79	8.8	156.02	295	29.98	70	72	534.200	540.200	SRI 3	0.9891
									0.000			2.7	0.6															
093	AAO	NHG	03	1135	1204	13-Oct-94	< 0.6		0.000			2.7	0.6	22	5000	705	0.8	79	9.2	155.73	295	29.98	73	71	540.500	546.500	SRI 3	0.9891
									0.000			2.7	0.6															
093	AAO	NHG	04	1236	1304	13-Oct-94	< 0.6		0.000		380	2.7	0.6	22	5000	705	0.8	76	8.6	156.91	293	29.98	68	68	546.800	552.800	SRI 3	0.9891
									0.000			2.7	0.6															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							< 0.6		Testing Interval Averages									78	8.9									
									σ									1.7	0.3									
093	AAO	NHS	02	1043	1112	13-Oct-94	1.6 ± 0.02		0.502	1	208	7.5	1.6	22	5000	705	0.8	79	8.8	156.02	295	29.98	70	72	534.200	540.200	SRI 3	0.9891
									0.512			7.6	1.6															
093	AAO	NHS	03	1135	1204	13-Oct-94	1.4 ± 0.03		0.457		192	6.3	1.4	22	5000	705	0.8	79	9.2	155.73	295	29.98	73	71	540.500	546.500	SRI 3	0.9891
									0.470			6.4	1.4															
093	AAO	NHS	04	1236	1304	13-Oct-94	1.3 ± 0.03		0.397		224	6.4	1.3	22	5000	705	0.8	76	8.6	156.91	293	29.98	68	68	546.800	552.800	SRI 3	0.9891
									0.386			6.2	1.3															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							1.4 ± 0.16		Testing Interval Averages									78	8.9									
									σ									1.7	0.3									

Table A-2, continued (Reference Table 3-1)

W o r k e r	S i t e	Q u a l i t y	N u m b e r				NH ₃ Concentration		Analytical					Reactor Conditions					Dry Gas Meter									
									NH ₃	Dil	Vol	NH ₃	NH ₃	Condition Number	Flow	Temp.	NH ₄ NO _x	Unit # Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter ID	Corr. Factor
				Time, Begin	Time, End	Date	Average	σ	μg/ml		ml	μM	ppm(v), dry, 3% O ₂		scfm	° F		MW	%	STD L, dry	° K	in. Hg	° F	° F	ft ³	ft ³		
093	AAI	NHG	05	1441	1519	13-Oct-94	1.5	± 0.01	0.573	1	261	10.7	1.5	24	400	705	1	77	2.9	155.52	298	29.98	76	79	653.800	659.800	Stack 1	0.998
093	AAI	NHG	06	1534	1613	13-Oct-94	1.1	± 0.01	0.577			10.8	1.5	24	400	705	1	77	2.8	154.66	300	29.98	80	81	660.000	666.000	Stack 1	0.998
093	AAI	NHG	07	1626	1704	13-Oct-94	1.0	± 0.80	0.439			7.7	1.1	24	400	705	1	78	2.6	154.51	300	29.98	81	81	666.200	672.200	Stack 1	0.998
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							1.2	± 0.28	0.436			7.6	1.1	Testing Interval Averages					77	2.8								
									0.129		346	3.2	0.5	0.450					σ	0.6	0.2							
093	AAI	NHS	05	1441	1519	13-Oct-94	1.2	± 0.004	0.443	1	276	8.7	1.3	24	400	705	1	77	2.9	155.52	298	29.98	76	79	653.800	659.800	Stack 1	0.998
093	AAI	NHS	06	1534	1613	13-Oct-94	1.3	± 0.03	0.441			8.7	1.2	24	400	705	1	77	2.8	154.66	300	29.98	80	81	660.000	666.000	Stack 1	0.998
093	AAI	NHS	07	1626	1704	13-Oct-94	1.6	± 0.00	0.584		217	9.1	1.3	24	400	705	1	78	2.6	154.51	300	29.98	81	81	666.200	672.200	Stack 1	0.998
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							1.4	± 0.21	0.605			9.4	1.3	Testing Interval Averages					77	2.8								
									0.717		226	11.6	1.6	0.719					σ	0.6	0.2							
093	AAO	NHG	05	1439	1512	13-Oct-94	< 0.7		0.000	1	393	2.8	0.7	24	400	705	1	77	10.1	154.42	298	29.98	75	78	553.700	559.700	SRI 3	0.9891
093	AAO	NHG	06	1535	1605	13-Oct-94	< 0.6		0.000		403	2.9	0.6	24	400	705	1	77	9.3	153.70	299	29.98	78	80	560.000	566.000	SRI 3	0.9891
093	AAO	NHG	07	1625	1652	13-Oct-94	< 0.5		0.000		315	2.3	0.5	24	400	705	1	78	9.0	153.70	299	29.98	78	80	566.300	572.300	SRI 3	0.9891
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							< 0.6		0.000			2.3	0.5	Testing Interval Averages					77	9.5								
																			σ	0.6	0.6							
093	AAO	NHS	05	1439	1512	13-Oct-94	1.8	± 0.02	0.536	1	194	7.4	1.8	24	400	705	1	77	10.1	154.42	298	29.98	75	78	553.700	559.700	SRI 3	0.9891
093	AAO	NHS	06	1535	1605	13-Oct-94	1.7	± 0.02	0.543			7.5	1.8	24	400	705	1	77	9.3	153.70	299	29.98	78	80	560.000	566.000	SRI 3	0.9891
093	AAO	NHS	07	1625	1652	13-Oct-94	1.7	± 0.01	0.455		228	7.4	1.7	24	400	705	1	78	9.0	153.70	299	29.98	78	80	566.300	572.300	SRI 3	0.9891
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							1.7	± 0.06	0.464			7.6	1.7	Testing Interval Averages					77	9.5								
									0.534		210	8.0	1.8	0.528					σ	0.6	0.6							

Table A-2, continued (Reference Table 3-1)

W e s t e r	S i t e	O b j e c t	N o. E v e n t				NH ₃ Concentration		Analytical					Reactor Conditions					Dry Gas Meter									
				Time, Begin	Time, End	Date	ppm (v), dry, @ 3% O ₂		NH ₃	OH	Vol.	NH ₃	NH ₃	Condition Number	Flow	Temp.	NH ₃ / NO _x	Unit & Boiler Load,	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter LD	Corr. Factor
							Average	σ	mg/ml		ml	μ M	ppm(v), dry, 3% O ₂		scfm	°F		MW	%	STD L dry	°K	in. Hg	°F	°F	ft ³	ft ³		
093	BAI	NHG	02	1043	1118	12-Oct	0.6	± 0.03	0.187	1	277	3.7	0.6	22	5000	705	0.8	84	4.0	156.09	297	29.95	74	76	593.000	599.000	Stack 1	0.998
									0.200			4.0	0.6															
093	BAI	NHG	03	1137	1215	12-Oct	0.6	± 0.00	0.182		302	3.9	0.6	22	5000	705	0.8	86	4.2	157.95	298	29.95	76	79	599.200	605.300	Stack 1	0.998
									0.180			3.9	0.6															
093	BAI	NHG	04	1233	1312	12-Oct	0.7	± 0.01	0.204		313	4.6	0.7	22	5000	705	0.8	83	4.2	154.93	299	29.95	78	80	605.500	611.500	Stack 1	0.998
									0.199			4.4	0.7															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							0.6	± 0.06						Testing Interval Averages					84	4.1								
														σ					1.5	0.1								
093	BAI	NHS	02	1043	1118	12-Oct	0.3	± 0.00	0.145	1	181	1.9	0.3	22	5000	705	0.8	84	4.0	156.09	297	29.95	74	76	593.000	599.000	Stack 1	0.998
									0.147			1.9	0.3															
093	BAI	NHS	03	1137	1215	12-Oct	0.4	± 0.01	0.184		193	2.5	0.4	22	5000	705	0.8	86	4.2	157.95	298	29.95	76	79	599.200	605.300	Stack 1	0.998
									0.191			2.6	0.4															
093	BAI	NHS	04	1233	1312	12-Oct	0.4	± 0.00	0.171		213	2.6	0.4	22	5000	705	0.8	83	4.2	154.93	299	29.95	78	80	605.500	611.500	Stack 1	0.998
									0.171			2.6	0.4															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							0.4	± 0.06						Testing Interval Averages					84	4.1								
														σ					1.5	0.1								
093	BAO	NHG	02	1042	1111	12-Oct	< 0.5		0.030	1	323	2.3	0.5	22	5000	705	0.8	84	8.0	156.31	294	29.95	68	71	489.700	495.700	SRI 3	0.9891
									0.027			2.3	0.5															
093	BAO	NHG	03	1137	1206	12-Oct	< 0.5		0.016		354	2.5	0.5	22	5000	705	0.8	86	7.5	156.60	293	29.95	67	70	496.200	502.200	SRI 3	0.9891
									0.017			2.5	0.5															
093	BAO	NHG	04	1234	1303	12-Oct	< 0.5		0.014		371	2.7	0.5	22	5000	705	0.8	83	7.3	156.01	294	29.95	69	72	502.700	508.700	SRI 3	0.9891
									0.014			2.7	0.5															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							< 0.5							Testing Interval Averages					84	7.6								
														σ					1.5	0.4								
093	BAO	NHS	02	1042	1111	12-Oct	0.7	± 0.01	0.348	1	148	3.7	0.7	22	5000	705	0.8	84	8.0	156.31	294	29.95	68	71	489.700	495.700	SRI 3	0.9891
									0.355			3.8	0.7															
093	BAO	NHS	03	1137	1206	12-Oct	0.9	± 0.01	0.426		158	4.8	0.9	22	5000	705	0.8	86	7.5	156.60	293	29.95	67	70	496.200	502.200	SRI 3	0.9891
									0.435			4.9	0.9															
093	BAO	NHS	04	1234	1303	12-Oct	0.8	± 0.01	0.344		184	4.5	0.9	22	5000	705	0.8	83	7.3	156.01	294	29.95	69	72	502.700	508.700	SRI 3	0.9891
									0.340			4.5	0.8															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							0.8	± 0.10						Testing Interval Averages					84	7.6								
														σ					1.5	0.4								

Table A-2, continued (Reference Table 3-1)

W e s t e r n	S i l e n t e r r y	O r i e n t e r r y	N o r t h e r n				NH ₃ Concentration		Analytical					Reactor Conditions					Dry Gas Meter									
									NH ₃	Dil	Vol	NH ₃	NH ₃	Condition Number	Flow	Temp.	NH ₃ / NO _x	Unit 5 Boiler Load,	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter LD	Corr. Factor
				Time, Begin	Time, End	Date	Average	σ	mg/ml		ml	μM	ppm(v), dry, 3% O ₂		scfm	°F		MW	%	STD L, dry	°K	In. Hg	°F	°F	m ³	m ³		
093	BAI	NHG	05	1457	1535	12-Oct	2.2	± 0.03	0.660	1	299	14.1	2.2	24	400	705	1	82	4.4	155.65	298	29.95	77	76	611.700	617.700	Stack 1	0.998
093	BAI	NHG	06	1554	1633	12-Oct	5.5	± 0.05	0.673			14.4	2.2	24	400	705	1	80	4.4	155.95	297	29.95	76	75	617.900	623.900	Stack 1	0.998
									1.540	316	34.8	5.4	1.560															
093	BAI	NHG	07	1648	1727	12-Oct	14.3	± 0.00	4.790		272	93.1	14.3	24	400	705	1	80	4.2	155.80	297	29.95	76	76	624.100	630.100	Stack 1	0.998
									4.790			93.1	14.3															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							7.3	± 6.28						Testing Interval Averages			81	4										
														σ			1.2	0.1										
093	BAI	NHS	05	1457	1535	12-Oct	1.8	± 0.07	0.809	1	204	11.8	1.8	24	400	705	1	82	4.4	155.65	298	29.95	77	76	611.700	617.700	Stack 1	0.998
093	BAI	NHS	06	1554	1633	12-Oct	3.9	± 0.00	0.763			11.1	1.7	24	400	705	1	80	4.4	155.95	297	29.95	76	75	617.900	623.900	Stack 1	0.998
									1.770	200	25.3	3.9	1.770															
093	BAI	NHS	07	1648	1727	12-Oct	8.9	± 0.05	3.830		213	58.3	9.0	24	400	705	1	80	4.2	155.80	297	29.95	76	76	624.100	630.100	Stack 1	0.998
									3.800			57.8	8.9															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							4.9	± 3.67						Testing Interval Averages			81	4										
														σ			1.2	0.1										
093	BAO	NHG	05	1456	1528	12-Oct	< 0.5		0.008	1	355	2.5	0.5	24	400	705	1	82	7.5	154.41	297	29.95	74	78	509.400	515.400	SRI 1	0.9891
093	BAO	NHG	06	1556	1624	12-Oct	< 0.5		0.008			2.5	0.5	24	400	705	1	80	7.3	153.84	299	29.95	76	80	516.000	522.000	SRI 1	0.9891
									0.009	351	2.5	0.5	0.009															
093	BAO	NHG	07	1646	1720	12-Oct	< 0.5		0.010		342	2.4	0.5	24	400	705	1	80	7.0	154.12	298	29.95	78	76	522.500	528.500	SRI 1	0.9891
									0.049			2.4	0.5															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							< 0.5							Testing Interval Averages			81	7.3										
														σ			1.2	0.3										
093	BAO	NHS	05	1456	1528	12-Oct	2.3	± 0.02	0.869	1	191	11.9	2.3	24	400	705	1	82	7.5	154.41	297	29.95	74	78	509.400	515.400	SRI 1	0.9891
093	BAO	NHS	06	1556	1624	12-Oct	4.5	± 0.03	0.879			12.0	2.3	24	400	705	1	80	7.3	153.84	299	29.95	76	80	516.000	522.000	SRI 1	0.9891
									2.820	117	23.6	4.5	2.790															
093	BAO	NHS	07	1646	1720	12-Oct	12.7	± 0.03	5.230		182	68.0	12.7	24	400	705	1	80	7.0	154.12	298	29.95	78	76	522.500	528.500	SRI 1	0.9891
									5.250			68.3	12.8															
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							6.5	± 5.51						Testing Interval Averages			81	7.3										
														σ			1.2	0.3										

Table A-2, continued (Reference Table 3-1)

W e s t e r n	S i t e	O u t l e t	N u m b e r				NH ₃ Concentration		Analytical					Reactor Conditions						Dry Gas Meter							
							ppm (v), dry, @ 3% O ₂		NH ₃	Dil	Vol	NH ₃	NH ₃	Condition Number	Flow	Temp.	kg/ NO _x	Unit & Boiler Load,	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter ID
				Time, Begin	Time, End	Date	Average	σ	mg/ml		ml	μM	ppm(v), dry, 3% O ₂		scfm	° F		MW	%	STD L, dry	° K	In. Hg	° F	° F	ft ³	ft ³	
091	CAI NHG 02	1028	1104	29-Sep	1.7	± 0.03	0.311 0.318	1	368	8.2 8.4	1.7	22	5000	705	0.8	85	2.0	102.76	302	30.04	83	87	439.300	443.300	Stack 1	1.001	
091	CAI NHG 03	1259	1335	29-Sep	1.4	± 0.00	0.516 0.518		255	9.4 9.4	1.4	22	5000	705	0.8	85	2.6	152.47	308	30.04	90	92	445.600	451.600	Stack 1	1.001	
091	CAI NHG 04	1354	1432	29-Sep	0.8	± 0.01	0.280 0.285		288	5.8 5.9	0.8	22	5000	705	0.8	85	2.5	151.78	307	30.04	93	94	451.800	457.800	Stack 1	1.001	
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂					1.3	± 0.44						Testing Interval Averages					85	2									
										σ					0	0											
091	CAI NHS 02	1028	1104	29-Sep	2.1	± 0.05	0.650 0.671	1	218	10.1 10.4	2.1	22	5000	705	0.8	85	2.0	102.76	302	30.04	83	87	439.300	443.300	Stack 1	1.001	
091	CAI NHS 03	1259	1335	29-Sep	1.7	± 0.00	0.781 0.781		209	11.7 11.7	1.7	22	5000	705	0.8	85	2.6	152.47	308	30.04	90	92	445.600	451.600	Stack 1	1.001	
091	CAI NHS 04	1354	1432	29-Sep	2.1	± 0.02	0.953 0.969		212	14.4 14.7	2.1	22	5000	705	0.8	85	2.5	151.78	307	30.04	93	94	451.800	457.800	Stack 1	1.001	
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂					2.0	± 0.26						Testing Interval Averages					85	2									
										σ					0	0											
091	CAO NHG 02	1033	1104	29-Sep	< 0.5		0.033 0.031	1	388	2.8 2.8	0.5	22	5000	705	0.8	85	5.0	152.59	302	30.04	82	86	391.200	397.200	SRI 3	0.989	
091	CAO NHG 03	1304	1335	29-Sep	< 0.5		0.027 0.025		420	3.0 3.0	0.5	22	5000	705	0.8	85	5.3	151.20	305	30.04	87	91	397.500	403.500	SRI 3	0.989	
091	CAO NHG 04	1359	1429	29-Sep	< 0.4		0.014 0.011		338	2.4 2.4	0.4	22	5000	705	0.8	85	5.2	150.24	307	30.04	92	93	404.000	410.000	SRI 3	0.989	
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂					< 0.5							Testing Interval Averages					85	5									
										σ					0	0											
091	CAO NHS 02	1033	1104	29-Sep	2.2	± 0.01	0.736 0.742	1	248	13.0 13.1	2.2	22	5000	705	0.8	85	5.0	152.59	302	30.04	82	86	391.200	397.200	SRI 3	0.989	
091	CAO NHS 03	1304	1335	29-Sep	2.4	± 0.03	0.775 0.788		257	14.2 14.5	2.4	22	5000	705	0.8	85	5.3	151.20	305	30.04	87	91	397.500	403.500	SRI 3	0.989	
091	CAO NHS 04	1359	1429	29-Sep	2.5	± 0.03	0.843 0.856		240	14.5 14.7	2.5	22	5000	705	0.8	85	5.2	150.24	307	30.04	82	93	404.000	410.000	SRI 3	0.989	
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂					2.4	± 0.17						Testing Interval Averages					85	5									
										σ					0	0											

Table A-2, continued (Reference Table 3-1)

W e i t h	S i t e	N u m b e r				NH ₃ Concentration		Analytical					Reactor Conditions					Dry Gas Meter											
						ppm (v), dry, @ 3% O ₂		NH ₃	Dil	Vol.	NH ₃	NH ₃	Condition Number	Flow	Temp.	NH ₃ /NO _x	Unit & Boiler Load,	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter LD	Corr. Factor		
			Time, Begin	Time, End	Date	Average	σ	mg/ml		ml	μM	ppm(v), dry, 3% O ₂		scfm	° F		MW	%	STD L, dry	° K	in. Hg	° F	° F	m ³	m ³				
091	CAI	NHG	06	0921	0957	30-Sep	3.1	± 0.07	1.21	1	257	22.2	3.1	24	400	705	1	86	2.3	154.86	301	30.04	80	85	464.600	470.600	Stack 1	1.001	
091	CAI	NHG	07	1020	1058	30-Sep	3.7	± 0.02	1.25			22.9	3.2	24	400	705	1	86	2.5	153.44	304	30.04	86	89	470.800	476.800	Stack 1	1.001	
									1.27		283	25.7	3.6																
091	CAI	NHG	08	1239	1315	30-Sep	4.1	± 0.01	1.28			25.9	3.7	24	400	705	1	87	1.9	226.23	309	30.04	96	98	477.000	486.000	Stack 1	1.001	
									2.43		254	44.1	4.1																
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							3.6	± 0.48	2.42			43.9	4.1	Testing Interval Averages					86	2									
																			σ	1	0								
091	CAI	NHS	06	0921	0957	30-Sep	6.5	± 0.00	3.12	1	208	46.4	6.5	24	400	705	1	86	2.3	154.86	301	30.04	80	85	464.600	470.600	Stack 1	1.001	
091	CAI	NHS	07	1020	1058	30-Sep	7.2	± 0.01	3.12			46.4	6.5	24	400	705	1	86	2.5	153.44	304	30.04	86	89	470.800	476.800	Stack 1	1.001	
									3.44		207	50.9	7.2																
091	CAI	NHS	08	1239	1315	30-Sep	5.7	± 0.08	3.45			51.0	7.2	24	400	705	1	87	1.9	226.23	309	30.04	96	98	477.000	486.000	Stack 1	1.001	
									4.21		204	61.3	5.7																
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₃							6.5	± 0.78	4.13			60.2	5.6	Testing Interval Averages					86	2									
																			σ	1	0								
091	CAO	NHG	06	0926	0957	30-Sep	< 0.5		0.004	1	377	2.7	0.5	24	400	705	1	86	5.7	153.44	300	30.04	78	84	414.300	420.300	SRI 3	0.989	
091	CAO	NHG	07	1025	1053	30-Sep	0.5	± 0.05	0.008			2.7	0.5	24	400	705	1	86	6.9	152.17	303	30.04	85	86	420.700	426.700	SRI 3	0.989	
									0.094		333	2.4	0.4																
091	CAO	NHG	08	1244	1316	30-Sep	< 0.5		0.116			2.8	0.5	24	400	705	1	87	6.7	150.38	306	30.04	90	94	427.200	433.200	SRI 3	0.989	
									0.086		388	2.8	0.5																
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₄							< 0.5		0.080			2.8	0.5	Testing Interval Averages					86	6									
																			σ	1	1								
091	CAO	NHS	06	0926	0957	30-Sep	4.4	± 0.00	1.54	1	232	25.5	4.4	24	400	705	1	86	5.7	153.44	300	30.04	78	84	414.300	420.300	SRI 3	0.989	
091	CAO	NHS	07	1025	1053	30-Sep	11.1	± 0.00	1.54			25.5	4.4	24	400	705	1	86	6.9	152.17	303	30.04	85	86	420.700	426.700	SRI 3	0.989	
									3.65		227	59.2	11.1																
091	CAO	NHS	08	1244	1316	30-Sep	6.1	± 0.06	3.65			59.2	11.1	24	400	705	1	87	6.7	150.38	306	30.04	90	94	427.200	433.200	SRI 3	0.989	
									2.63		171	32.1	6.0																
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₅							7.2	± 3.51	2.67			32.6	6.1	Testing Interval Averages					86	6									
																			σ	1	1								

Table A-3

Week	Site	Gas	Number				Concentration		Analytical								Dry Gas Meter										
									SO ₂ *	Dil	Vol.	SO ₄ *	SO ₂ , or SO ₃		Unit 5 Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter LD	Corr. Factor		
				Time, Begin	Time, End	Date	Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		MW	%	STD I, dry	° K	In. Hg	° F	° F	ft ³	ft ³				
092	SI	SO ₂	01	1004	1018	7-Oct-94	1.1	±	0.00	4.199	1	95.4	4	1.1		88	1.8	77.57	301	30.13	79	84	536.100	539.100	Stack 1	0.998	
092	SI	SO ₂	02	1030	1043	7-Oct-94	1.3	±	0.00	4.210			4	1.1		88	1.8	76.58	304	30.13	86	91	539.300	542.300	Stack 1	0.998	
092	SI	SO ₂	03	1054	1107	7-Oct-94	1.3	±	0.00	3.868	1	114	5	1.3		88	1.8	76.58	304	30.13	86	91	539.300	542.300	Stack 1	0.998	
										3.888			5	1.3													
										4.730	1	93.6	5	1.3		89	1.8	76.23	306	30.13	89	93	542.600	545.600	Stack 1	0.998	
										4.734			5	1.3													
Average SO ₂ Concentration, ppm(v), dry @ 3% O ₂							1.3	±	0.01						Average	88	1.8										
															σ	1	0.0										
092	SI	SO ₂	01	1004	1018	7-Oct-94	1876	±	9.8	4.898	200	682	6959	1883													
										4.862				6908	1869												
092	SI	SO ₂	02	1030	1043	7-Oct-94	1893	±	3.3	4.498		736	6897	1891													
										4.509				6914	1895												
092	SI	SO ₂	03	1054	1107	7-Oct-94	1872	±	1.9	4.794		680	6792	1870													
										4.801				6801	1873												
Average SO ₂ Concentration, ppm(v), dry @ 3% O ₂							1880	±	11.2																		

Table A-4 (Reference Table 3-2)

[illegible]

Table A-4, continued (Reference Table 3-2)

W e s t e r N u m b e r				Concentration ppm (v), dry, @ 3% O ₂	Analytical					Reactor Conditions						Dry Gas Meter										
					SO ₂ *	Dil	Vol.	SO ₂ *	SO ₂ , or SO ₃	Condition Number	Flow	Temp.	Hz NO _x	Unit & Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor		
	Time, Begin	Time, End	Date, 1984	Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		scfm	° F		MW	%	STD I, dry	° K	In. Hg	° F	° F	ft ³	ft ³			
076 BAI SO ₃ 01	1307	1320	14-Jun-84	5.9	± 0.13	0.631	25	115	19	6.0	22	5	700	0.8	79	4.0	74.00	312	30.16	102	103	582.200	585.200	Stack 1	1.0000	
076 BAI SO ₃ 02	1335	1349	14-Jun-84	8.4	± 0.26	0.612			18	5.8	22	5	700	0.8	80	3.9	74.70	313	30.16	103	105	585.700	588.700	Stack 1	1.0000	
076 BAI SO ₃ 03	1403	1417	14-Jun-84	15.7	± 0.04	0.805		130	27	8.6	22	5	700	0.8	79	4.2	74.50	314	30.16	105	106	589.200	592.200	Stack 1	1.0000	
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				12.1	± 5.2						Testing Interval Averages						79	4.0								
											σ						1	0.2								
076 BAI SO ₂ 01	1307	1320	14-Jun-84	2007	± 38	4.384	200	703	6421	2033.9																
076 BAI SO ₂ 02	1335	1349	14-Jun-84	2654	± 32	4.268			6251	1980.1																
076 BAI SO ₂ 03	1403	1417	14-Jun-84	1651	± 4	4.861		837	8476	2676.4																
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				2104	± 508																					
076 BAO SO ₃ 01	1312	1325	14-Jun-84	8.6	± 0.03	0.828	25	94.8	20	8.7	22	5	700	0.8	79	8.2	74.48	311	30.16	100	100	48.600	49.600	Stack 2	0.9897	
076 BAO SO ₃ 02	1341	1355	14-Jun-84	9.8	± 0.12	0.824			20	8.6	22	5	700	0.8	80	8.1	74.46	311	30.16	100	100	50.100	53.100	Stack 2	0.9897	
076 BAO SO ₃ 03	1408	1423	14-Jun-84	11.4	± 0.06	1.220		74.3	24	9.9	22	5	700	0.8	80	8.0	74.39	311	30.16	100	101	53.400	56.400	Stack 2	0.9897	
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				10.6	± 1.1						Testing Interval Averages						80	8.1								
											σ						1	0.1								
076 BAO SO ₂ 01	1312	1325	14-Jun-84	2171	± 2	4.011	200	613	5122	2172.0																
076 BAO SO ₂ 02	1341	1355	14-Jun-84	2209	± 4	4.006			5116	2169.3																
076 BAO SO ₂ 03	1408	1423	14-Jun-84	2190	± 11	3.936		641	5256	2211.3																
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				2190	± 19																					

Table A-4, continued (Reference Table 3-2)

Well ID	Sample Type	Date	Time, Begin	Time, End	Concentration		Analytical					Reactor Conditions						Dry Gas Meter								
					ppm (v), dry, @ 3% O ₂		SO ₂ *	Dil	Vol.	SO ₂ *	SO ₂ , or SO ₃	Condition Number	Flow	Temp.	NH ₃ NO _x	Unit 5 Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor
					Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		scfm	° F		MW	%	STD I, dry	° K	In. Hg	° F	° F	ft ³	ft ³		
076	CAI SO ₃ 01	1338	1350	13-Jun-94	15.3	± 0.00	2.181	25	90.3	51	15.3	22	5	700	0.8	80	3.4	76.94	304	30.13	87	87	570.500	573.500	Stack 1	1.0000
076	CAI SO ₃ 02	1403	1416	13-Jun-94	21.2	± 0.07	2.182			51	15.3	22	5	700	0.8	80	3.3	76.80	304	30.13	87	89	574.000	577.000	Stack 1	1.0000
076	CAI SO ₃ 03	1427	1442	13-Jun-94	20.1	± 0.13	2.628		104	71	21.1	22	5	700	0.8	80	3.4	76.25	308	30.13	91	93	577.400	580.400	Stack 1	1.0000
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂					20.6	± 0.8	2.452		105	67	20.1	Testing Interval Averages		80	3.4											
							2.429			66	20.0	σ		0	0.1											

076	CAI SO ₂ 01	1338	1350	13-Jun-94	1860	± 17	5.457	200	553	6287	1872.1													
							5.386			6205	1847.7													
076	CAI SO ₂ 02	1403	1416	13-Jun-94	1805	± 0	4.901		596	6085	1805.0													
							4.902			6087	1805.4													
076	CAI SO ₂ 03	1427	1442	13-Jun-94	1802	± 3	4.513		637	5989	1799.7													
							4.523			6002	1803.7													
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂					1822	± 33																		

076	CAO SO ₃ 01	1342	1356	13-Jun-94	11.9	± 0.05	1.535	25	86	34	11.8	22	5	700	0.8	80	5.4	75.26	307	30.13	94	93	35.900	38.900	Stack 2	0.9897
							1.544			35	11.9															
076	CAO SO ₃ 02	1408	1421	13-Jun-94	13.2	± 0.06	1.938		75	38	13.1	22	5	700	0.8	80	5.6	75.46	308	30.13	92	92	39.300	42.300	Stack 2	0.9897
							1.951			38	13.2															
076	CAO SO ₃ 03	1435	1448	13-Jun-94	12.8	± 0.07	1.376		103	37	12.8	22	5	700	0.8	80	5.6	75.46	308	30.13	92	92	42.600	45.600	Stack 2	0.9897
							1.365			37	12.7															
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂					13.0	± 0.3	Testing Interval Averages		80	5.5																
							σ		0	0.1																

076	CAO SO ₂ 01	1342	1356	13-Jun-94	1963.4	± 3.7	4.474	200	612	5704	1960.8													
							4.486			5720	1966.0													
076	CAO SO ₂ 02	1408	1421	13-Jun-94	1953.4	± 9.1	4.286		632	5643	1959.8													
							4.258			5606	1947.0													
076	CAO SO ₂ 03	1435	1448	13-Jun-94	1918.0	± 9.3	3.941		675	5542	1924.6													
							3.914			5504	1911.4													
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂					1945	± 24																		

Table A-5 (Reference Table 3-3)

W e e k	S i t e	G a s	N u m b e r				Concentration		Analytical					Reactor Conditions					Dry Gas Meter									
							ppm (v), dry, @ 3% O ₂		SO ₂ *	Dil	Vol.	SO ₂ *	SO ₂ , or SO ₃	Condition Number	Flow	Temp.	NH ₃ NO _x	Unit 5 Boiler Load,	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor
				Time, Begin	Time, End	Date, 1994	Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		scfm	° F		MW	%	STD I, dry	° K	In. Hg	° F	° F	m ³	m ³		
004	AAI	SO ₃	01	0956	1010	17-Oct-94	23.2	± 0.01	6.636	12.5	86.5	75	23.2	22	5000	700	0.8	80	4.3	77.77	300	30.18	80	82	673.500	676.500	Stack 1	0.9980
									6.632			75	23.2															
004	AAI	SO ₃	02	1026	1040	17-Oct-94	22.9	± 1.97	4.106		131	70	21.5	22	5000	700	0.8	80	4.4	79.11	301	30.18	82	83	676.900	679.900	Stack 1	0.9980
									4.637			79	24.3															
004	AAI	SO ₃	03	1055	1108	17-Oct-94	19.1	± 0.02	4.065		114	60	19.1	22	5000	700	0.8	80	4.5	77.34	302	30.18	83	85	680.200	683.200	Stack 1	0.9980
									4.071			60	19.1															
Average SO ₃ Concentration, ppm(v), wet @ 3% O ₂							21.0	± 2.7						Testing Interval Averages					80	4.4								
														σ					0	0.1								

004	AAI	SO ₂	01	0956	1010	17-Oct-94	1954	± 0.7	3.812	200	792	8290	1953.4														
									3.814			8293	1954.5														
004	AAI	SO ₂	02	1026	1040	17-Oct-94	1896	± 2.2	3.679		806	8178	1897.6														
									3.673			8168	1894.6														
004	AAI	SO ₂	03	1055	1108	17-Oct-94	1821	± 8.6	3.432		803	5741	1814.9														
									3.455			5780	1827.1														
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							1890	± 67																			

004	AAO	SO ₃	01	0949	1001	17-Oct-94	18.8	± 0.07	3.894	12.5	99.0	50	18.8	22	5000	700	0.8	80	7.3	78.53	295	30.18	70	72	572.900	575.900	SRI 3	0.9891
									3.874			50	18.7															
004	AAO	SO ₃	02	1020	1037	17-Oct-94	12.5	± 0.02	2.519		104	34	12.5	22	5000	700	0.8	80	7.0	78.46	295	30.18	71	72	576.500	579.500	SRI 3	0.9891
									2.512			34	12.5															
004	AAO	SO ₃	03	1050	1105	17-Oct-94	15.4	± 0.06	3.679		85.3	41	15.4	22	5000	700	0.8	80	7.3	78.24	296	30.18	73	73	579.900	582.900	SRI 3	0.9891
									3.660			41	15.3															
Average SO ₃ Concentration, ppm(v), wet @ 3% O ₂							15.6	± 3.1						Testing Interval Averages					80	7								
														σ					0	0.2								

004	AAO	SO ₂	01	0949	1001	17-Oct-94	1358	± 5.9	2.783	200	626	3829	1382.6														
									2.786			3807	1354.2														
004	AAO	SO ₂	02	1020	1037	17-Oct-94	1429	± 4.8	2.935		637	3895	1432.0														
									2.921			3876	1425.2														
004	AAO	SO ₂	03	1050	1105	17-Oct-94	1451	± 1.8	2.819		656	3853	1451.8														
									2.814			3846	1449.2														
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							1413	± 48																			

Table A-5, continued (Reference Table 3-3)

W o r k o r d e r N u m b e r				Concentration ppm (v), dry, @ 3% O ₂	Analytical					Reactor Conditions						Dry Gas Meter									
					SO ₂ *	Dil	Vol.	SO ₂ *	SO ₂ , or SO ₃	Condition Number	Flow	Temp.	NH ₃ NO _x	Unit 5 Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor	
	Time, Begin	Time, End	Date, 1994	Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		scfm	° F		MW	%	STD l, dry	° K	In. Hg	° F	° F	ft ³	ft ³		
003 BAI SO3 01	1307	1322	11-Oct-94	4.8	± 0.01	1.285	12.5	98.3	18	4.8	22	5000	700	0.8	88	3.4	78.47	296	30.00	73	73	579.200	582.200	Stack 1	0.998
003 BAI SO3 02	1347	1400	11-Oct-94	4.6	± 0.01	1.283			16	4.8	22	5000	700	0.8	88	3.6	78.47	296	30.00	73	73	582.600	585.600	Stack 1	0.998
003 BAI SO3 03	1415	1429	11-Oct-94	3.0	± 0.05	1.169		103	16	4.6	22	5000	700	0.8	89	3.7	78.40	296	30.00	73	74	585.800	588.800	Stack 1	0.998
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				3.8	± 1.2	0.738		106	10	3.0	Testing Interval Averages					88	3.6								
						0.722			10	3.0	σ					1	0.2								
003 BAI SO2 01	1307	1322	11-Oct-94	2002	± 0.0	4.264	200	772	6858	2002.4															
003 BAI SO2 02	1347	1400	11-Oct-94	2028	± 5.8	4.264			6858	2002.4															
003 BAI SO2 03	1415	1429	11-Oct-94	2064	± 7.6	4.201		783	6853	2024.0															
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				2032	± 31	4.218			6881	2032.2															
						4.425		755	6960	2069.6															
						4.402			6924	2056.9															
003 BAO SO3 01	1300	1315	11-Oct-94	11.7	± 0.02	2.905	13	73.9	28	11.7	22	5000	700	0.8	88	8.7	78.73	292	30.00	65	68	472.300	475.300	SRI 3	0.9891
003 BAO SO3 01	1340	1354	11-Oct-94	8.4	± 0.03	2.913			28	11.7	22	5000	700	0.8	88	7.8	78.36	294	30.00	67	71	476.000	479.000	SRI 3	0.9891
003 BAO SO3 01	1408	1425	11-Oct-94	8.8	± 0.02	1.641		100	21	8.3	22	5000	700	0.8	88	7.6	78.51	293	30.00	68	68	479.600	482.600	SRI 3	0.9891
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				9.6	± 1.8	1.648			21	8.4	Testing Interval Averages					88	8								
						1.497		118	23	8.8	σ					1	1								
						1.492			23	8.8															
003 BAO SO2 01	1300	1315	11-Oct-94	1729	± 2.1	3.515	200	566	4145	1730.2															
003 BAO SO2 01	1340	1354	11-Oct-94	1817	± 4.5	3.509			4138	1727.2															
003 BAO SO2 01	1408	1425	11-Oct-94	1633	± 6.8	2.856		783	4659	1819.8															
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				1726	± 92	2.846			4643	1813.4															
						2.883		710	4264	1637.6															
						2.866			4239	1627.9															

Table A-5, continued (Reference Table 3-3)

W e s t e r n S t a t e	S i t e	O a s e	N u m b e r				Concentration		Analytical					Reactor Conditions						Dry Gas Meter												
							ppm (V), dry, @ 3% O ₂		SO ₂ *	Dil	Vol.	SO ₂ *	SO ₂ , or SO ₃	Condition Number	Flow	Temp.	NH ₃ NO _x	Unit 5 Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor				
				Time, Begin	Time, End	Date, 1994	Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		scfm	° F		MW	%	STD I, dry	° K	In. Hg	° F	° F	ft ³	ft ³						
093	CAI	SO3	01	0931	0947	10-Oct-94	3.4	±	0.01	0.896	12.5	101	11.8	3.4			22	5000	700	0.8	88	2.8	77.87	297	29.94	77	75	546.200	549.200	Stack 1	0.998	
										0.898			11.8	3.4																		
093	CAI	SO3	02	1003	1017	10-Oct-94	4.7	±	0.06	1.076		118	16.5	4.7			22	5000	700	0.8	88	2.7	78.17	298	29.94	74	74	549.700	552.700	Stack 1	0.998	
										1.064			16.8	4.7																		
093	CAI	SO3	03	1041	1058	10-Oct-94	3.5	±	0.04	0.860		111	12.4	3.5			22	5000	700	0.8	89	2.7	78.31	298	29.94	73	73	553.000	556.000	Stack 1	0.998	
										0.874			12.6	3.6																		
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							4.1	±	0.8						Testing Interval Averages					88	2.7											
															σ					1	0.1											
093	CAI	SO2	01	0931	0947	10-Oct-94	1964	±	2.7	4.176	200	793	6899	1962.5																		
										4.184			6912	1966.3																		
093	CAI	SO2	02	1003	1017	10-Oct-94	1938	±	6.1	4.312		767	6890	1942.0																		
										4.293			6860	1933.4																		
093	CAI	SO2	03	1041	1058	10-Oct-94	1944	±	0.3	4.441		747	6911	1944.2																		
										4.440			6910	1943.8																		
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							1949	±	14																							
093	CAO	SO3	01	0926	0941	10-Oct-94	7.6	±	0.05	1.988	12.5	97.8	25.3	7.5			22	5000	700	0.8	88	3.5	77.54	298	29.94	73	74	437.400	440.400	SRI 3	0.989	
										2.005			25.5	7.6																		
093	CAO	SO3	02	0957	1013	10-Oct-94	7.6	±	0.01	1.707		116	25.8	7.6			22	5000	700	0.8	89	3.5	77.98	294	29.94	71	70	441.100	444.100	SRI 3	0.989	
										1.703			25.7	7.6																		
093	CAO	SO3	03	1038	1050	10-Oct-94	6.6	±	0.01	1.716		101	22.6	6.6			22	5000	700	0.8	89	3.5	78.35	293	29.94	68	68	445.200	448.200	SRI 3	0.989	
										1.720			22.6	6.7																		
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							7.3	±	0.5						Testing Interval Averages					89	4											
															σ					1	0											
093	CAO	SO2	01	0926	0941	10-Oct-94	1515	±	0.8	3.996	200	612	5095	1514.1																		
										3.999			5099	1515.2																		
093	CAO	SO2	02	0957	1013	10-Oct-94	1427	±	3.5	3.703		627	4837	1429.4																		
										3.690			4820	1424.3																		
093	CAO	SO2	03	1038	1050	10-Oct-94	1495	±	6.0	3.346		727	5068	1490.5																		
										3.365			5097	1498.9																		
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							1479	±	46																							

Table A-6 (Reference Table 3-4)

Well Number				Concentration ppm (v), dry, @ 3% O ₂	Analytical					Reactor Conditions						Dry Gas Meter													
					Cl ⁻	Dil	Vol.	Cr	HCl	Condition Number	Flow	Temp.	NH ₃ NO _x	Unit 5 Boiler Load	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter LD	Corr. Factor					
	Time, Begin	Time, End	Date	Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		scfm	° F		MW	%	STD I, dry	° K	In. Hg	° F	° F	ft ³	ft ³						
094	AAI	HCl	01	1309	1323	17-Oct	92.4	±	0.32	1.428	25	783	291	92.6	22	5000	700	0.8	80	4.5	76.85	304	30.18	88	87	683.500	688.500	Stack 1	0.998
094	AAI	HCl	02	1334	1347	17-Oct	94.2	±	0.45	1.421			290	92.2	22	5000	700	0.8	80	4.4	76.78	304	30.18	88	88	686.900	689.900	Stack 1	0.998
094	AAI	HCl	03	1356	1408	17-Oct	91.5	±	0.40	1.335		853	297	93.9	22	5000	700	0.8	80	4.6	76.43	306	30.18	90	91	690.200	693.200	Stack 1	0.998
Average HCl Concentration, ppm(v), wet @ 3% O ₂							93	±	1.9	1.344			299	94.5	Testing Interval Averages					80	4.5								
										1.610		680	285	91.8															
										1.600				283	91.2														
093	AAO	HCl	01	1304	1319	17-Oct	82.1	±	6.40	0.986	25	790	203	77.6	22	5000	700	0.8	80	7.4	77.65	298	30.18	76	78	583.300	586.300	SRI 3	0.9891
093	AAO	HCl	02	1328	1343	17-Oct	80.9	±	0.69	1.101			227	86.6	22	5000	700	0.8	80	7.5	77.44	299	30.18	78	79	586.900	589.900	SRI 3	0.9891
093	AAO	HCl	03	1350	1404	17-Oct	80.2	±	0.52	1.160		697	211	81.4	22	5000	700	0.8	80	7.4	77.44	299	30.18	78	79	590.300	593.300	SRI 3	0.9891
Average HCl Concentration, ppm(v), wet @ 3% O ₂							81	±	1.0	1.146			208	80.4	Testing Interval Averages					80	7								
										1.098		735	210	80.6															
										1.088				208	79.9														

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W e b s i t e	S t a t e	N u m b e r				Concentration		Analytical					Reactor Conditions					Dry Gas Meter												
								CF	Dil	Vol.	CF	HCl	Condition Number	Flow	Temp.	HH ₂ NO _x	Unit 5 Boiler Load	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter I.D.	Corr. Factor			
			Time, Begin	Time, End	Date	Average	σ	mg/ml		ml	μM	ppm, dry, @ 3% O ₂		scfm	° F		MW	%	STD I, dry	° K	In. Hg	° F	° F	ft ³	ft ³					
093	BAI	HCl	01	0954	1006	11-Oct	105.2	±	6.98	1.786	25	805	374	110.2	22	5000	700	0.8	88	3.5	78.32	296	30.00	74	74	568.900	571.900	Stack 1	0.998	
093	BAI	HCl	02	1018	1031	11-Oct	97.6	±	0.15	1.626			341	100.3	22	5000	700	0.8	89	3.3	78.32	296	30.00	74	74	572.300	575.300	Stack 1	0.998	
093	BAI	HCl	03	1046	1059	11-Oct	104.8	±	0.61	1.421		908	336	97.7	22	5000	700	0.8	89	3.3	78.32	296	30.00	74	74	572.300	575.300	Stack 1	0.998	
										1.418			335	97.5	22	5000	700	0.8	89	3.5	78.32	296	30.00	74	74	575.800	578.800	Stack 1	0.998	
										1.695		810	358	105.2	22	5000	700	0.8	89	3.5	78.32	296	30.00	74	74	575.800	578.800	Stack 1	0.998	
										1.681			355	104.3																
Average HCl Concentration, ppm(v), wet @ 3% O ₂							101	±	5.0						Testing Interval Averages					89	3.4									
093	BAO	HCl	01	0947	1002	11-Oct	88.3	±	0.46	1.205	25	740	232	88.0	22	5000	700	0.8	88	7.4	78.36	294	30.00	68	70	461.200	464.200	SRI 3	0.9891	
093	BAO	HCl	02	1012	1028	11-Oct	95.0	±	6.92	1.214			234	88.7	22	5000	700	0.8	89	7.3	78.36	294	30.00	68	70	464.800	467.800	SRI 3	0.9891	
093	BAO	HCl	03	1041	1055	11-Oct	96.0	±	1.77	1.317		774	265	99.9	22	5000	700	0.8	89	7.3	78.36	294	30.00	68	70	464.800	467.800	SRI 3	0.9891	
										1.188			239	90.1	22	5000	700	0.8	88	9.3	78.36	294	30.00	68	70	468.500	471.500	SRI 3	0.9891	
										1.095		753	215	94.7	22	5000	700	0.8	88	9.3	78.36	294	30.00	68	70	468.500	471.500	SRI 3	0.9891	
										1.124			220	97.2																
Average HCl Concentration, ppm(v), wet @ 3% O ₂							93	±	4.1						Testing Interval Averages					88	8									

Table A-7 (Reference Table 3-5)

INPUT DATA			
DATE: 6/9/94			
RUN ID: 075-AAO-01			
Flue gas O2	8.3 % wet	Nozzle diameter	0.219 in.
Flue gas CO2	10.7 % wet	Gas meter corr.	1.002
Flue gas N2	72.32 % wet	Pitot corr. (Cp)	0.821
Flue gas H2O	8.68 % wet	Duct Area	3.36 ft2
Ambient Pressure	30.01 in. Hg		
Stack Pressure	-22.5 in. H2O		
Stack Temp	338.67 °F		
Volume water	104 ml	Meter volume	54.666 ft3
Particle mass	8542.8 mg	SQRT DP pitot	0.9326
Run time	90 min	AVG DH orifice	1.31 in. H2O
Meter Temp	104.61 °F		
FINAL CALCULATED DATA			
% WATER	8.68%	gr/ACF :	1.4629 wet
% ISOKINETIC	98.69%	gr/SCF :	2.5970 dry
STACK VEL.	64.43 ft/s	mg/ACM :	3347.80 wet
		mg/SCM :	5942.89 dry
STACK FLOW	12989 ACFM (wet)		
STACK FLOW	7295 SCFM (dry)	LB/MBTU	5.9336

Table A-7, continued (Reference Table 3-5)

INPUT DATA			
DATE: 6/9/94			
RUN ID: 075-AAO-02			
Flue gas O2	8.3 % wet	Nozzle diameter	0.219 in.
Flue gas CO2	10.7 % wet	Gas meter corr.	1.002
Flue gas N2	72.24 % wet	Pitot corr. (Cp)	0.821
Flue gas H2O	8.76 % wet	Duct Area	3.36 ft2
Ambient Pressure	30.01 in. Hg		
Stack Pressure	-22.5 in. H2O		
Stack Temp	339 °F		
Volume water	104.2 ml	Meter volume	54.551 ft3
Particle mass	7693.8 mg	SQRT DP pitot	0.9518
Run time	90 min	AVG DH orifice	1.302 in. H2O
Meter Temp	108 °F		
FINAL CALCULATED DATA			
% WATER	8.76%	gr/ACF :	1.3266 wet
% ISOKINETIC	96.00%	gr/SCF :	2.3584 dry
STACK VEL.	65.78 ft/s	mg/ACM :	3035.86 wet
		mg/SCM :	5396.93 dry
STACK FLOW	13262 ACFM (wet)		
STACK FLOW	7438 SCFM (dry)	LB/MBTU	5.3885

Table A-7, continued (Reference Table 3-5)

INPUT DATA			
DATE: 6/9/94			
RUN ID: 075-AAO-03			
Flue gas O2	8.3 % wet	Nozzle diameter	0.219 in.
Flue gas CO2	10.7 % wet	Gas meter corr.	1.002
Flue gas N2	72.2 % wet	Pitot corr. (Cp)	0.821
Flue gas H2O	8.8 % wet	Duct Area	3.36 ft2
Ambient Pressure	30.01 in. Hg		
Stack Pressure	-22.5 in. H2O		
Stack Temp	337.89 °F		
Volume water	106.2 ml	Meter volume	55.522 ft3
Particle mass	8237.2 mg	SQRT DP pitot	0.9303
Run time	90 min	AVG DH orifice	1.304 in. H2O
Meter Temp	110.278 °F		
FINAL CALCULATED DATA			
% WATER	8.80%	gr/ACF :	1.4023 wet
% ISOKINETIC	99.55%	gr/SCF :	2.4903 dry
STACK VEL.	64.25 ft/s	mg/ACM :	3209.06 wet
		mg/SCM :	5698.71 dry
STACK FLOW	12953 ACFM (wet)		
STACK FLOW	7272 SCFM (dry)	LB/MBTU	5.6898

Table A-7, continued (Reference Table 3-5)

INPUT DATA			
DATE: 6/10/94			
RUN ID: 075-BAO-01			
Flue gas O2	7.8 % wet	Nozzle diameter	0.219 in.
Flue gas CO2	13 % wet	Gas meter corr.	1.002
Flue gas N2	71.24 % wet	Pitot corr. (Cp)	0.821
Flue gas H2O	7.96 % wet	Duct Area	3.36 ft2
Ambient Pressure	30.04 in. Hg		
Stack Pressure	-21 in. H2O		
Stack Temp	317.56 °F		
Volume water	102 ml	Meter volume	58.302 ft3
Particle mass	8454.9 mg	SQRT DP pitot	0.9984
Run time	90 min	AVG DH orifice	1.5 in. H2O
Meter Temp	99.78 °F		
FINAL CALCULATED DATA			
% WATER	7.96%	gr/ACF :	1.3982 wet
% ISOKINETIC	97.58%	gr/SCF :	2.3858 dry
STACK VEL.	67.44 ft/s	mg/ACM :	3199.69 wet
		mg/SCM :	5459.75 dry
STACK FLOW	13596 ACFM (wet)		
STACK FLOW	7936 SCFM (dry)	LB/MBTU	5.2431

Table A-7, continued (Reference Table 3-5)

INPUT DATA			
DATE: 6/10/94			
RUN ID: 075-BAO-02			
Flue gas O ₂	7.8 % wet	Nozzle diameter	0.219 in.
Flue gas CO ₂	13 % wet	Gas meter corr.	1.002
Flue gas N ₂	71.22 % wet	Pitot corr. (C _p)	0.821
Flue gas H ₂ O	7.98 % wet	Duct Area	3.36 ft ²
Ambient Pressure	30.04 in. Hg		
Stack Pressure	-21.0 in. H ₂ O		
Stack Temp	314 °F		
Volume water	101.3 ml	Meter volume	58.259 ft ³
Particle mass	8093.5 mg	SQRT DP pitot	1.0089
Run time	90 min	AVG DH orifice	1.53 in. H ₂ O
Meter Temp	105 °F		
FINAL CALCULATED DATA			
% WATER	7.98%	gr/ACF :	1.3579 wet
% ISOKINETIC	95.41%	gr/SCF :	2.3062 dry
STACK VEL.	67.99 ft/s	mg/ACM :	3107.35 wet
		mg/SCM :	5277.62 dry
STACK FLOW	13706 ACFM (wet)		
STACK FLOW	8038 SCFM (dry)	LB/MBTU	5.0682

Table A-7, continued (Reference Table 3-5)

INPUT DATA			
DATE: 6/10/94			
RUN ID: 075-BAO-03			
Flue gas O2	7.8 % wet	Nozzle diameter	0.219 in.
Flue gas CO2	13 % wet	Gas meter corr.	1.002
Flue gas N2	71.24 % wet	Pitot corr. (Cp)	0.821
Flue gas H2O	7.96 % wet	Duct Area	3.36 ft2
Ambient Pressure	30.04 in. Hg		
Stack Pressure	-21 in. H2O		
Stack Temp	316.55 °F		
Volume water	104.6 ml	Meter volume	60.638 ft3
Particle mass	8464 mg	SQRT DP pitot	1.0552
Run time	90 min	AVG DH orifice	1.661 in. H2O
Meter Temp	107.83 °F		
FINAL CALCULATED DATA			
% WATER	7.96%	gr/ACF :	1.3664 wet
% ISOKINETIC	94.61%	gr/SCF :	2.3285 dry
STACK VEL.	71.23 ft/s	mg/ACM :	3126.94 wet
		mg/SCM :	5328.59 dry
STACK FLOW	14360 ACFM (wet)		
STACK FLOW	8393 SCFM (dry)	LB/MBTU	5.1172

APPENDIX A-2

Testing and Analytical Services for the Innovative Clean Coal Technology Demonstration of Selective Catalytic Reduction (SCR) Technology for the Control of Nitrogen Oxide (NO_x) Emissions from High Sulfur Coal, Final Report, Task 4: Air Heater Tests, Third Parametric Series, SRI report to SCS, September 11, 1995.

**TESTING AND ANALYTICAL SERVICES FOR THE INNOVATIVE CLEAN COAL
TECHNOLOGY DEMONSTRATION OF SELECTIVE CATALYTIC REDUCTION
(SCR) TECHNOLOGY FOR THE CONTROL OF NITROGEN OXIDE (NO_x)
EMISSIONS FROM HIGH SULFUR COAL**

Final Report for Task 4

**Air Heater Tests
Reactors A, B, C
Third Parametric Series**

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September 11, 1995

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Section 1

INTRODUCTION

This report is the ninth in a series of reports describing the results of testing and analytical services for the Innovative Clean Coal Technology Demonstration of Selective Catalytic Reduction (SCR) Technology for the control of nitrogen oxide (NO_x) emissions from high-sulfur, coal-fired boilers. The test results for the third sequence of air heater tests are summarized in this report. The tests were conducted in November and December 1994.

The SCR test facility is located at Gulf Power Company's Plant Crist Unit 5 in Pensacola, Florida. The test facility includes three large SCR reactors, each designed to treat 5000 wscfm of flue gas, and six small reactors, each processing 400 wscfm of flue gas. An air heater capable of removing sufficient heat to reduce the flue gas temperature from a range of 600 to 750 °F down to 300 °F was included in the design of each of the three large reactors. The three large reactors are designated as reactors A, B, and C. Reactors A and B incorporate Ljungstrom-type air heaters and Reactor C's air heater incorporates a heat pipe design.

The original design of the SCR test facility also included bypass heat exchangers on each of the three large reactors. These units were intended for use during parametric testing of the reactors (Task 4: Long Term Parametric Tests) so that flue gas containing higher concentrations of slip ammonia could be diverted around the air heaters. However, the bypass heat exchangers did not function as planned and the practice of bypassing the air heaters on Reactors A, B and C during parametric testing was abandoned. Thus, the air heater test data presented in this report include the effects of day-long periods of exposure to ammonia concentrations normally ranging from a few parts per million by volume (ppm(v)) to 20 ppm(v), although brief excursions approached 100 ppm(v).

Air heater testing included the determinations of particulate mass concentration (inlet and outlet of Reactor A and B air heaters) and measurements of the concentrations of sulfur dioxide, sulfur trioxide, hydrogen chloride and ammonia (inlet and outlet of Reactor A, B and C air heaters). All tests were conducted with manual sampling methods. Ammonia samples were segregated into solid and gas-phase fractions to characterize the gas/solid phase partitioning of ammonia across the air heaters. In general, simultaneous tests for gaseous species were performed at the inlet and outlet of each of the three air heaters. In addition, ash mineral analyses and the measurement of the concentrations of twenty trace metals were conducted on the fly ash samples collected at the inlet and outlet of the air heaters on Reactors A and B. Also, a portion of the air heater outlet fly ash samples from Reactors A and B were submitted for laboratory resistivity measurements.

This report is divided into several sections. Section 2 describes the test methods used for the air heater testing. Section 3 reviews all of the test results. The test data are briefly summarized in Section 4. Tables containing original data summaries and laboratory reports that were produced for the air heater testing are contained in Appendices A, B, C, and D.

Section 2

TEST METHODS

A variety of test methods were used to characterize air heater performance. The following subsections briefly describe the test methods for ammonia (NH_3), sulfur dioxide (SO_2), sulfur trioxide (SO_3), hydrogen chloride (HCl), and particulate mass concentration. Figure 2-1 shows a sketch of a large reactor and its air heater (not to scale). The test port locations for air heater inlet and outlet measurements are indicated on the diagram. Test ports (three horizontal ports) downstream of the third catalyst layer (the normal reactor outlet test location) were used to measure concentrations of air heater inlet gas constituents. Three test ports (horizontal) were installed in a transition piece in the outlet ducting of the Reactor A and B air heaters that were suitable for particulate and gas phase flue gas constituent testing. Test ports at this same location in the Reactor C air heater outlet were not installed. However, a single test port (horizontal) in a section of ducting at the inlet transition to the cyclone on Reactor C (downstream of the reactor bypass duct) was suitable for testing gas phase flue gas constituents (Reactor C air heater outlet). Turbulent flow at this location precluded mass concentration tests, however.

Air heater tests were performed with the reactors operating at Test Condition 22, the normal baseline or long-term operating condition. These operating conditions included a flue gas temperature of 700 °F, an NH_3/NO_x ratio of 0.8, and a flue gas flow rate of 5000 wscfm (100% of design flow rate). During measurements of air heater inlet and outlet ammonia concentrations only, additional tests were performed at Test Condition 24. The operating parameters for these tests were a flue gas temperature of 700 °F, an NH_3/NO_x ratio of 1.0, and a flue gas flow rate of 5000 wscfm.

AMMONIA

Ammonia concentrations were measured simultaneously at the air heater inlet (downstream of the third catalyst layer) and at the air heater outlet on each of the large reactors. At each site and at each test condition, three independent tests were performed to determine an average ammonia concentration. Sampling ports located downstream of the third catalyst layer were used to measure air heater inlet ammonia concentration. Flue gas was sampled at three equally-spaced points in each of the three test ports (a total of nine traverse points) to determine an average inlet ammonia concentration for each test. At the air heater outlet sampling location on Reactors A and B the probe also sampled at three equally-spaced points in each of the three test ports (a total of nine traverse points). At the single Reactor C outlet test port, the ammonia probe traversed three, equally-spaced, points (front to rear) during each test.

Figure 2-1. Schematic drawing of SCR air heater cross section (side view).

Figure 2-2. Schematic diagram of the ammonia sampling train.

A schematic drawing of the ammonia sampling train is shown in Figure 2-2. The flue gas sample is drawn through a glass-lined probe and a heated filter to remove particulate. The filter is maintained at the nominal flue gas temperature. The gas sample passes through a length of PTFE tubing to a set of three impingers in an ice bath. The first two impingers contain a 0.1 normal solution of sulfuric acid. The third impinger serves as a trap to prevent the solutions from accidentally being drawn into the pump. A second glass wool plug is placed in the line between the last two impingers to collect any ammonia aerosols that may escape the second impinger. The remainder of the train consists of a silica gel column to remove the last traces of water from the flue gas sample, a leak-free pump, and a dry gas meter to measure the volume of the sample.

The samples were segregated during sample collection into a solid-phase sample and a gas-phase sample. The solid-phase sample consisted of the heated filter, all of the collected particulate, and the probe-wash liquid. The gas-phase sample consisted of the impinger liquids and the wash and rinse liquids. The two samples were analyzed separately to characterize the ammonia partitioning between the gas and solid phases.

At the outset of the Task 4 parametric testing, modified Greenberg-Smith type impingers were used for ammonia sampling. However, 100 mL gas sampling impingers, each containing about 50 mL of solution, were used for the air heater ammonia testing to reduce the detection limit to less than 1 ppm(v) for a reasonable sample volume, about 3 ft³ of gas. The lower detection limit was needed for much of the air heater ammonia testing because ammonia concentrations are very low at the reactor exit when operating at the reactor design condition with an NH₃/NO_x ratio of 0.8.

The impinger solutions are made alkaline in the laboratory (converting the NH₄⁺ ion to free NH₃ in solution). The concentration of ammonia is then determined with an ammonia ion specific electrode, Orion Model 920A. As mentioned above, three individual measurements of ammonia concentration are made for each test condition. Two independent determinations of the ammonia concentration are then conducted on each sample.

SULFUR DIOXIDE AND SULFUR TRIOXIDE

During the air heater evaluation, SO₂ and SO₃ concentrations were measured simultaneously at the reactor outlet downstream of the third catalyst layer (air heater inlet) and the air heater outlet. Sulfur dioxide (SO₂) and sulfur trioxide (SO₃) were collected in a controlled condensation

sampling train. All tests were conducted using single-point sampling in either the right-hand port (air heater inlet test location) or middle port (air heater outlet test location).

Figure 2-3. Schematic diagram of the controlled condensation sampling train for SO_2 and SO_3 .

A schematic drawing of the SO_2/SO_3 sampling train is shown in Figure 2-3. The flue gas sample is drawn through a heated, quartz-lined probe maintained above 550 °F. The sample then passes through a quartz filter housed in a heated quartz filter holder, also maintained at 550 °F. The next element in the train is the SO_3 condenser. The condenser is a length of quartz tubing packed with quartz wool and maintained between 120 °F and 130 °F in a heated water bath. The sample next passes through a length of PTFE tubing to a set of three impingers in an ice bath. The first two impingers contain a 3% solution of hydrogen peroxide to oxidize SO_2 . The third impinger serves as a trap to prevent the solutions from accidentally being drawn into the pump. The remainder of the train consists of a silica gel column to remove the last traces of water from the sample, a leak-free pump, and a dry gas meter to measure the volume of the sample.

The SO_3 is collected in the condensing element and the SO_2 is collected in the bubblers by oxidation with the hydrogen peroxide, converting it to H_2SO_4 in solution. In the condenser the SO_3 present begins a hydration reaction with the water vapor present making H_2SO_4 . The excess water vapor also condenses to produce a condensate of concentrated aqueous H_2SO_4 . Thus, two solutions of H_2SO_4 are collected; one a very concentrated solution of limited amount containing the original SO_3 and the other a relatively weak solution in far greater amount containing the original SO_2 . The concentrations of the sulfate ion are determined by ion chromatography using a DIONEX Model DX-100 Ion Chromatograph.

HYDROGEN CHLORIDE

Figure 2-4. Schematic diagram of the chloride sampling train.

A schematic sketch of the chloride sampling train is shown in Figure 2-4. The flue gas sample is drawn through a heated, quartz-lined probe maintained above 550 °F. The sample then passes through a quartz filter housed in a heated quartz filter holder, also maintained at 550 °F. The sample next passes through a length of PTFE tubing to a set of three impingers in an ice bath. The first two impingers contain type 1 de-ionized water for removal of HCl vapor. The third impinger serves as a trap to prevent the solutions from accidentally being drawn into the pump. The remainder of the train consists of a silica gel column to remove the last traces of water from the sample, a leak-free pump, and a dry gas meter to measure the volume of the sample.

The chloride ion concentration is determined by ion chromatography using a DIONEX Model DX-100 Ion Chromatograph. Hydrogen chloride concentrations were determined by single-point sampling (at the mid-point of the duct) at the air heater inlet (downstream of the third catalyst layer, right-hand port) and at the air heater outlet (middle port). Inlet and outlet tests were conducted simultaneously.

MASS CONCENTRATION

Mass concentration was measured using a sampling train similar to that defined in the EPA Reference Test Method 17. A schematic drawing of the train used for mass concentration sampling is shown below in Figure 2-5.

Figure 2-5. Schematic drawing of the mass concentration sampling train.

This train consists of a filter holder and nozzle that is designed to operate in the flue gas stream, followed by a heated sampling probe, a condenser, a drying column, a gas meter, a pump, and finally a flow control mechanism, usually a calibrated orifice. An S-type pitot and thermocouple located near the nozzle provide a means for sampling isokinetically during each test. The glass fiber thimbles are desiccated before and after sampling and then weighed on an electronic microbalance.

Particulate mass concentrations were measured simultaneously downstream of catalyst layer 3 (air heater inlet) and at each air heater outlet (except Reactor C). At the air heater inlet, the three sample ports immediately above the access door at the fourth catalyst layer were used to obtain the sample. During each test particulate was sampled at three, equally-spaced, positions within the three test ports (a total of nine traverse points). At the air heater outlets on reactors A and B, three ports are available for mass sampling. During each test particulate was sampled at three, equally-

spaced, positions within the three test ports (a total of nine traverse points). Three runs were made at each test site to give a meaningful statistical average.

SAMPLING QUALITY ASSURANCE

The measures adopted to ensure that meaningful results were obtained during the various testing procedures can be divided into three categories; equipment maintenance and calibrations, operating techniques, and analytical techniques. New equipment was obtained for use in the SCR testing program and preventive maintenance and calibrations are performed at regular intervals. Due to the dynamic nature of the process, each measurement requires three replicate samples. The replicates are averaged to yield a representative value. Variability gives a means to discern any anomalies not revealed by other quality control checks.

The sample trains are leak-checked by drawing a vacuum of 15 in. Hg before and after each sampling run. No in-leakage is tolerated. If any loss of pressure is observed within one minute, the source of the leakage is found and eliminated prior to testing. During each run the oxygen level of the gas exiting the dry gas meter is measured to detect air in-leakage that could dilute the samples.

Ammonia samples are analyzed with an ion-specific electrode. The instrument is calibrated using 0.1 µg/ml, 0.5 µg/ml, 1.0 µg/ml, 5.0 µg/ml and 10 µg/ml standards. At the conclusion of each analytical session, a sample spiked with a known amount of ammonia is analyzed and the result compared with the predicted concentration. A blank sample is analyzed to detect zero drift and a mid-range standard is also analyzed to detect calibration drift.

Both the sulfate (SO₂ & SO₃) samples and the chloride (HCl) samples are analyzed by means of ion chromatography. This instrument is calibrated using a minimum of three points on the calibration curve. As with the ammonia analysis, spiked samples, blanks, and standards are analyzed to ensure that calibration drift has not occurred.

While gas-phase flue gas constituents are being sampled, both field blanks and sample blanks are run as quality control checks. The field blank consists of a container of type 1 de-ionized water that is exposed to ambient air at the sampling site. Sample blanks are obtained by passing ambient air through the probe and through the impingers filled with the appropriate solution. These blanks would detect sample contamination should it occur.

Section 3

AIR HEATER TEST RESULTS

AMMONIA CONCENTRATIONS

Concentrations of ammonia were measured simultaneously at each of the three air heater inlet and outlet test locations during December 1994. All three air heaters were tested with the reactors operating at Test Conditions 22 and 24. Test Condition 22, the baseline or normal long-term operating condition has a flow rate of 5,000 wscfm, a flue gas temperature of 700°F, and a NH_3/NO_x ratio of 0.8. The operating parameters for Test Condition 24 are the same, except that the NH_3/NO_x ratio is 1.0. The test data are summarized in Table 3-1.

The ammonia concentration tests conducted downstream of catalyst layer 3 (air preheater inlet) and at the air preheater outlets on Reactors A, B, and C were designed to segregate the ammonia into gas and solid phases. A heated (maintained at the flue gas temperature) fiberglass thimble in a quartz thimble holder outside the stack was attached downstream of the probe. The thimble filtered out the fly ash from the flue gas. The thimble containing the ash catch and the probe wash were placed in a separate container and analyzed separately for ammonia. This sample was considered to contain the solid-phase ammonia from the volume of gas sampled. The Teflon sample lines connecting the thimble holder to the impingers were rinsed and the rinse liquid, the impinger liquid, all inter-impinger connector rinses and a final, glass-wool plug (to capture any aerosols escaping from the last impinger) were placed in another sample container. This sample was considered to contain the gas-phase ammonia from the volume of flue gas sampled. In table 3-1 the column headed "Gas-Phase NH_3 , ppm(v), @ 3% O_2 , dry" shows the results of the analysis of the impinger catches plus rinses. The next column, headed "Solid-Phase NH_3 , Equivalent ppm(v), @ 3% O_2 , dry" shows the result of the analysis of the ash catch and probe wash. The solid phase concentration is expressed as an equivalent volumetric concentration (as though it were a gaseous constituent of the stream) to give a basis for the comparison of gas-phase ammonia and solid-phase ammonia.

At the inlet of each air heater the volumetric concentration of ammonia was split generally evenly between the gas and solid phases under both test conditions. Unfortunately, the ash sample from the Reactor C air heater inlet and outlet at Test Condition 22 were both contaminated and could not be analyzed. As expected, at the air heater outlet almost all of the ammonia was present in the solid phase. For all three reactors at Test Condition 22 the gas-phase ammonia concentration at the air heater outlet was below the detection limit. This is true also for Reactor A at Test Condition 24, but not for the other two reactor air heaters, which had measurable concentrations of gas-phase ammonia. This was a direct result of a higher inlet concentration.

Of interest, also, in this test program was the solid phase ammonia concentration expressed on a weight basis, typically as ppm(w) or $\mu\text{g/g}$ (micrograms of ammonia per gram of ash). The method used to measure ammonia concentrations during these tests did not lend itself to expressing the solid-phase ammonia concentrations on a weight basis because ash weights were not measured. However, it was possible to obtain an estimate of the weight concentration of ammonia on the ash by assuming that the mass concentration during the ammonia tests on December 15, 16, and 20, 1994, was the same as that measured when mass concentrations were measured on November 8 and 9, 1994 at the same sites.

Table 3-1. SCR Reactor Air Preheater Tests, November-December, 1994: Ammonia Concentrations

Reactor	Date	$\frac{\text{NH}_3}{\text{NO}_x}$	Air Preheater Location	Gas-Phase NH_3 , ppm(v), @ 3% O_2 , dry	Solid-Phase NH_3 , Equivalent ppm(v), @ 3% O_2 , dry	Estimated Solid-Phase NH_3 , $\mu\text{g/g}$	Estimated Upper Limit Solid-Phase NH_3 , $\mu\text{g/g}$	Estimated Lower Limit Solid-Phase NH_3 , $\mu\text{g/g}$
A	15-Dec-94	0.8	Inlet	1.2 ± 0.2	1.2 ± 0.2	125	167	94
			Outlet	< 0.3	3.9 ± 0.3	481	520	444
A	14-Dec-94	1.0	Inlet	2.9 ± 0.7	4.1 ± 1.1	424	634	271
			Outlet	< 0.4	6.0 ± 0.8	749	861	640
B	16-Dec-94	0.8	Inlet	0.9 ± 0.1	0.8 ± 0.2	76	103	54
			Outlet	< 0.4	3.1 ± 0.4	431	506	361
B	16-Dec-94	1.0	Inlet	17.4 ± 4.5	12.2 ± 5.1	1119	1723	604
			Outlet	1.1 ± 0.8	12.9 ± 6.6	1792	2792	854
C	20-Dec-94	0.8	Inlet	4.0 ± 0.3	Samples Contaminated			
			Outlet	< 0.3				
C	20-Dec-94	1.0	Inlet	20.5 ± 1.8	14.6 ± 0.4	1420	1643	1242
			Outlet	0.7 ± 0.5	18.0 ± 0.3	2367	2462	2277

The last three columns in Table 3-1 show the estimated weight concentrations of ammonia on the ash. The column headed "Estimated Solid-Phase NH_3 , $\mu\text{g/g}$ " shows the solid-phase ammonia concentration calculated from the average solid-phase ammonia concentration shown in the table and the average mass concentration measured a month earlier. The next two columns are an attempt to estimate a confidence interval for these data based on the standard deviations of the triplicate mass trains and the triplicate ammonia runs. These calculations are based on the volumetric concentrations of the solid phase ammonia and the particulate, both expressed at the same temperature and pressure, i.e. standard conditions. The upper limit shown is the quotient of the mean volumetric concentration of solid-phase ammonia plus one standard deviation and the mean particulate volumetric concentration minus one standard deviation. The lower limit shown is the quotient of the mean solid-phase ammonia concentration (mass per unit volume) minus one standard deviation and the mean particulate mass concentration plus one standard deviation. These calculations give the largest spread that can be obtained from these data.

The ratio of inlet to outlet concentrations of ammonia based on the estimated solid-phase ammonia concentrations (weight basis) are generally similar in magnitude to those ratios calculated from the solid-phase ammonia concentrations calculated from the ammonia train test data. It should be noted that the possibility exists that some gas-phase ammonia may have reacted with sulfur trioxide present in the flue gas, as the gas stream cooled in the probe, to form ammonium bisulfate or ammonium sulfate. Other reactions involving chlorides etc. are also probably possible. These reaction products would be collected with the solid-phase ammonia sample even though the ammonia was in the gas-phase in the duct. This possible sampling error would cause the solid-phase concentrations to be high. The original data summaries for the ammonia concentration tests at Test Conditions 22 and 24 can be found in Table A-1 in Appendix A.

SO_2 and SO_3 CONCENTRATIONS

Concentrations of sulfur dioxide and sulfur trioxide were measured simultaneously at the air heater inlet and outlet test locations of Reactors A, B, and C during operation at Test Condition 22. The tests were conducted in December 1994. The test results are presented in Table 3-2.

SO_3 concentrations at the air heater inlets ranged from 2.3 ± 0.9 to 20.7 ± 2.6 ppm(v) dry @ 3% O_2 , while SO_3 concentrations at the air heater outlets ranged from 5.8 ± 0.5 to 16.0 ± 1.9 ppm(v) dry @ 3% O_2 . The SO_3 concentration across the Reactor A air heater decreased by a factor of 0.8, while the SO_3 concentrations across Reactor B and C air heaters increased by factors of 1.5 and 2.5, respectively. Air heater inlet SO_2 concentrations averaged $1,845 \pm 58$ ppm(v) dry @ 3% O_2 , while the air heater outlet SO_2 concentrations averaged $1,852 \pm 66$ ppm(v) dry @ 3% O_2 . Since the standard deviations of the mean concentrations at the inlet and outlet overlap, it can be concluded that no measurable difference in SO_2 concentration was observed. Table A-2 in Appendix A contains the original data summaries for these tests.

HCl CONCENTRATIONS

Measurements of the concentration of hydrogen chloride were conducted simultaneously at the inlet and outlet of each of the three large reactor air heaters in December 1994. Three independent tests were performed at each test location. Single point sampling was used. The test results are presented in Table 3-3 as the average concentration and the standard deviation. Air heater inlet

Table 3-2. SCR Reactor Air Preheater Tests: SO₂ and SO₃ Concentrations

			SO ₂	
	Inlet	Outlet	Inlet	Outlet
Reactor	ppm (v), dry, @ 3% O ₂	ppm (v), dry, @ 3% O ₂	ppm (v), dry, @ 3% O ₂	ppm (v), dry, @ 3% O ₂
A	20.7 ± 2.6	16.0 ± 1.9	1782 ± 7	1813 ± 40
B	6.0 ± 1.7	9.1 ± 0.4	1859 ± 10	1812 ± 13
C	2.3 ± 0.9	5.8 ± 0.5	1896 ± 20	1930 ± 33

Table 3-3. SCR Reactor Air Preheater Tests: HCl Concentration

Reactor	HCl Concentration	
	Inlet	Outlet
	ppm (v), dry, @ 3% O ₂	ppm (v), dry, @ 3% O ₂
A	228 ± 17	237 ± 12
B	246 ± 4	245 ± 2
C	262 ± 10	258 ± 8

HCl concentrations fell within the range of 228 ± 17 to 262 ± 10 ppm(v) dry @ 3% O₂. Air heater outlet HCl concentrations fell within the range of 237 ± 12 to 258 ± 8 ppm(v) dry @ 3% O₂. The HCl concentrations were essentially identical between the air heater inlet and outlet, however, the absolute concentrations were higher for Reactor B compared to Reactor A (5.6%) and for Reactor C compared to Reactor B (5.9%). The original data summaries for these HCl tests are presented in Table A-3 in Appendix A.

PARTICULATE MASS CONCENTRATION

Particulate mass concentrations were measured simultaneously at the inlet and outlet of the air heaters on Reactors A and B. The tests took place in early November 1994. Three individual tests were performed at each test site. No measurements were possible on the Reactor C air heater because sampling ports in a location suitable for mass concentration measurements could not be installed on that reactor.

Table 3-4 presents the mass concentration data for the air heater tests. The average air heater inlet mass concentration was 3.21 ± 0.49 gr/dscf on Reactor A and 3.62 ± 0.29 gr/dscf on Reactor B. The average air heater outlet mass concentration was 2.66 ± 0.04 gr/dscf on Reactor A and 2.42 ± 0.05 gr/dscf on Reactor B. The mass concentration was lower at the air heater outlet compared to the air heater inlet by factors of 1.2 and 1.5 for Reactors A and B, respectively. The original data summaries for the mass concentration tests can be found in Table A-4 in Appendix A.

FLY ASH RESISTIVITY

Fly ash resistivity was measured in the laboratory on fly ash samples collected at the outlet of the air heaters on Reactors A and B. The technique for measuring resistivity was based on the IEEE 548 (1984) test method, commonly referred to as a descending temperature method. The atmosphere in the laboratory oven holding the samples was controlled to a moisture content of 7.9%, comparable to that occurring in the actual Unit 5 flue gas. Figure 4-1 presents the relationship between resistivity (ohm-cm) and inverse temperature (1000°K) and the temperature in degrees Fahrenheit. This is a moderate resistivity ash (5×10^{10} ohm-cm @ 291°F). The resistivity for this ash is almost a factor of ten lower than that for the Unit 5 hot-side ESP inlet fly ash collected during Task 1 testing in early 1993 (3.9×10^{11} ohm-cm @ 293°F). Appendix B contains the raw data tables from the laboratory resistivity tests.

FLY ASH MINERAL ANALYSIS

Portions of the fly ash samples collected at the inlet and outlet of the air heaters on Reactors A and B were submitted for mineral ash analysis. The data are presented in Table 3-5 on a weight %, ignited basis. There is very little difference among the four ash samples. The original laboratory report on the mineral analysis tests from Commercial Testing and Engineering Co. is reproduced in Appendix C.

Table 3-4. SCR Reactor Air Heater Tests: Inlet and Outlet Mass Concentrations

Reactor	Air Heater Inlet, gr/dscf	Air Heater Outlet, gr/dscf
A	3.21 ± 0.49	2.66 ± 0.04
B	3.62 ± 0.29	2.42 ± 0.05
C	Not Tested	Not Tested

PLANT CRIST SCR TEST FACILITY
LABORATORY DUST RESISTIVITY
DESCENDING TEMPERATURE MODE

Figure 3-1. Resistivity/temperature relationship for air heater inlet and outlet fly ashes.

Table 3-5. SCR Reactor Air Heater Tests: Ash Mineralogy

Chemical Constituent	Reactor A Inlet, % weight	Reactor A Outlet, % weight	Reactor B Inlet, % weight	Reactor B Outlet, % weight
SiO ₂	47.59	48.58	47.58	48.36
Al ₂ O ₃	23.73	24.03	24.77	25.04
TiO ₂	1.15	1.15	1.2	1.24
Fe ₂ O ₃	16.81	16.61	16.82	15.18
CaO	2.93	2.98	2.54	2.51
MgO	0.91	0.93	1.06	0.93
K ₂ O	2.76	2.81	2.92	2.96
Na ₂ O	0.94	0.96	0.98	1.04
SO ₃	0.79	0.88	0.69	0.95
P ₂ O ₅	0.49	0.49	0.59	0.59
SrO	0.08	0.08	0.1	0.1
BaO	0.10	0.07	0.12	0.07
MnO	0.11	0.09	0.1	0.1
Undetermined	1.61	0.34	0.53	0.93
Loss on Ignition	12.28	12.60	12.38	11.91
Silica Value	69.74	70.30	69.97	72.2
Base:Acid Ratio	0.34	0.33	0.33	0.3
T ₂₅₀ Temperature	2498 °F	2509 °F	2507 °F	2541 °F
Fouling Index	0.32	0.32	0.32	0.31

METALS EXTRACTIONS

Galbraith Laboratories was selected to perform metals extractions from the Reactor A and B air heater inlet and outlet fly ash samples. The metals of interest included antimony, cesium, copper, molybdenum, rubidium, tin, zinc, beryllium, barium, cadmium, cobalt, chromium, nickel, strontium, manganese, vanadium, mercury, arsenic, selenium, and lead. The concentrations of these metals are listed in Table 3-6 on a parts per million basis. There was essentially no enrichment or depletion of the metal concentrations across the air heaters, except for selenium and mercury. The concentrations of these two metals increased by an order of magnitude or greater across the air heater. This can be explained because of the transition from gas phase to solid phase for these elements as cooling occurred within and across the air heater. Appendix D provides the original laboratory report from Galbraith Laboratories, Inc.

Table 3-6. Trace element concentrations in Reactor A and B air heater fly ashes.

Element	Reactor A 11/8/94		Reactor B 11/9/94		Element
	Air Heater Inlet	Air Heater Outlet	Air Heater Inlet	Air Heater Outlet	
	Concentration (ppm)				
Antimony	15.0	12.0	12.0	17.3	Antimony
Cesium	<33	<32	<32	<31	Cesium
Copper	125	125	144	148	Copper
Molybdenum	26.3	25.2	25.3	27.8	Molybdenum
Rubidium	93.2	117	155	142	Rubidium
Tin	78.2	83.9	93.1	75.8	Tin
Zinc	247	252	227	241	Zinc
Beryllium	17.6	17.3	17.7	18.2	Beryllium
Barium	305	357	455	431	Barium
Cadmium	4.3	<4.0	<4.0	<4.0	Cadmium
Cobalt	50.6	50.1	53.8	54.1	Cobalt
Chromium	148	151	151	168	Chromium
Nickel	156	157	167	179	Nickel
Strontium	472	546	766	736	Strontium
Manganese	173	168	158	160	Manganese
Vanadium	348	348	368	380	Vanadium
Mercury	0.019	0.63	<0.010	1.29	Mercury
Arsenic	145	146	146	171	Arsenic
Selenium	<0.56	3.7	<0.54	6.7	Selenium
Lead	298	227	277	319	Lead

Section 4

SUMMARY

This report is the ninth in a series of reports describing the results of testing and analytical services for the Innovative Clean Coal Technology Demonstration of Selective Catalytic Reduction (SCR) Technology for the control of nitrogen oxide (NO_x) emissions from high-sulfur, coal-fired boilers. The test results for the third sequence of air heater tests are summarized in this report. The tests were conducted in November and December 1994.

The SCR test facility is located at Gulf Power Company's Plant Crist Unit 5 in Pensacola, Florida. The test facility includes three large SCR reactors, each designed to treat 5000 wscfm of flue gas, and six small reactors, each processing 400 wscfm of flue gas. An air heater capable of removing sufficient heat to reduce the flue gas temperature from a range of 600 to 750°F down to 300°F was included in the design of each of the three large reactors. The three large reactors are designated as reactors A, B, and C. Reactors A and B incorporate Ljungstrom-type air heaters and Reactor C's air heater incorporates a heat pipe design.

Air heater testing included the determinations of particulate mass concentration (inlet and outlet of Reactor A and B air heaters) and measurements of the concentrations of sulfur dioxide, sulfur trioxide, hydrogen chloride and ammonia (inlet and outlet of Reactor A, B and C air heaters). All tests were conducted with manual sampling methods. Ammonia samples were segregated into solid and gas-phase fractions to characterize the gas/solid phase partitioning of ammonia across the air heaters. In general, simultaneous tests for gaseous species were performed at the inlet and outlet of each of the three air heaters. In addition, ash mineral analyses and the measurement of the concentrations of twenty trace metals were conducted on the fly ash samples collected at the inlet and outlet of the air heaters on Reactors A and B. Also, a portion of the air heater outlet fly ash samples from Reactors A and B were submitted for laboratory resistivity measurements.

AMMONIA CONCENTRATIONS

Concentrations of ammonia were measured simultaneously at each of the three air heater inlet and outlet test locations during December 1994. The ammonia concentration tests conducted downstream of catalyst layer 3 (air preheater inlet) and at the air preheater outlets on Reactors A, B, and C were designed to segregate the ammonia into gas and solid phases. All three air heaters were tested with the reactors operating at Test Conditions 22 and 24. Test Condition 22, the baseline or normal long-term operating condition has a flow rate of 5,000 wscfm, a flue gas temperature of 700°F, and a NH_3/NO_x ratio of 0.8. The operating parameters for Test Condition 24 are the same, except that the NH_3/NO_x ratio is 1.0.

At the inlet of each air heater the volumetric concentration of ammonia was split generally evenly between the gas and solid phases under both test conditions. Unfortunately, the ash sample from the Reactor C air heater inlet and outlet at Test Condition 22 were both contaminated and could not be analyzed. As expected, at the air heater outlet almost all of the ammonia was present in the solid phase. For all three reactors at Test Condition 22 the gas-phase ammonia concentration at the air heater outlet was below the detection limit. This is true also for Reactor A at Test

Condition 24, but not for the other two reactor air heaters, which had measurable concentrations of gas-phase ammonia. This was a direct result of a higher inlet concentration.

The ratio of inlet to outlet concentrations of ammonia based on the estimated solid-phase ammonia concentrations on a weight basis are generally similar in magnitude to those ratios calculated from the solid-phase ammonia concentrations calculated from the ammonia train test data. It should be noted that the possibility exists that some gas-phase ammonia may have reacted with sulfur trioxide present in the flue gas, as the gas stream cooled in the probe, to form ammonium bisulfate or ammonium sulfate. Other reactions involving chlorides etc. are also probably possible. These reaction products would be collected with the solid-phase ammonia sample even though the ammonia was in the gas-phase in the duct. This possible sampling error would cause the solid-phase concentrations to be high.

SO₂ AND SO₃ CONCENTRATIONS

SO₃ concentrations at the air heater inlets ranged from 2.3 ± 0.9 to 20.7 ± 2.6 ppm(v) dry @ 3% O₂, while SO₃ concentrations at the air heater outlets ranged from 5.8 ± 0.5 to 16.0 ± 1.9 ppm(v) dry @ 3% O₂. The SO₃ concentration across the Reactor A air heater decreased by a factor of 0.8, while the SO₃ concentrations across Reactor B and C air heaters increased by factors of 1.5 and 2.5, respectively. Air heater inlet SO₂ concentrations averaged $1,845 \pm 58$ ppm(v) dry @ 3% O₂, while the air heater outlet SO₂ concentrations averaged $1,852 \pm 66$ ppm(v) dry @ 3% O₂. Within the tolerance of the standard deviations given for average SO₂ concentrations in Table 3-2, there was no statistical difference in the concentrations of SO₂ at the inlet and outlet of each of the air heaters.

HCl CONCENTRATIONS

Air heater inlet HCl concentrations fell within the range of 228 ± 17 to 262 ± 10 ppm(v) dry @ 3% O₂. Air heater outlet HCl concentrations fell within the range of 237 ± 12 to 258 ± 8 ppm(v) dry @ 3% O₂. The HCl concentrations were essentially identical between the air heater inlet and outlet, however, the absolute concentrations were higher for Reactor B compared to Reactor A (5.6%) and for Reactor C compared to Reactor B (5.9%).

PARTICULATE MASS CONCENTRATIONS

The average air heater inlet mass concentration was 3.21 ± 0.49 gr/dscf on Reactor A and 3.62 ± 0.29 gr/dscf on Reactor B. The average air heater outlet mass concentration was 2.66 ± 0.04 gr/dscf on Reactor A and 2.42 ± 0.05 gr/dscf on Reactor B. The mass concentration was lower at the air heater outlet compared to the air heater inlet by factors of 1.2 and 1.5 for Reactors A and B, respectively.

FLY ASH RESISTIVITY

The Reactor A and B air heater outlet fly ashes are composed of a moderate resistivity ash (5×10^{10} ohm-cm @ 291°F). The resistivity for this ash is almost a factor of ten lower than that for the

Unit 5 hot-side ESP inlet fly ash collected during Task 1 testing in early 1993 (3.9×10^{11} ohm-cm @ 293°F).

FLY ASH MINERAL ANALYSIS

The chemical composition of the Reactor A and B inlet and outlet fly ashes were very similar and the concentrations of the various compounds were typical of fly ash from high-sulfur coal.

METALS EXTRACTIONS

Metals extractions were performed on fly ashes from the Reactor A and B air heater inlet and outlet. The metals of interest included antimony, cesium, copper, molybdenum, rubidium, tin, zinc, beryllium, barium, cadmium, cobalt, chromium, nickel, strontium, manganese, vanadium, mercury, arsenic, selenium, and lead. There was essentially no enrichment or depletion of the metal concentrations across the air heaters, except for selenium and mercury. The concentrations of these two metals increased by an order of magnitude or greater across the air heater. This can be explained because of the transition from gas phase to solid phase for these elements as cooling occurred within and across the air heater.

APPENDIX A

ORIGINAL DATA SUMMARIES

NH₃ Concentrations
SO₂ Concentrations
SO₃ Concentrations
HCl Concentrations
Particulate Mass Concentrations

Table A-1 (Reference Table 3-1)

W o o k	S i t e	N u m b e r				NH ₃ Concentration ppm (v), dry, @ 3% O ₂	Reactor Conditions										Analytical					Dry Gas Meter				
							Condition Number	Flow	Temp.	MW	Unk & Boiler Load	Sample O ₂	NH ₃ as N	Oil	Vol.	NH ₃	NH ₃	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter ID	Corr. Factor
			Time, Begin	Time, End	Date	Average	σ	scfm	° F	MW	%	µg/ml	ml	µM	ppm, dry, 3% O ₂	STD L, dry	° K	in. Hg	° F	° F	m ³	m ³				
102	AAI	NHG 05	0924	0959	15-Dec-94	1.0 ± 0.01	22	5000	700	0.8	85	4.4	0.261	1	349	6.5	1.0	152.85	299	30.25	72	84	693.200	699.200	Stack 3	0.973
102	AAI	NHG 06	1026	1059	15-Dec-94	1.3 ± 0.03	22	5000	700	0.8	86	4.5	0.268			6.6	1.1	150.33	304	30.25	84	90	699.500	705.500	Stack 3	0.973
102	AAI	NHG 07	1124	1155	15-Dec-94	1.3 ± 0.01	22	5000	700	0.8	84	4.8	0.389			7.9	1.3	149.51	305	30.25	88	92	705.700	711.700	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						1.2 ± 0.16	Testing Interval Averages						85	4.6												
												1	0.2													
102	AAI	NHS 05	0924	0959	15-Dec-94	1.2 ± 0.03	22	5000	700	0.8	85	4.4	0.449	1	225	7.2	1.1	152.85	299	30.25	72	84	693.200	699.200	Stack 3	0.973
102	AAI	NHS 06	1026	1059	15-Dec-94	1.4 ± 0.02	22	5000	700	0.8	86	4.5	0.465			7.5	1.2	150.33	304	30.25	84	90	699.500	705.500	Stack 3	0.973
102	AAI	NHS 07	1124	1155	15-Dec-94	1.1 ± 0.02	22	5000	700	0.8	84	4.8	0.510			8.5	1.4	149.51	305	30.25	88	92	705.700	711.700	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						1.2 ± 0.16	Testing Interval Averages						85	4.6												
												1	0.2													
102	AAO	NHG 05	0940	1009	15-Dec-94	< 0.3	22	5000	700	0.8	85	7.4	0.024	1	237	1.7	0.3	162.54	289	30.25	58	63	157.100	163.100	Stack 1	1.001
102	AAO	NHG 06	1036	1104	15-Dec-94	< 0.3	22	5000	700	0.8	86	7.8	0.025			1.7	0.3	161.92	290	30.25	61	64	163.500	169.500	Stack 1	1.001
102	AAO	NHG 07	1133	1201	15-Dec-94	< 0.3	22	5000	700	0.8	84	7.4	0.032			1.7	0.3	160.99	292	30.25	63	68	169.900	175.900	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						< 0.3	Testing Interval Averages						85	7.5												
												1	0.2													
102	AAO	NHS 05	0940	1009	15-Dec-94	4.0 ± 0.10	22	5000	700	0.8	85	7.4	1.710	1	175	21.4	3.9	162.54	289	30.25	58	63	157.100	163.100	Stack 1	1.001
102	AAO	NHS 06	1036	1104	15-Dec-94	4.0 ± 0.04	22	5000	700	0.8	86	7.8	1.770			22.1	4.0	161.92	290	30.25	61	64	163.500	169.500	Stack 1	1.001
102	AAO	NHS 07	1133	1201	15-Dec-94	3.6 ± 0.01	22	5000	700	0.8	84	7.4	2.130			21.4	4.1	160.99	292	30.25	63	68	169.900	175.900	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						3.9 ± 0.25	Testing Interval Averages						85	7.5												
												1	0.2													

Table A-1, continued (Reference Table 3-1)

W o r k o n n u m b e r	S i t e	G a s	N u m b e r				NH ₃ Concentration		Reactor Conditions										Analytical					Dry Gas Meter				
							ppm (v), dry, @ 3% O ₂		Condition Number	Flow	Temp.	NH ₃ /NO _x	Unit & Boiler Load	Sample O ₂	NH ₃ as N	Disl	Vol.	NH ₃	NH ₃	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter ID	Corr. Factor
				Time, Begin	Time, End	Date	Average	σ		scfm	° F		MW	%	µg/ml		ml	µM	ppm, dry, 3% O ₂	STD l, dry	° K	in. Hg	° F	° F	ft ³	ft ³		
102	AAI	NHG	01	1354	1432	14-Dec-94	2.2	± 0.00	24	5000	700	1.0	83	4.2	0.558	1	364	14.5	2.2	154.90	294	30.20	64	76	668.500	674.500	Stack 3	0.973
102	AAI	NHG	02	1458	1533	14-Dec-94	2.9	± 0.04	24	5000	700	1.0	83	4.2	0.558			14.5	2.2	152.17	299	30.20	76	83	674.800	680.800	Stack 3	0.973
102	AAI	NHG	03	1618	1655	14-Dec-94	3.7	± 0.07	24	5000	700	1.0	84	4.3	0.722		348	17.9	2.8	151.33	301	30.20	82	83	681.000	687.000	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							2.9	± 0.04	Testing Interval Averages				83	4.2	0.737			18.3	2.9									
									σ				1	0.1	0.845			22.9	3.7									
															0.869			23.6	3.8									
102	AAI	NHS	01	1354	1432	14-Dec-94	3.3	± 0.02	24	5000	700	1.0	83	4.2	1.310	1	229	21.4	3.3	154.90	294	30.20	64	76	668.500	674.500	Stack 3	0.973
102	AAI	NHS	02	1458	1533	14-Dec-94	3.7	± 0.03	24	5000	700	1.0	83	4.2	1.320			21.6	3.3	152.17	299	30.20	76	83	674.800	680.800	Stack 3	0.973
102	AAI	NHS	03	1618	1655	14-Dec-94	5.4	± 0.10	24	5000	700	1.0	84	4.3	1.510			23.2	3.7	151.33	301	30.20	82	83	681.000	687.000	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							4.1	± 1.08	Testing Interval Averages				83	4.2	1.530			23.5	3.7									
									σ				1	0.1	2.220			33.1	5.3									
															2.280			34.0	5.4									
102	AAO	NHG	01	1408	1435	14-Dec-94	< 0.4		24	5000	700	1.0	83	7.8	0.066	1	260	1.9	0.4	161.49	290	30.20	64	62	133.900	139.900	Stack 1	1.001
102	AAO	NHG	02	1508	1537	14-Dec-94	< 0.4		24	5000	700	1.0	83	7.5	0.062			1.9	0.4	161.34	291	30.20	64	63	140.200	146.200	Stack 1	1.001
102	AAO	NHG	03	1626	1655	14-Dec-94	< 0.4		24	5000	700	1.0	84	7.3	0.039			2.0	0.4	161.96	289	30.20	61	62	146.500	152.500	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							< 0.4		Testing Interval Averages				83	7.5	0.035			2.0	0.4									
									σ				1	0.3	0.033			2.0	0.4									
															0.021			2.0	0.4									
102	AAO	NHS	01	1408	1435	14-Dec-94	5.4	± 0.13	24	5000	700	1.0	83	7.8	2.310	1	171	28.2	5.3	161.49	290	30.20	64	62	133.900	139.900	Stack 1	1.001
102	AAO	NHS	02	1508	1537	14-Dec-94	5.7	± 0.05	24	5000	700	1.0	83	7.5	2.390			29.2	5.5	161.34	291	30.20	64	63	140.200	146.200	Stack 1	1.001
102	AAO	NHS	03	1626	1655	14-Dec-94	6.9	± 0.10	24	5000	700	1.0	84	7.3	2.330			30.6	5.7	161.96	289	30.20	61	62	146.500	152.500	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							6.0	± 0.30	Testing Interval Averages				83	7.5	2.360			31.0	5.8									
									σ				1	0.3	2.390			37.8	6.9									
															2.410			38.6	7.0									

7.

Week	Site	Gas	Number				NH ₃ Concentration		Reactor Conditions										Analytical					Dry Gas Meter				
									ppm (v), dry, @ 3% O ₂		Condition Number	Flow	Temp.	NH ₃ /NO _x	Unk. Boiler Load	Sample O ₂	NH ₃ as N	Dil	Vol.	NH ₃	NH ₃	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End
				Time, Begin	Time, End	Date	Average	σ	scfm	° F		MW	%	μg/ml	ml	μM	ppm, dry, 3% O ₂	STD L, dry	° K	In. Hg	° F	° F	ft ³	ft ³				
102	BAI	NHG	02	0938	1012	16-Dec-94	0.9 ± 0.01		22	5000	705	0.8	83	5.0	0.215	1	364	5.6	0.9	152.98	298	30.22	74	80	738.000	744.000	Stack 3	0.973
															0.219			5.7	0.9									
102	BAI	NHG	03	1036	1112	16-Dec-94	0.9 ± 0.01		22	5000	705	0.8	83	5.2	0.247		306	5.4	0.9	149.91	304	30.22	86	90	744.500	750.500	Stack 3	0.973
															0.251			5.5	0.9									
102	BAI	NHG	04	1131	1204	16-Dec-94	0.8 ± 0.03		22	5000	705	0.8	83	4.9	0.212		304	4.6	0.8	149.09	306	30.22	90	92	751.000	757.000	Stack 3	0.973
															0.201			4.4	0.7									
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							0.9 ± 0.10		Testing Interval Averages					83	5.0													
									σ					0	0.2													
102	BAI	NHS	02	0938	1012	16-Dec-94	1.1 ± 0.03		22	5000	705	0.8	83	5.0	0.420	1	209	6.3	1.0	152.98	298	30.22	74	80	738.000	744.000	Stack 3	0.973
															0.439			6.6	1.1									
102	BAI	NHS	03	1036	1112	16-Dec-94	0.7 ± 0.00		22	5000	705	0.8	83	5.2	0.310		198	4.4	0.7	149.91	304	30.22	86	90	744.500	750.500	Stack 3	0.973
															0.310			4.4	0.7									
102	BAI	NHS	04	1131	1204	16-Dec-94	0.7 ± 0.02		22	5000	705	0.8	83	4.9	0.295		197	4.2	0.7	149.09	306	30.22	90	92	751.000	757.000	Stack 3	0.973
															0.285			4.0	0.7									
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							0.8 ± 0.20		Testing Interval Averages					83	5.0													
									σ					0	0.2													
102	BAO	NHG	02	0943	1013	16-Dec-94	< 0.4		22	5000	705	0.8	83	8.0	0.032	1	314	2.2	0.4	159.16	295	30.22	70	72	200.500	206.500	Stack 1	1.001
															0.029			2.2	0.4									
102	BAO	NHG	03	1045	1114	16-Dec-94	< 0.4		22	5000	705	0.8	83	8.2	0.030		286	2.0	0.4	159.31	294	30.22	70	71	207.000	213.000	Stack 1	1.001
															0.027			2.0	0.4									
102	BAO	NHG	04	1138	1206	16-Dec-94	< 0.5		22	5000	705	0.8	83	8.2	0.027		334	2.4	0.5	158.27	296	30.22	72	76	213.400	219.400	Stack 1	1.001
															0.026			2.4	0.5									
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							< 0.4		Testing Interval Averages					83	8.1													
									σ					0	0.1													
102	BAO	NHS	02	0943	1013	16-Dec-94	3.6 ± 0.08		22	5000	705	0.8	83	8.0	1.640	1	154	18.0	3.5	159.16	295	30.22	70	72	200.500	206.500	Stack 1	1.001
															1.690			18.6	3.6									
102	BAO	NHS	03	1045	1114	16-Dec-94	2.9 ± 0.07		22	5000	705	0.8	83	8.2	1.190		172	14.6	2.9	159.31	294	30.22	70	71	207.000	213.000	Stack 1	1.001
															1.230			15.1	3.0									
102	BAO	NHS	04	1138	1206	16-Dec-94	2.8 ± 0.02		22	5000	705	0.8	83	8.2	1.160		168	13.9	2.8	158.27	296	30.22	72	76	213.400	219.400	Stack 1	1.001
															1.170			14.0	2.8									
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂							3.1 ± 0.42		Testing Interval Averages					83	8.1													
									σ					0	0.1													

Table A-1, continued (Reference Table 3-1)

Week	Site	Number				NH ₃ Concentration ppm (v), dry, @ 3% O ₂	Reactor Conditions										Analytical					Dry Gas Meter				
							Condition Number	Flow	Temp.	NH ₃ /NO _x	Unit 6 Boiler Load	Sample O ₂	NH ₃ as N	Dil	Vol.	NH ₃	NH ₃	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter LD	Corr. Factor
			Time, Begin	Time, End	Date	Average	σ	scfm	° F		MW	%	µg/ml	ml	µM	ppm, dry, 3% O ₂	STD l, dry	° K	in. Hg	° F	° F	ft ³	ft ³			
102	BAI	NHG 05	1344	1414	16-Dec-94	12.9 ± 0.20	24	400	705	1.0	83	5.0	3.200	1	337	77.0	12.7	152.70	299	30.22	70	86	757.300	763.300	Stack 3	0.973
102	BAI	NHG 06	1436	1520	16-Dec-94	17.5 ± 0.14	24	400	705	1.0	83	4.9	3.270			78.7	13.0	150.04	304	30.22	85	90	763.500	769.500	Stack 3	0.973
102	BAI	NHG 07	1545	1620	16-Dec-94	21.8 ± 0.33	24	400	705	1.0	83	4.9	4.320		337	104	17.4	149.50	305	30.22	87	92	770.200	776.200	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						17.4 ± 4.48	Testing Interval Averages						83	4.9												
							σ						0	0.1												
102	BAI	NHS 05	1344	1414	16-Dec-94	6.8 ± 0.12	24	400	705	1.0	83	5.0	2.760	1	205	40.4	6.7	152.70	299	30.22	70	86	757.300	763.300	Stack 3	0.973
102	BAI	NHS 06	1436	1520	16-Dec-94	13.2 ± 0.16	24	400	705	1.0	83	4.9	2.830			41.4	6.8	150.04	304	30.22	85	90	763.500	769.500	Stack 3	0.973
102	BAI	NHS 07	1545	1620	16-Dec-94	16.8 ± 0.24	24	400	705	1.0	83	4.9	3.440		318	78.1	13.1	149.50	305	30.22	87	92	770.200	776.200	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						12.2 ± 5.09	Testing Interval Averages						83	4.9												
							σ						0	0.1												
102	BAO	NHG 05	1352	1421	16-Dec-94	< 0.4	24	400	705	1.0	83	7.9	0.036	1	302	2.2	0.4	158.12	297	30.22	77	72	219.800	225.800	Stack 1	1.001
102	BAO	NHG 06	1445	1515	16-Dec-94	0.9 ± 0.02	24	400	705	1.0	83	7.8	0.035			2.2	0.4	158.57	296	30.22	73	73	226.300	232.300	Stack 1	1.001
102	BAO	NHG 07	1549	1619	16-Dec-94	1.9 ± 0.05	24	400	705	1.0	83	7.8	0.230			4.4	0.8	161.14	291	30.22	67	62	232.700	238.700	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						1.1 ± 0.79	Testing Interval Averages						83	7.8												
							σ						0	0.1												
102	BAO	NHS 05	1352	1421	16-Dec-94	7.6 ± 0.14	24	400	705	1.0	83	7.9	0.236			4.5	0.9	158.12	297	30.22	77	72	219.800	225.800	Stack 1	1.001
102	BAO	NHS 06	1445	1515	16-Dec-94	10.8 ± 0.17	24	400	705	1.0	83	7.8	0.446		328	10.4	2.0	158.57	296	30.22	73	73	226.300	232.300	Stack 1	1.001
102	BAO	NHS 07	1549	1619	16-Dec-94	20.2 ± 0.00	24	400	705	1.0	83	7.8	0.430			10.1	1.9	161.14	291	30.22	67	62	232.700	238.700	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂						12.9 ± 6.56	Testing Interval Averages						83	7.8												
							σ						0	0.1												

Table A-1, continued (Reference Table 3-1)

W o r k i t e m N u m b e r				NH ₃ Concentration ppm (v), dry, @ 3% O ₂		Reactor Conditions										Analytical					Dry Gas Meter				
						Condition Number	Flow	Temp.	NH ₃ / NO _x	Unit S Boiler Load	Sample O ₂	NH ₃ as N	Dil	Vol.	NH ₃	NH ₃	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter LD	Corr. Factor
	Time, Begin	Time, End	Date	Average	σ		scfm	° F		MW	%	µg/ml		ml	µM	ppm, dry, 3% O ₂	STD L, dry	° K	In. Hg	° F	° F	m ³	m ³		
103 CAI NHG 05	1358	1435	20-Dec-94	22.5 ± 0.13		24	400	705	1.0	83	4.2	7.070	1	282	142	22.4	152.70	299	30.22	72	84	853.200	859.200	Stack 3	0.973
103 CAI NHG 06	1451	1523	20-Dec-94	19.1 ± 0.23		24	400	705	1.0	82	4.4	7.130			144	22.6	150.18	304	30.22	82	92	859.600	865.600	Stack 3	0.973
103 CAI NHG 07	1541	1614	20-Dec-94	20.1 ± 0.00		24	400	705	1.0	83	4.1	5.140		318	117	18.9	149.50	305	30.22	88	91	866.000	872.000	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂				20.5 ± 1.76		Testing Interval Averages				83	4.2	4.670			126	20.1									
											σ	1	0.2		128	20.1									
103 CAI NHS 05	1358	1435	20-Dec-94	15.0 ± 0.14		24	400	705	1.0	83	4.2	6.680	1	199	95.0	14.9	152.70	299	30.22	72	84	853.200	859.200	Stack 3	0.973
103 CAI NHS 06	1451	1523	20-Dec-94	14.3 ± 0.05		24	400	705	1.0	82	4.4	6.770			96.2	15.1	150.18	304	30.22	82	92	859.600	865.600	Stack 3	0.973
103 CAI NHS 07	1541	1614	20-Dec-94	14.6 ± 0.00		24	400	705	1.0	83	4.1	5.920		209	88.4	14.3	149.50	305	30.22	88	91	866.000	872.000	Stack 3	0.973
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂				14.6 ± 0.36		Testing Interval Averages				83	4.2	6.020		212	91.2	14.6									
											σ	1	0.2		91.2	14.6									
103 CAO NHG 05	1413	1444	20-Dec-94	< 0.3		24	400	705	1.0	83	4.5	0.038	1	291	2.1	0.3	161.60	290	30.22	62	64	305.030	311.030	Stack 1	1.001
103 CAO NHG 06	1507	1537	20-Dec-94	0.5 ± 0.03		24	400	705	1.0	82	4.3	0.033			2.1	0.3	161.14	291	30.22	64	65	312.600	318.600	Stack 1	1.001
103 CAO NHG 07	1557	1627	20-Dec-94	1.3 ± 0.06		24	400	705	1.0	83	4.0	0.156		295	3.3	0.5	160.83	292	30.22	65	66	308.000	315.000	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂				0.7 ± 0.54		Testing Interval Averages				83	4.3	0.168			3.5	0.5									
											σ	1	0.3		9.3	1.4									
103 CAO NHS 05	1413	1444	20-Dec-94	18.2 ± 0.15		24	400	705	1.0	83	4.5	8.930	1	190	121	18.3	161.60	290	30.22	62	64	305.030	311.030	Stack 1	1.001
103 CAO NHS 06	1507	1537	20-Dec-94	17.6 ± 0.11		24	400	705	1.0	82	4.3	8.830			120	18.1	161.14	291	30.22	64	65	312.600	318.600	Stack 1	1.001
103 CAO NHS 07	1557	1627	20-Dec-94	18.0 ± 0.06		24	400	705	1.0	83	4.0	4.610	2	178	117	17.6	160.83	292	30.22	65	66	308.000	315.000	Stack 1	1.001
Average NH ₃ Concentration, ppm(v), dry @ 3% O ₂				18.0 ± 0.30		Testing Interval Averages				83	4.3	4.850			118	17.7									
											σ	1	0.3		122	18.0									

Table A-2 (Reference Table 3-2)

Week	Site	Quarter	Number				Concentration		Analytical					Reactor Conditions					Dry Gas Meter								
				ppm (v), dry, @ 3% O ₂			SO ₂ ^a	DM	Vol.	SO ₂ ^a	SO ₂ or SO ₃	Condition Number	Flow	Temp.	NH ₃ NO _x	Unit S Boiler Load,	Sample O ₂	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor	
				Time, Begin	Time, End	Date	Average	σ	μg/ml		ml	μM	ppm(v), dry, @ 3% O ₂		scfm	° F		MW	%	STD L, dry	° K	in. Hg	° F	° F	m ³	m ³	
102	AAI	SO3	01	1402	1416	15-Dec-94	17.7 ± 0.12	2.519 2.494	25	82.9	54	17.8 54	22	5	700	0.8	84	4.8	75.30	303	30.25	82	90	712.100	715.100	Stack 3	0.9730
102	AAI	SO3	02	1429	1443	15-Dec-94	22.4 ± 0.06	3.211 3.198		83.3	70	22.4 69	22	5	700	0.8	85	4.1	74.15	308	30.25	91	98	715.800	718.800	Stack 3	0.9730
102	AAI	SO3	03	1458	1511	15-Dec-94	22.1 ± 0.02	2.979 2.976		88.0	68	22.1 68	22	5	700	0.8	85	4.1	73.75	309	30.25	94	101	719.200	722.200	Stack 3	0.9730
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							20.7 ± 2.6						Testing Interval Averages					85	4.3								
													σ					1	0.3								
102	AAI	SO2	01	1402	1416	15-Dec-94	1783 ± 20	3.965 3.903	200	606	5501	1797.1 5415															
								4.079 4.077		654	5558	1788.9 1788.0															
102	AAI	SO2	02	1429	1443	15-Dec-94	1788 ± 1	4.077 3.859		654	5555	1788.0 1774.4															
								3.883		682	5483	1776.2															
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							1782.3 ± 6.6																				
102	AAO	SO3	01	1406	1421	15-Dec-94	14.8 ± 0.00	1.900 1.900	25	80.1	40	14.8 40	22	5	700	0.8	84	7.5	80.34	292	30.25	66	67	178.300	179.300	Stack 1	1.0010
102	AAO	SO3	02	1433	1448	15-Dec-94	18.2 ± 0.05	2.333 2.324		82.4	50	18.3 50	22	5	700	0.8	85	7.2	80.27	292	30.25	67	67	179.700	182.700	Stack 1	1.0010
102	AAO	SO3	03	1500	1515	15-Dec-94	15.0 ± 0.11	2.036 2.057		77.3	41	14.9 41	22	5	700	0.8	85	7.2	80.42	292	30.25	66	66	183.100	186.100	Stack 1	1.0010
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							16.0 ± 1.9						Testing Interval Averages					85	7.3								
													σ					1	0.2								
102	AAO	SO2	01	1406	1421	15-Dec-94	1859 ± 13	3.495 3.461	200	689	5017	1868.4 4968															
								3.099 3.068		770	4923	1795.1 4922															
102	AAO	SO2	02	1433	1448	15-Dec-94	1795 ± 0	2.882 2.877		816	4911	1787.4 4903															
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂							1813.3 ± 40.1																				

Table A-2, continued (Reference Table 3-2)

W e b s i t e N u m b e r				Concentration		Analytical					Reactor Conditions					Dry Gas Meter									
						SO ₂ ⁺	Dil	Vol.	SO ₂ ⁺	SO ₂ , or SO ₃	Condition Number	Flow	Temp.	Rel. NO _x	Unit 5 Boiler Load,	Sample O ₂	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter LD	Corr. Factor
	Time, Begin	Time, End	Date	Average	σ	μg/ml		ml	μM	ppm(v), dry, @ 3% O ₂		scfm	°F		MW	%	STD L, dry	°K	In. Hg	°F	°F	m ³	m ³		
102 BAI SO3 01	0907	0921	17-Dec-94	7.4	± 1.64	1.002	25	75.0	20	6.3	22	5	700	0.8	84	4.6	76.77	296	30.16	70	78	782.900	785.900	Stack 3	0.9730
						1.373			27	8.6															
102 BAI SO3 02	0934	0947	17-Dec-94	6.3	± 0.03	0.913		81.6	19	6.4	22	5	700	0.8	84	4.7	75.56	301	30.16	76	80	786.200	789.200	Stack 3	0.9730
						0.907			19	6.3															
102 BAI SO3 03	0959	1013	17-Dec-94	4.1	± 0.02	0.623		76.1	12	4.1	22	5	700	0.8	82	4.9	74.67	305	30.16	86	92	789.500	792.500	Stack 3	0.9730
						0.619			12	4.1															
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				6.0	± 1.7						Testing Interval Averages					83	4.7								
											σ					1	0.2								
102 BAI SO2 01	0907	0921	17-Dec-94	1847	± 6	4.381	200	633	5777	1851.2															
						4.300				5750	1842.4														
102 BAI SO2 02	0934	0947	17-Dec-94	1805	± 66	4.258		626	5553	1818.9															
						4.476				5837	1912.0														
102 BAI SO2 03	0959	1013	17-Dec-94	1864	± 1	3.719		717	5555	1864.4															
						3.717				5552	1863.4														
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				1858.7	± 10.3																				
102 BAO SO3 01	0911	0927	17-Dec-94	8.9	± 0.02	1.016	25	90.0	24	8.9	22	5	700	0.8	84	7.5	80.16	292	30.16	65	67	240.200	243.200	Stack 1	1.0010
						1.019			24	8.9															
102 BAO SO3 02	0937	0952	17-Dec-94	9.6	± 0.02	1.345		77.0	27	9.6	22	5	700	0.8	84	7.6	85.12	293	30.16	67	70	243.600	246.600	Stack 1	1.0010
						1.348			27	9.6															
102 BAO SO3 03	1003	1018	17-Dec-94	9.0	± 0.03	1.255		73.6	24	9.0	22	5	700	0.8	82	7.4	79.65	294	30.16	69	70	247.100	250.100	Stack 1	1.0010
						1.260			24	9.0															
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				9.1	± 0.4						Testing Interval Averages					83	7.5								
											σ					1	0.1								
102 BAO SO2 01	0911	0927	17-Dec-94	1805	± 9	3.484	200	664	4820	1798.6															
						3.508				4853	1811.0														
102 BAO SO2 02	0937	0952	17-Dec-94	1805	± 16	3.248		756	5129	1816.6															
						3.207				5064	1793.7														
102 BAO SO2 03	1003	1018	17-Dec-94	1827	± 9	3.122		756	4917	1833.6															
						3.1				4883	1820.6														
Average SO ₂ Concentration, ppm(v), wet @ 3% O ₂				1812.3	± 12.8																				

Table A-2, continued (Reference Table 3-2)

Time, Begin, End, Date			Concentration	Analytical				Reactor Conditions				Dry Gas Meter													
				SO ₂	Dil	Vol.	SO ₂	SO ₃	SO ₂ or SO ₃	Condition Number	Flow	Temp.	NH ₃ Boiler Load	MW	%	STD L	Temp.	Barometric Pressure	Temp.	Volume	Volume	End	Factor		
Average			ppm (V), dry, @ 3% O ₂	μg/m ³	ml	μM	ppm(V), dry, @ 3% O ₂	scfm	° F	° F	° F	° F	° F	° F	° F	° F	° F	° F	° F	° F	° F	° F			
103 CAI SO ₂ 01	1100	1114	19-Dec-94	1.7	± 0.02	0.260	25	91.5	6	1.7	22	5	700	0.8	86	2.3	76.25	292	30.26	60	72	805.500	806.500	Stack 3	0.9730
103 CAI SO ₂ 02	1133	1147	19-Dec-94	3.3	± 0.00	0.406	94.6	12	3.3	22	5	700	0.8	86	2.1	76.79	297	30.26	70	82	806.800	811.800	Stack 3	0.9730	
103 CAI SO ₂ 03	1206	1221	19-Dec-94	1.8	± 0.05	0.339	74.8	7	1.8	22	5	700	0.8	87	2.1	75.93	301	30.26	78	86	812.000	815.000	Stack 3	0.9730	
Average SO ₂ Concentration, ppm(V), wet @ 3% O ₂				2.3	± 0.8	0.327	6	1.8	0.327	Testing Interval Averages			σ	1	0.1										
103 CAI SO ₂ 01	1100	1114	19-Dec-94	1819	± 4	4.980	200	671	6976	1921.7				86	2.2										
103 CAI SO ₂ 02	1133	1147	19-Dec-94	1866	± 10	4.824	673	6764	1876.6				86	2.1											
103 CAI SO ₂ 03	1206	1221	19-Dec-94	1864	± 7	4.305	746	6661	1879.2				86	2.1											
Average SO ₂ Concentration, ppm(V), wet @ 3% O ₂				1862.2	± 19.7	4.327				Testing Interval Averages			σ	1	0.1										
103 CAO SO ₂ 01	1110	1123	19-Dec-94	5.3	± 0.03	1.434	25	50.3	19	5.2	22	5	700	0.8	86	3.4	82.06	286	30.26	55	57	261.530	264.530	Stack 1	1.0010
103 CAO SO ₂ 02	1143	1156	19-Dec-94	6.3	± 0.01	1.368	61.1	22	6.3	22	5	700	0.8	86	3.8	81.59	286	30.26	58	60	264.930	267.930	Stack 1	1.0010	
103 CAO SO ₂ 03	1218	1232	19-Dec-94	6.0	± 0.03	1.276	62.7	21	6.0	22	5	700	0.8	87	3.8	81.46	286	30.26	60	63	266.250	271.260	Stack 1	1.0010	
Average SO ₂ Concentration, ppm(V), wet @ 3% O ₂				5.8	± 0.5	1.264	Testing Interval Averages			σ	1	0.2													
103 CAO SO ₂ 01	1110	1123	19-Dec-94	1866	± 14	4.624	200	702	6763	1888.1				86	3.7										
103 CAO SO ₂ 02	1143	1156	19-Dec-94	1904	± 2	5.28	621	6631	1903.2				86	3.7											
103 CAO SO ₂ 03	1218	1232	19-Dec-94	1927	± 1	4.63	664	6664	1928.6				86	3.7											
Average SO ₂ Concentration, ppm(V), wet @ 3% O ₂				1830.0	± 33.2	4.633				Testing Interval Averages			σ	1	0.2										

Table A-3 (Reference Table 3-3)

W e e k	S i t e	G a s	N u m b e r				HCl Concentration ppm (v), dry, @ 3% O ₂	Reactor Conditions						Analytical					Dry Gas Meter									
								Condition Number	Flow	Temp.	NH ₃ NO _x	Unit & Boiler Load,	Sample O ₂	Cl ⁻	OH ⁻	Vol.	Cl ⁻	Cl ⁻	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor	
				Time, Begin	Time, End	Date																						Average
102	AAI	HCl	01	1550	1602	15-Dec-94	222.2 ± 0.23	22	5000	700	0.8	85	3.7	1.382	25	725	707	222.3	74.06	306	30.25	96	94	722.500	725.500	Stack 3	0.973	
102	AAI	HCl	02	1611	1628	15-Dec-94	239.8 ± 1.64	22	5000	700	0.8	85	4.1	1.380		706	222.0	74.42	307	30.25	91	94	726.000	729.000	Stack 3	0.973		
102	AAI	HCl	03	1634	1648	15-Dec-94	216.4 ± 0.00	22	5000	700	0.8	85	4.2	1.347		791	751	241.0	74.15	308	30.25	92	97	729.300	732.300	Stack 3	0.973	
Average HCl Concentration, ppm(v), wet @ 3% O ₂							228.1 ± 16.6	Testing Interval Averages						85	4.0													
								σ						0	0.3													
102	AAO	HCl	01	1554	1607	15-Dec-94	224.0 ± 1.14	22	5000	700	0.8	85	7.2	1.113	25	790	620	224.8	80.73	291	30.25	64	64	186.400	189.400	Stack 1	1.0010	
102	AAO	HCl	02	1614	1628	15-Dec-94	242.7 ± 5.30	22	5000	700	0.8	85	7.2	1.105		616	223.2	94.27	291	30.25	63	64	189.900	193.400	Stack 1	1.0010		
102	AAO	HCl	03	1638	1652	15-Dec-94	245.7 ± 3.74	22	5000	700	0.8	85	7.2	1.348		835	794	246.4	76.49	307	30.25	93	93	193.800	196.800	Stack 1	1.0010	
Average HCl Concentration, ppm(v), wet @ 3% O ₂							237.4 ± 11.7	Testing Interval Averages						85	7													
								σ						0	0													

Table A-3, continued (Reference Table 3-3)

[illegible]

Table A-3, continued (Reference Table 3-3)

Well ID	Site	Gas	Number				HCl Concentration		Reactor Conditions							Analytical					Dry Gas Meter									
									Condition Number	Flow	Temp.	NH ₃ NO _x	Unit 5 Boiler Load,	Sample O ₂	Cr	Dil	Vol.	Cr	Cr	Volume, Total	Temp, Avg.	Barometric Pressure	Temp, Begin	Temp, End	Volume, Begin	Volume, End	Meter I.D	Corr. Factor		
				Time, Begin	Time, End	Date	Average	σ		scfm	° F		MW	%	μ g/ml		ml	μ M	ppm, dry, @ 3% O ₂	STD L, dry	° K	in. Hg	° F	° F	ft ³	ft ³				
103	CAI	HCl	01	1335	1350	19-Dec-94	294.1	± 2.92	22	5000	700	0.8	87	2.4	2.692	25	541	1027	292.1	76.22	300	30.28	78	82	815.300	818.300	Stack 3	0.973		
103	CAI	HCl	02	1404	1418	19-Dec-94	255.1	± 1.30	22	5000	700	0.8	87	2.3	2.730			1042	296.2	75.52	302	30.28	82	88	818.700	821.700	Stack 3	0.973		
103	CAI	HCl	03	1429	1441	19-Dec-94	268.8	± 8.76	22	5000	700	0.8	87	2.3	2.513		506	897	256.0	75.03	304	30.28	88	91	822.200	825.200	Stack 3	0.973		
Average HCl Concentration, ppm(v), wet @ 3% O ₂							261.9	± 9.7	Testing Interval Averages						87	2.3														
									σ						0	0.1														
103	CAO	HCl	01	1332	1345	19-Dec-94	253.6	± 0.32	22	5000	700	0.8	87	3.8	1.662	25	747	876	253.3	81.04	290	30.28	62	63	271.600	274.600	Stack 1	1.0010		
103	CAO	HCl	02	1359	1415	19-Dec-94	266.2	± 0.00	22	5000	700	0.8	87	3.7	1.665			877	253.8	80.73	291	30.28	64	65	275.000	278.000	Stack 1	1.0010		
103	CAO	HCl	03	1423	1440	19-Dec-94	253.0	± 0.00	22	5000	700	0.8	87	3.8	1.618		808	922	266.2	80.65	291	30.28	65	65	278.300	281.300	Stack 1	1.0010		
Average HCl Concentration, ppm(v), wet @ 3% O ₂							257.6	± 7.6	Testing Interval Averages						87	4														
									σ						0	0.1														

Table A-4, (Reference Table 3-4)

INPUT DATA

DATE: 8-Nov-94
RUN ID: 097-AAI-M17-1

Flue gas O ₂	3.4 % wet	Nozzle diameter	0.469 in.
Flue gas CO ₂	15.6 % wet	Gas meter corr.	1.017
Flue gas N ₂	73.1 % wet	Pitot corr. (Cp)	0.822
Flue gas H ₂ O	7.9 % wet	Duct Area	15.5677 ft ²
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-13 in. H ₂ O		
Stack Temp	675 °F		
Volume water	24.1 ml	Meter volume	13.274 ft ³
Particle mass	2104.3 mg	SQRT DP pitot	0.1425
Run time	45 min	AVG DH orifice	0.280 in. H ₂ O
Meter Temp	85 °F		

RESULTS

% WATER	7.9%	gr/ACF :	1.0289 wet
% ISOKINETIC	84.8%	gr/SCF :	2.6372 dry
STACK VEL.	11.48 ft/s	mg/ACM :	2354.5 wet
		mg/SCM :	6034.9 dry
STACK FLOW	10721 ACFM (wet)		
STACK FLOW	4143 SCFM (dry)	LB/MBTU	4.4706

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 8-Nov-94
RUN ID: 097-AAI-M17-02

Flue gas O ₂	3.4 % wet	Nozzle diameter	0.469 in.
Flue gas CO ₂	15.6 % wet	Gas meter corr.	1.017
Flue gas N ₂	71.9 % wet	Pitot corr. (Cp)	0.822
Flue gas H ₂ O	9.1 % wet	Duct Area	15.5677 ft ²
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-13 in. H ₂ O		
Stack Temp	675 °F		
Volume water	40.2 ml	Meter volume	19.013 ft ³
Particle mass	3938.6 mg	SQRT DP pitot	0.1425
Run time	63 min	AVG DH orifice	0.280 in. H ₂ O
Meter Temp	85 °F		

RESULTS

% WATER	9.1%	gr/ACF :	1.3272 wet
% ISOKINETIC	87.7%	gr/SCF :	3.4461 dry
STACK VEL.	11.50 ft/s	mg/ACM :	3037.1 wet
		mg/SCM :	7886.0 dry
STACK FLOW	10742 ACFM (wet)		
STACK FLOW	4098 SCFM (dry)	LB/MBTU	5.8418

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 8-Nov-94
RUN ID: 097-AAI-M17-03

Flue gas O ₂	3.4 % wet	Nozzle diameter	0.469 in.
Flue gas CO ₂	15.6 % wet	Gas meter corr.	1.017
Flue gas N ₂	72.2 % wet	Pitot corr. (Cp)	0.822
Flue gas H ₂ O	8.8 % wet.	Duct Area	15.5677 ft ²
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-13 in. H ₂ O		
Stack Temp	675 °F		
Volume water	39.2 ml	Meter volume	19.117 ft ³
Particle mass	4060.9 mg	SQRT DP pitot	0.1425
Run time	63 min	AVG DH orifice	0.280 in. H ₂ O
Meter Temp	85 °F		

RESULTS

% WATER	8.8%	gr/ACF :	1.3647 wet
% ISOKINETIC	88.0%	gr/SCF :	3.5338 dry
STACK VEL.	11.50 ft/s	mg/ACM :	3122.9 wet
		mg/SCM :	8086.6 dry
STACK FLOW	10738 ACFM (wet)		
STACK FLOW	4107 SCFM (dry)	LB/MBTU	5.9904

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 8-Nov-94
RUN ID: 097-AAO-M17-01

Flue gas O ₂	8.3 % wet	Nozzle diameter	0.219 in.
Flue gas CO ₂	10.7 % wet	Gas meter corr.	1.08
Flue gas N ₂	73.9 % wet	Pitot corr. (Cp)	0.821
Flue gas H ₂ O	7.1 % wet	Duct Area	3.36 ft ²
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-23 in. H ₂ O		
Stack Temp	318 °F		
Volume water	71 ml	Meter volume	42.724 ft ³
Particle mass	7062.1 mg	SQRT DP pitot	0.7479
Run time	90 min	AVG DH orifice	0.768 in. H ₂ O
Meter Temp	100 °F		

RESULTS

% WATER	7.1%	gr/ACF :	1.4883 wet
% ISOKINETIC	101.7%	gr/SCF :	2.6575 dry
STACK VEL.	50.89 ft/s	mg/ACM :	3405.8 wet
		mg/SCM :	6081.5 dry
STACK FLOW	10259 ACFM (wet)		
STACK FLOW	5690 SCFM (dry)	LB/MBTU	6.2570

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 8-Nov-94
RUN ID: 097-AAO-M17-02

Flue gas O ₂	8.3 % wet	Nozzle diameter	0.219 in.
Flue gas CO ₂	10.7 % wet	Gas meter corr.	1.008
Flue gas N ₂	73.1 % wet	Pitot corr. (Cp)	0.821
Flue gas H ₂ O	7.9 % wet	Duct Area	3.36 ft ²
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-23 in. H ₂ O		
Stack Temp	318 °F		
Volume water	76.5 ml	Meter volume	43.409 ft ³
Particle mass	6787.4 mg	SQRT DP pitot	0.7531
Run time	90 min	AVG DH orifice	0.777 in. H ₂ O
Meter Temp	100 °F		

RESULTS

% WATER	7.9%	gr/ACF :	1.4940 wet
% ISOKINETIC	96.5%	gr/SCF :	2.6933 dry
STACK VEL.	51.32 ft/s	mg/ACM :	3418.9 wet
		mg/SCM :	6163.5 dry
STACK FLOW	10346 ACFM (wet)		
STACK FLOW	5684 SCFM (dry)	LB/MBTU	6.3413

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 8-Nov-94
RUN ID: 097-AAO-M17-03

Flue gas O ₂	8.3 % wet	Nozzle diameter	0.219 in.
Flue gas CO ₂	10.7 % wet	Gas meter corr.	1.008
Flue gas N ₂	72.6 % wet	Pitot corr. (Cp)	0.821
Flue gas H ₂ O	8.4 % wet	Duct Area	3.36 ft ²
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-23 in. H ₂ O		
Stack Temp	318 °F		
Volume water	81.7 ml	Meter volume	43.470 ft ³
Particle mass	6606.4 mg	SQRT DP pitot	0.7476
Run time	90 min	AVG DH orifice	0.763 in. H ₂ O
Meter Temp	100 °F		

RESULTS

% WATER	8.4%	gr/ACF :	1.4445 wet
% ISOKINETIC	97.8%	gr/SCF :	2.6179 dry
STACK VEL.	50.99 ft/s	mg/ACM :	3305.7 wet
		mg/SCM :	5990.9 dry
STACK FLOW	10279 ACFM (wet)		
STACK FLOW	5617 SCFM (dry)	LB/MBTU	6.1638

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, (Reference Table 3-4)

INPUT DATA

DATE: 9-Nov-94
RUN ID: 097-BAI-M17-01

Flue gas O ₂	3.4 % wet	Nozzle diameter	0.469 in.
Flue gas CO ₂	15.6 % wet	Gas meter corr.	1.017
Flue gas N ₂	70.5 % wet	Pitot corr. (Cp)	0.822
Flue gas H ₂ O	10.5 % wet.	Duct Area	15.5677 ft ²
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-13.3 in. H ₂ O		
Stack Temp	687 °F		
Volume water	35.2 ml	Meter volume	14.331 ft ³
Particle mass	3351 mg	SQRT, DP pitot	0.1463
Run time	45 min	AVG DH orifice	0.320 in. H ₂ O
Meter Temp	90 °F		

RESULTS

% WATER	10.5%	gr/ACF :	1.4708 wet
% ISOKINETIC	91.1%	gr/SCF :	3.9421 dry
STACK VEL.	11.90 ft/s	mg/ACM :	3365.8 wet
		mg/SCM :	9021.1 dry
STACK FLOW	11118 ACFM (wet)		
STACK FLOW	4126 SCFM (dry)	LB/MBTU	6.6827

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 9-Nov-94
RUN ID: 097-BAI-M17-02

Flue gas O ₂	3.4 % wet	Nozzle diameter	0.469 in.
Flue gas CO ₂	15.6 % wet	Gas meter corr.	1.017
Flue gas N ₂	70.0 % wet	Pitot corr. (Cp)	0.822
Flue gas H ₂ O	11.0 % wet	Duct Area	15.5677 ft ²
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-13.3 in. H ₂ O		
Stack Temp	687 °F		
Volume water	37.5 ml	Meter volume	14.535 ft ³
Particle mass	3023.7 mg	SQRT DP pitot	0.1463
Run time	45 min	AVG DH orifice	0.320 in. H ₂ O
Meter Temp	90 °F		

RESULTS

% WATER	11.0%	gr/ACF :	1.3016 wet
% ISOKINETIC	92.8%	gr/SCF :	3.5072 dry
STACK VEL.	11.91 ft/s	mg/ACM :	2978.6 wet
		mg/SCM :	8025.8 dry
STACK FLOW	11127 ACFM (wet)		
STACK FLOW	4108 SCFM (dry)	LB/MBTU	5.9453

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 9-Nov-94
RUN ID: 097-BAI-M17-03

Flue gas O ₂	3.4 % wet	Nozzle diameter	0.469 in.
Flue gas CO ₂	15.6 % wet	Gas meter corr.	1.017
Flue gas N ₂	71.1 % wet	Pitot corr. (Cp)	0.822
Flue gas H ₂ O	9.9 % wet	Duct Area	15.5677 ft ²
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-13.3 in. H ₂ O		
Stack Temp	687 °F		
Volume water	33.3 ml	Meter volume	14.482 ft ³
Particle mass	2918.4 mg	SQRT DP pitot	0.1463
Run time	45 min	AVG DH orifice	0.320 in. H ₂ O
Meter Temp	90 °F		

RESULTS

% WATER	9.9%	gr/ACF :	1.2762 wet
% ISOKINETIC	91.5%	gr/SCF :	3.3974 dry
STACK VEL.	11.89 ft/s	mg/ACM :	2920.3 wet
		mg/SCM :	7774.6 dry
STACK FLOW	11107 ACFM (wet)		
STACK FLOW	4150 SCFM (dry)	LB/MBTU	5.7593

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 9-Nov-94
RUN ID: 097-BAO-M17-01

Flue gas O ₂	3.5 % wet	Nozzle diameter	0.219 in.
Flue gas CO ₂	15 % wet	Gas meter corr.	1.008
Flue gas N ₂	73.4 % wet	Pitot corr. (Cp)	0.821
Flue gas H ₂ O	8.1 % wet	Duct Area	3.36 ft ²
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-20 in. H ₂ O		
Stack Temp	310 °F		
Volume water	86.1 ml	Meter volume	47.064 ft ³
Particle mass	6821.1 mg	SQRT DP pitot	0.8158
Run time	90 min	AVG DH orifice	0.924 in. H ₂ O
Meter Temp	90 °F		

RESULTS

% WATER	8.1%	gr/ACF :	1.3814 wet
% ISOKINETIC	98.5%	gr/SCF :	2.4616 dry
STACK VEL.	54.64 ft/s	mg/ACM :	3161.3 wet
		mg/SCM :	5633.1 dry
STACK FLOW	11016 ACFM (wet)		
STACK FLOW	6150 SCFM (dry)	LB/MBTU	4.1969

STANDARD CONDITIONS =32°F, 29.921 in Hg

Table A-4, continued (Reference Table 3-4)

INPUT DATA

DATE: 9-Nov-94
RUN ID: 097-BAO-M17-02

Flue gas O ₂	3.5 % wet	Nozzle diameter	0.219 in.
Flue gas CO ₂	15 % wet	Gas meter corr.	1.008
Flue gas N ₂	73.3 % wet	Pitot corr. (Cp)	0.821
Flue gas H ₂ O	8.2 % wet	Duct Area	3.36 ft ²
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-20 in. H ₂ O		
Stack Temp	310 °F		
Volume water	89.4 ml	Meter volume	48.234 ft ³
Particle mass	6780.7 mg	SQRT DP pitot	0.8280
Run time	90 min	AVG DH orifice	0.949 in. H ₂ O
Meter Temp	90 °F		

RESULTS

% WATER	8.2%	gr/ACF :	1.3384 wet
% ISOKINETIC	99.5%	gr/SCF :	2.3875 dry
STACK VEL.	55.47 ft/s	mg/ACM :	3062.9 wet
		mg/SCM :	5463.6 dry
STACK FLOW	11183 ACFM (wet)		
STACK FLOW	6236 SCFM (dry)	LB/MBTU	4.0706

STANDARD CONDITIONS =32°F, 29.921 in Hg

APPENDIX B

LABORATORY RESISTIVITY DATA SHEETS

RESISTIVITY TEST DATA

START DATE 15 DEC 94 APPARATUS NO. 2 TEST TYPE:
 PROJECT NO. 7613.07.01 DESCENDING ✓ 455°C
 TEST NO. _____ ASCENDING _____
 PLANT/COMPANY PLANT CRIST MT COMPOSITES ACID _____

Position	Cell No.	Cell Volume	Weight Full	Weight Empty	Weight Ash	Ash Density	Ash Volume	%P
1	—							
2	1							
3	—							
4	2							

Position	Ash I.D.	Thickness	Sink	A/(T-S)	Mesh Size
1	—				
2	097-AA0-M17-1,-2,-3			8.00	-60
3	—				
4	097-BA0-M17-1,-2,-3			7.84	"

Thermocouple Readings in °C

Time	_____	_____	_____	_____	_____	_____	_____	_____	_____
1	_____	_____	_____	5	_____	_____	_____	9	_____
2	_____	_____	_____	6	_____	_____	_____	10	_____
3	_____	_____	_____	7	_____	_____	_____	11	_____
4	_____	_____	_____	8	_____	_____	_____	12	_____

Gas Composition: _____

Water Bath Temperature: 43

Acid Bath Temperature: _____

Volume % Water:

Weight Wet: 44.800

Weight Dry: 44.610

Weight Water: .190

$$\frac{(.190)(1.244) \times 100}{(.190)(1.244) + [4 \cdot 0.8 \cdot (460/535)]} = 7.9\%$$

RESISTIVITY TEST DATA

TART DATE 15 DEC 94

APPARATUS NO. 2

PAGE NO. 1

PROJECT NO. _____

EST SAMPLE I.D. PLANT CRIST

Date/Time	Temperature		D.C. Volts	D.C. ' Amperes	A/L	Resistivity Ohm-cm	Comments
	*C	1000/*K					
5 DEC / 0838	435 439	1.46	-2000	.29 x 10 ⁻³	7.10	5.52 x 10 ⁻⁷	
	432 437	1.41	'	.32 x 10 ⁻³	7.34	4.90 x 10 ⁻⁷	
0900	377 391	1.51	.	.75 x 10 ⁻⁴		2.13 x 10 ⁻⁸	
	373 387	1.52	:	.81 x 10 ⁻⁴		1.94 x 10 ⁻⁸	
0920	329 346	1.62	:	.19 x 10 ⁻⁴		2.42 x 10 ⁻⁸	
	326 343	"	:	.21 x 10 ⁻⁴		7.47 x 10 ⁻⁸	
0942	285 303	1.74	.	.45 x 10 ⁻⁵		3.53 x 10 ⁻⁷	
	282 301	"	.	.52 x 10 ⁻⁵		3.02 x 10 ⁻⁷	
1005	245 263	1.87		.10 x 10 ⁻⁵		1.51 x 10 ⁻¹⁰	
	243 261	"		.12 x 10 ⁻⁵		1.31 x 10 ⁻¹⁰	
1023	218 235	1.97		.34 x 10 ⁻⁶		4.71 x 10 ⁻¹⁰	
	216 233	1.98		.40 x 10 ⁻⁶		3.92 x 10 ⁻¹⁰	
1100	175 191	2.16	.	.65 x 10 ⁻⁷		2.46 x 10 ⁻¹¹	
	173 189	"		.75 x 10 ⁻⁷		2.03 x 10 ⁻¹¹	
1141	140 154	2.34		.29 x 10 ⁻⁷		5.52 x 10 ⁻¹¹	
	139 153	2.35		.30 x 10 ⁻⁷		5.23 x 10 ⁻¹¹	
1236	107 118	2.56		.51 x 10 ⁻⁷		3.14 x 10 ⁻¹¹	
	107 118	"		.46 x 10 ⁻⁷		3.41 x 10 ⁻¹¹	
1350	80 89	2.76		.73 x 10 ⁻⁶		2.19 x 10 ⁻¹⁰	
	80 89	"	:	.61 x 10 ⁻⁶		2.57 x 10 ⁻¹⁰	
	/		:	x 10 ⁻		x10	
	/		.	x 10 ⁻		x10	
	/			x 10 ⁻		x10	
	/		.	x 10 ⁻		x10	
	/			x 10 ⁻		x10	
	/		.	x 10 ⁻		x10	
	/		:	x 10 ⁻		x10	
	/		.	x 10 ⁻		x10	
	/		:	x 10 ⁻		x10	
	/		.	x 10 ⁻		x10	

APPENDIX C

ASH MINERAL ANALYSIS LABORATORY REPORT

FROM

COMMERCIAL TESTING AND ENGINEERING CO.

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 708-953-9300 FAX: 708-953-9306

SINCE 1908

Member of the SGS Group (Société Générale de Surveillance)

January 5, 1995

PLEASE ADDRESS ALL CORRESPONDENCE TO:
216 OXMOOR CIRCLE, BIRMINGHAM, AL 35209
TEL: (205) 942-3120
FAX: (205) 942-0914

Southern Research Institute
2000-9th Avenue South
Birmingham, Alabama 35205

Sample identification by
Southern Research Institute

Kind of sample reported to us Sample No. 1 - Plant Crist

Sample taken at -----

Sample taken by Southern Research Institute P.O. Number: BH-52063

Date sampled -----

Date received December 20, 1994

Analysis Report No. 73-51211

ANALYSIS OF ASH

WEIGHT %, IGNITED BASIS

Silicon dioxide	47.59
Aluminum oxide	23.73
Titanium dioxide	1.15
Iron oxide	16.81
Calcium oxide	2.93
Magnesium oxide	0.91
Potassium oxide	2.76
Sodium oxide	0.94
Sulfur trioxide	0.79
Phosphorus pentoxide	0.49
Strontium oxide	0.08
Barium oxide	0.10
Manganese oxide	0.11
Undetermined	1.61
	100.00

Silica Value = 69.74
Base:Acid Ratio = 0.34
T₂₅₀ Temperature = 2498 °F

Type of Ash = BITUMINOUS
Fouling Index = 0.32
Slagging Index = XXXX

Loss On Ignition = 12.38

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

C-2

John T. Burt
Manager, Birmingham Laboratory

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 708-953-9300 FAX: 708-953-9306

SINCE 1908

Member of the SGS Group (Société Générale de Surveillance)

January 5, 1995

Southern Research Institute
2000-9th Avenue South
Birmingham, Alabama 35205

PLEASE ADDRESS ALL CORRESPONDENCE TO:
216 OXMOOR CIRCLE, BIRMINGHAM, AL 35209
TEL: (205) 942-3120
FAX: (205) 942-0914

Sample identification by
Southern Research Institute

Kind of sample reported to us Sample No. 2 - Plant Crist

Sample taken at -----

Sample taken by Southern Research Institute P.O. Number: BH-52063

Date sampled -----

Date received December 20, 1994

Analysis Report No. 73-51212

<u>ANALYSIS OF ASH</u>	<u>WEIGHT %, IGNITED BASIS</u>
Silicon dioxide	48.58
Aluminum oxide	24.03
Titanium dioxide	1.15
Iron oxide	16.61
Calcium oxide	2.98
Magnesium oxide	0.93
Potassium	2.81
Sodium	0.96
Sulfur trioxide	0.88
Phosphorus pentoxide	0.49
Strontium oxide	0.08
Barium oxide	0.07
Manganese oxide	0.09
Undetermined	0.34
	<u>100.00</u>

Silica Value = 70.30
Base:Acid Ratio = 0.33
T₂₅₀ Temperature = 2500 °F
Loss On Ignition = 12.50

Type of Ash = BITUMINOUS
Fouling Index = 0.32
Slagging Index = XXXXX

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

C-3

John T. Burd
Manager, Birmingham Laboratory

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 708-953-9300 FAX: 708-953-9306

SINCE 1908

Member of the SGS Group (Société Générale de Surveillance)

January 5, 1995

PLEASE ADDRESS ALL CORRESPONDENCE TO:
216 OXMOOR CIRCLE, BIRMINGHAM, AL 35209
TEL: (205) 942-3120
FAX: (205) 942-0914

Southern Research Institute
2000-9th Avenue South
Birmingham, Alabama 35205

Sample identification by
Southern Research Institute

Kind of sample reported to us Sample No. 3 - Plant Crist

Sample taken at -----

Sample taken by Southern Research Institute P.O. Number: BH-52063

Date sampled -----

Date received December 20, 1994

Analysis Report No. 73-51213

ANALYSIS OF ASH

WEIGHT %, IGNITED BASIS

Silicon dioxide	47.58
Aluminum oxide	24.77
Titanium dioxide	1.20
Iron oxide	16.82
Calcium oxide	2.54
Magnesium oxide	1.06
Potassium oxide	2.92
Sodium oxide	0.98
Sulfur trioxide	0.69
Phosphorus pentoxide	0.59
Strontium oxide	0.10
Barium oxide	0.12
Manganese oxide	0.10
Undetermined	0.53
	100.00

Silica Value = 69.77
Base:Acid Ratio = 0.33
T₂₅₀ Temperature = 2507 °F

Loss On Ignition = 12.38

Type of Ash = BITUMINOUS
Fouling Index = 0.32
Slagging Index = XXXXX

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

C-4

John T. Burt
Manager, Birmingham Laboratory

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 708-953-9300 FAX: 708-953-9306

SINCE 1908

Member of the SGS Group (Société Générale de Surveillance)

January 5, 1995

PLEASE ADDRESS ALL CORRESPONDENCE TO:
216 OXMOOR CIRCLE, BIRMINGHAM, AL 35209
TEL: (205) 942-3120
FAX: (205) 942-0914

Southern Research Institute
2000-9th Avenue South
Birmingham Alabama 35205

Sample identification by
Southern Research Institute

Kind of sample reported to us Sample No. 4 - Plant Crist

Sample taken at -----

Sample taken by Southern Research Institute P.O. Number: BH-52063

Date sampled -----

Date received December 20, 1994

Analysis Report No. 73-51214

ANALYSIS OF ASH

WEIGHT %, IGNITED BASIS

Silicon dioxide	48.36
Aluminum oxide	25.04
Titanium dioxide	1.24
Iron oxide	15.18
Calcium oxide	2.51
Magnesium oxide	0.93
Potassium oxide	2.96
Sodium oxide	1.04
Sulfur trioxide	0.95
Phosphorus pentoxide	0.59
Strontium oxide	0.10
Barium oxide	0.07
Manganese oxide	0.10
Undetermined	0.93
	<u>100.00</u>

Silica Value = 72.20
Base:Acid Ratio = 0.30
T₂₅₀ Temperature = 2541 °F

Loss On Ignition = 11.91

Type of Ash = BITUMINOUS
Fouling Index = 0.31
Slagging Index = XXXXX

C-5

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

John T. Burd
Manager, Birmingham Laboratory

APPENDIX D

METALS EXTRACTIONS LABORATORY REPORT

FROM

GALBRAITH LABORATORIES, INC.

GALBRAITH LABORATORIES, INC. *Accuracy with speed - since 1950*

GALBRAITH LABORATORIES, INC.
2323 Sycamore Drive
Knoxville, TN 37921-1750
615/546-1335
Fax: 615/546-7209

FAX TRANSMITTAL SHEET

DATE: 02/10/95
TO: Kenneth H. Cushing
COMPANY: Southern Research Inst
FAX NUMBER: 205-581-2448
OUR SAMPLE NUMBER: J-3483 - 86
TOTAL NUMBER OF PAGES INCLUDING FAX COVER: 5
MESSAGE:

Attached is the Lab Report for the above referenced Sample Number(s).

Thank you for providing Galbraith Laboratories the opportunity to handle your testing needs. If you have any questions and/or concerns, please do not hesitate to contact our Customer Service Department. Our business hours are Monday through Friday from 8:00 A.M. to 4:30 P.M. (EST).

Thank you,

Galbraith Laboratories, Inc.

GALBRAITH LABORATORIES, INC. Accuracy with speed - since 1950**LABORATORY REPORT**

Kenneth M Cushing
Southern Research Institute
2000 Ninth Ave South Box 55305
Birmingham AL 35255

Sample Received: 12/21/94
Report Date: 02/10/95
Purchase Order #: BH-52048

SAMPLE ID	LAB ID	ANALYSIS	RESULTS	
Plant Crist #1	J-3483	Antimony	15.0	ppm
		Cesium	<33	ppm
		Copper	125	ppm
		Molybdenum	26.3	ppm
		Rubidium	93.2	ppm
		Tin	78.2	ppm
		Zinc	247	ppm
		Beryllium	17.6	ppm
		Barium	305	ppm
		Cadmium	43	ppm
		Cobalt	50.6	ppm
		Chromium	148	ppm
		Nickel	156	ppm
		Strontium	472	ppm
		Manganese	173	ppm
		Vanadium	348	ppm
		Mercury	0.019 *	ppm
		Arsenic	145	ppm
		Selenium	<0.56	ppm
		Lead	298	ppm

Page 1 of 4

GALBRAITH LABORATORIES, INC. Accuracy with speed - since 1950

Laboratory Report

Kenneth M Cushing

SAMPLE ID	LAB ID	ANALYSIS	RESULTS
Plant Crist #2	J-3484	Antimony	12.0 ppm
		Cesium	<32 ppm
		Copper	125 ppm
		Molybdenum	25.2 ppm
		Rubidium	117 ppm
		Tin	83.9 ppm
		Zinc	252 ppm
		Beryllium	17.3 ppm
		Barium	357 ppm
		Cadmium	<4.0 ppm
		Cobalt	50.1 ppm
		Chromium	151 ppm
		Nickel	157 ppm
		Strontium	546 ppm
		Manganese	168 ppm
		Vanadium	348 ppm
		Mercury	0.63 ppm
		Arsenic	146 ppm
		Selenium	3.7 ppm
		Lead	227 ppm

Page 2 of 4

GALBRAITH LABORATORIES, INC. Accuracy with speed - since 1950**Laboratory Report**

Kenneth M Cushing

SAMPLE ID	LAB ID	ANALYSIS	RESULTS
Plant Crist #3	J-3485	Antimony	12.0 ppm
		Cesium	<32 ppm
		Copper	144 ppm
		Molybdenum	25.3 ppm
		Rubidium	155 ppm
		Tin	93.1 ppm
		Zinc	227 ppm
		Beryllium	17.7 ppm
		Barium	455 ppm
		Cadmium	<4.0 ppm
		Cobalt	53.8 ppm
		Chromium	151 ppm
		Nickel	167 ppm
		Strontium	766 ppm
		Manganese	158 ppm
		Vanadium	368 ppm
		Mercury	<0.010 ppm
		Arsenic	146 ppm
		Selenium	<0.54 ppm
		Lead	277 ppm

Page 3 of 4

GALBRAITH LABORATORIES, INC.

Accuracy with speed - since 1950

Laboratory Report

Kenneth M Cushing

SAMPLE ID	LAB ID	ANALYSIS	RESULTS
Plant Crist #4	J-3486	Antimony	17.3 ppm
		Cesium	<31 ppm
		Copper	148 ppm
		Molybdenum	27.8 ppm
		Rubidium	142 ppm
		Tin	75.8 ppm
		Zinc	241 ppm
		Beryllium	18.2 ppm
		Barium	431 ppm
		Cadmium	<4.0 ppm
		Cobalt	54.1 ppm
		Chromium	168 ppm
		Nickel	179 ppm
		Strontium	736 ppm
		Manganese	160 ppm
		Vanadium	380 ppm
		Mercury	1.29 ppm
		Arsenic	171 ppm
		Selenium	6.7 ppm
		Lead	319 ppm

* Value between $\bar{x} + \sigma$ and $\bar{x} + 3\sigma$

LB:dc

Page 4 of 4