DOE/PC/89652-T16

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

DOE Contract	**SCS Contract**
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DISCLAIMER

LEGAL NOTICE

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:

		Operating hours	
Catalyst supplier	Reactor designation	3rd qtr	4th qtr
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 O_2 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.

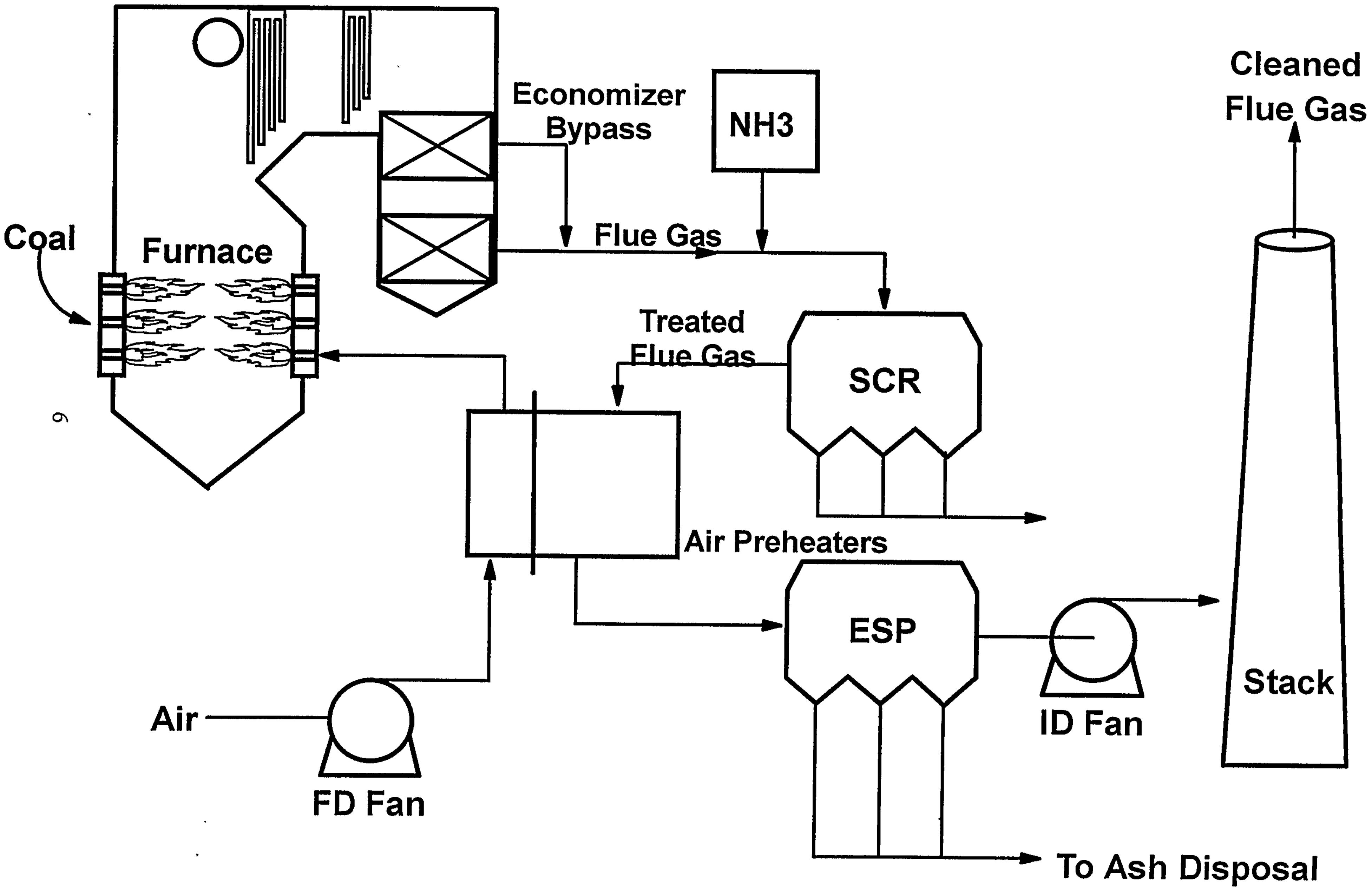

Figure 1. Flow Diagram of Typical SCR Installation.

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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 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 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).

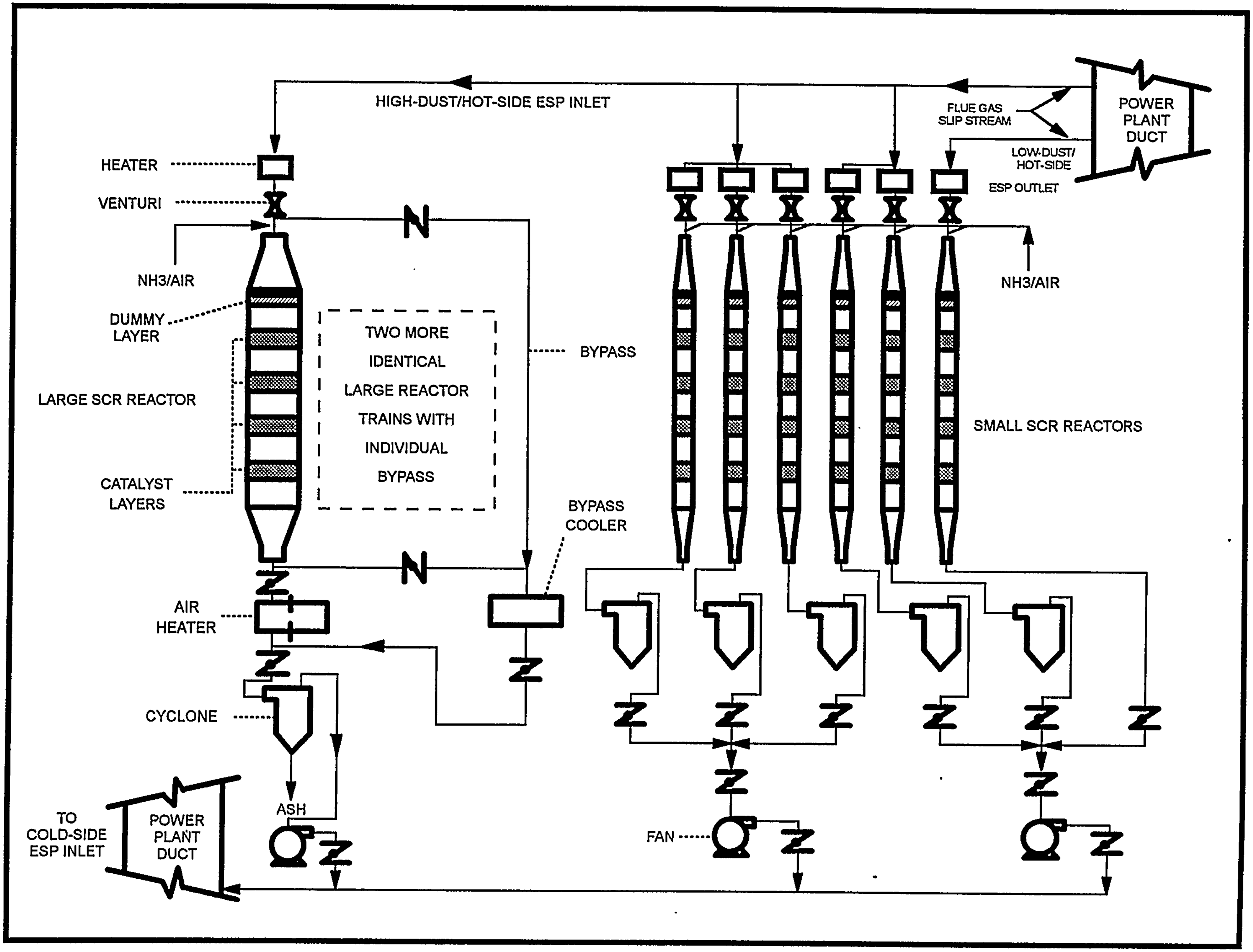

Figure 2. Prototype SCR Demonstration Facility-Process Flow Diagram

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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:

		Operating hours	
Catalyst supplier	Reactor designation	3rd qtr	4th qtr
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 O_2 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. SO_2 measurements normally have detection limits of 5 ppm with analytical repeatability to within 1% of the measured value. The SO_3 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. Test	Method	Units	Units	3rd Qtr. 94	4th Qtr. 94	1993 Average	1994 Average	*Project 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

	July - September 1994		
Constituent	Average	High	Low
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

	October - December 1994		
Constituent	Average	High	Low
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 NH_3-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 NO_2 is present, resulting in an effective 1:1 NH_3-to-NO_x stoichiometry. In practice, small amounts (1-2%) of NO_2 present results in a slightly reduced NO_x reduction efficiency. Initial estimates based on literature values indicated that NO_2 concentrations may be as high on 5% of the total NO_x present. However, closer analysis of the monitoring data indicated the actual NO_2 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

Date	Average	High	Low
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

PARAMETER	REACTOR A	REACTOR B	REACTOR C
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_2O)	7.12	3.99	2.57
AIR SIDE PRESS. DROP ("H_2O)	3.21	1.84	NA
AIR/GAS DIFF. PRESS. ("H_2O)	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

PARAMETER	REACTOR A	REACTOR B	REACTOR C
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_2O)	7.06	4.69	5.39
AIR SIDE PRESS. DROP ("H_2O)	2.99	1.95	NA
AIR/GAS DIFF. PRESS. ("H_2O)	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, SO_2, SO_3, HCl, N_2O, 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 SO_2 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_2O, 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

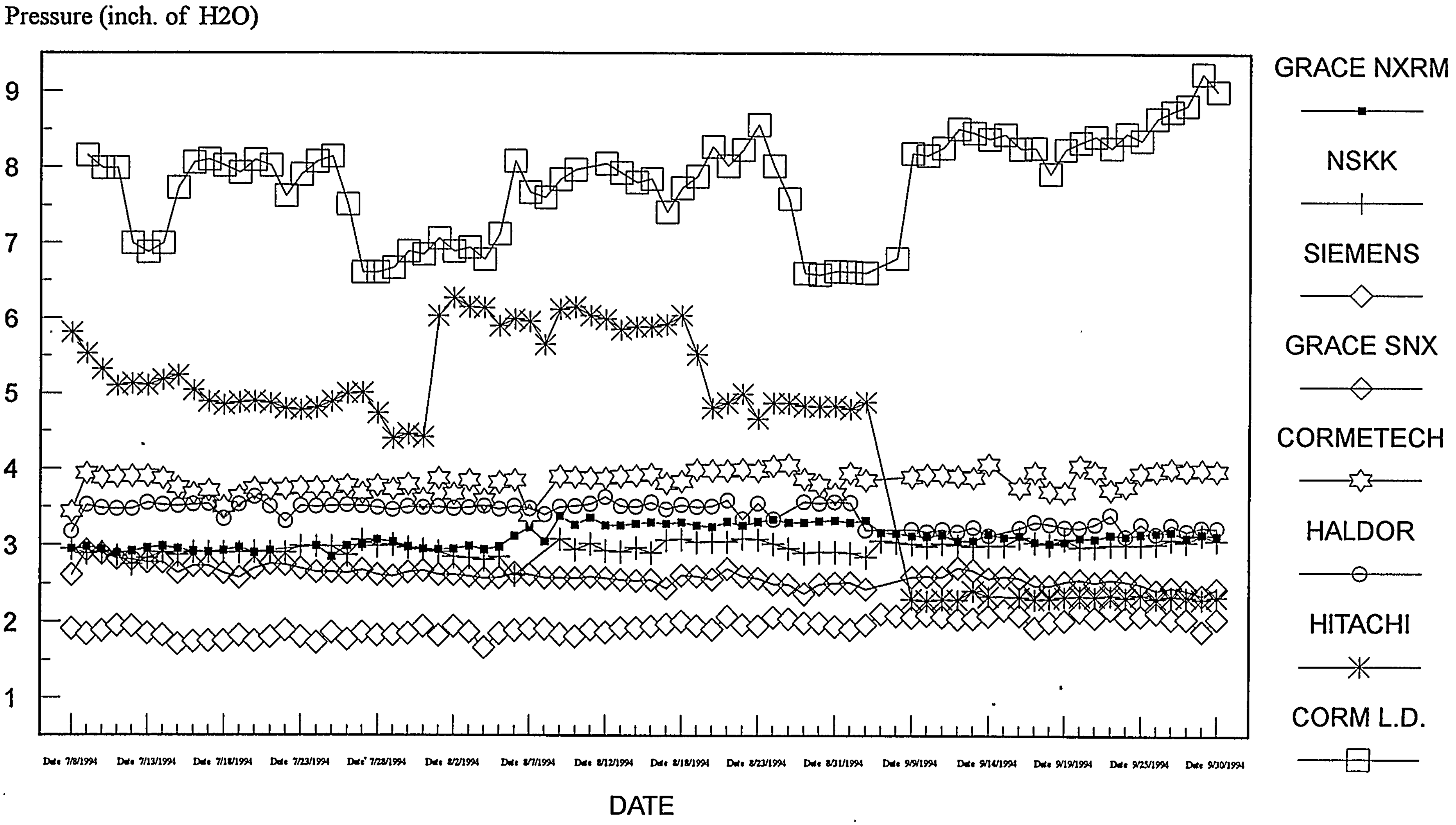
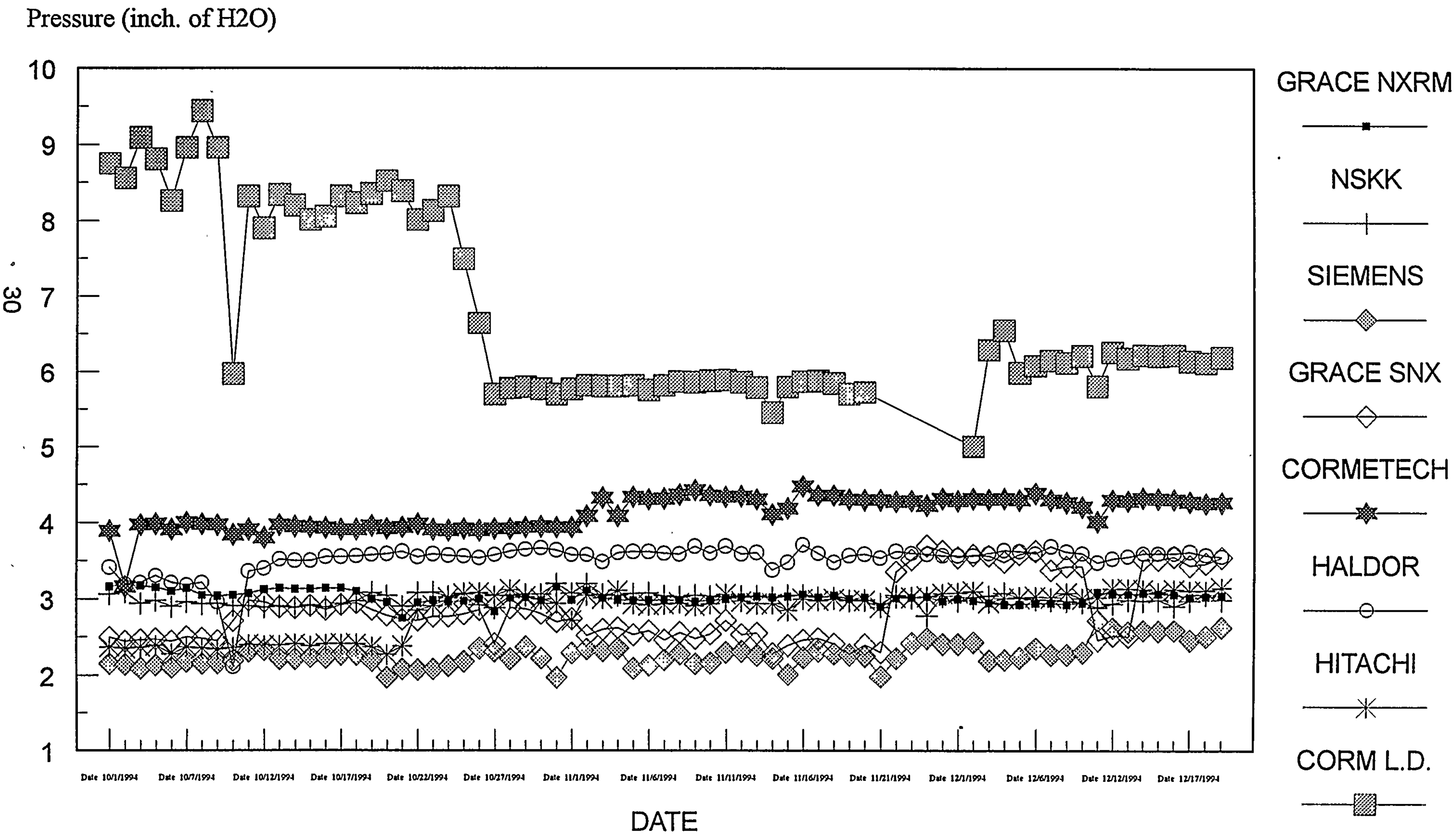


FIGURE 4

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 SO_2 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 SO_2 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 SO_2 oxidation decreasing with flow rate. In this case, large measurement variability of up to 0.30% SO_2 oxidation is the most probable cause for the uncharacteristic trend.

Figures 9a and 9b show SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 deposition occur in the test facility reactors. The general trend of increasing SO_2 oxidation is expected, however, and the plots provide a good basis for determining the potential for SO_3 formation across the SCR reactor at various operating temperatures.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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% O_2, dry) were 233 ± 11 ppmv and 219 ± 13 ppmv respectively. The N_2O 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% O_2).[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

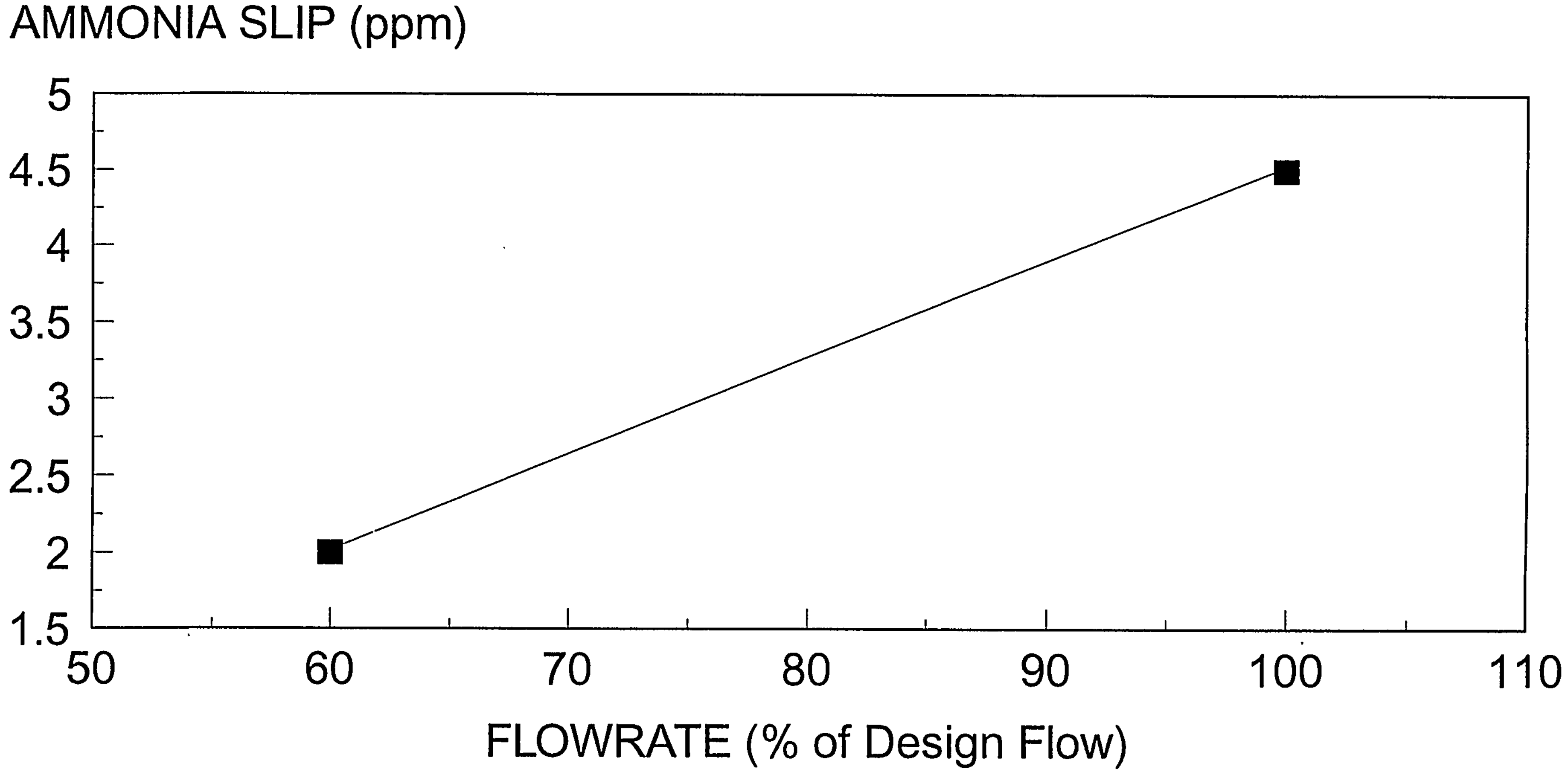
FLOW RATE (SCFM)	TEMP. (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS. SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
5109	702	3.555	1744	0.804	9.2	16.5	7.3	0.49
6622	706	3.490	1705	0.798	4.6	14.0	9.4	0.60
5072	758	3.433	2028	0.803	9.7	38.2	28.5	1.78

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

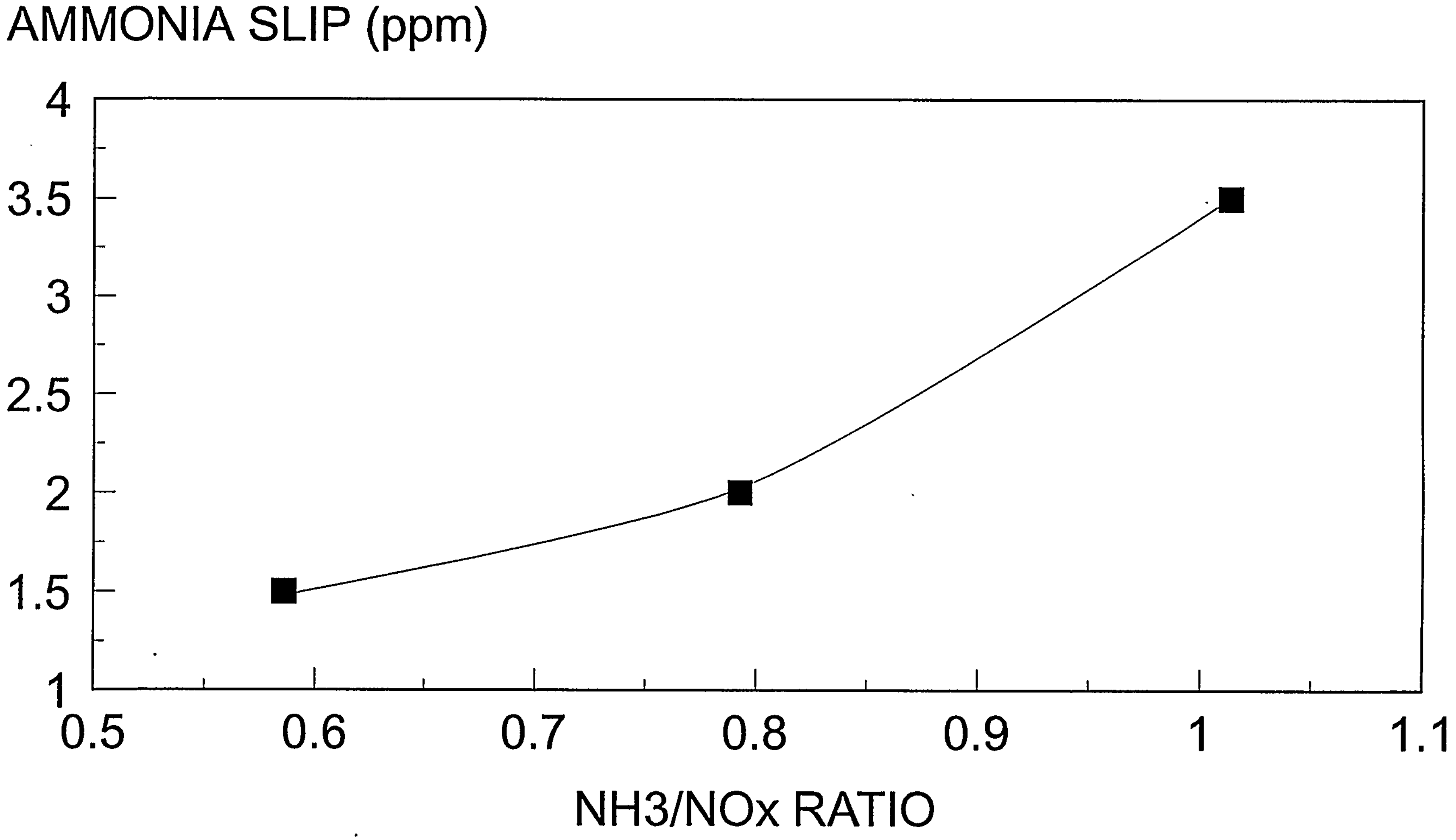
AMMONIA SLIP VS. FLOW RATE



GRACE NXRM: NH3/NOx=0.80, 620 F

FIGURE 6a

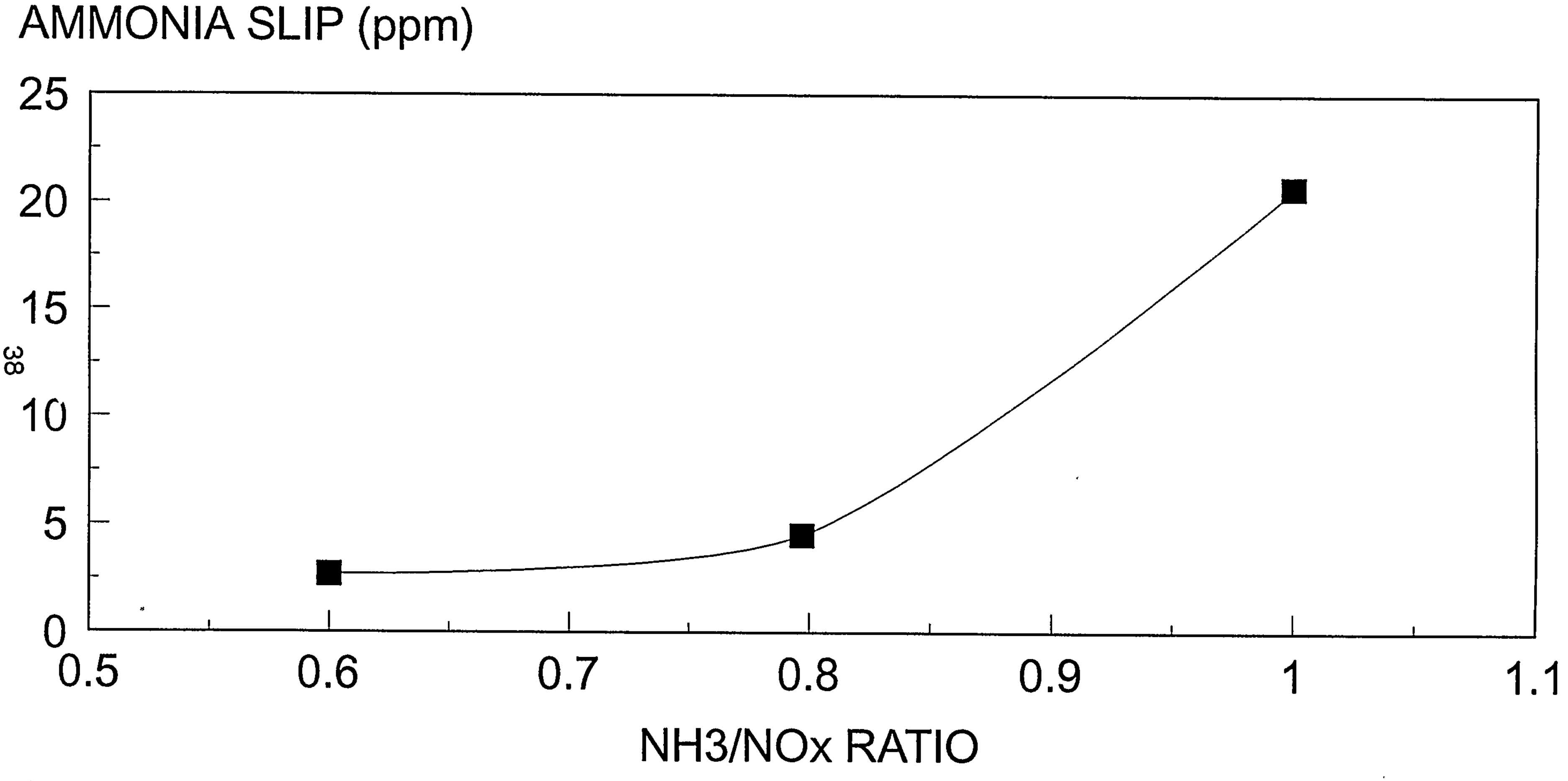
AMMONIA SLIP VS. NH3/NOx RATIO



GRACE NXRM: DESIGN FLOW, 620F

FIGURE 6b

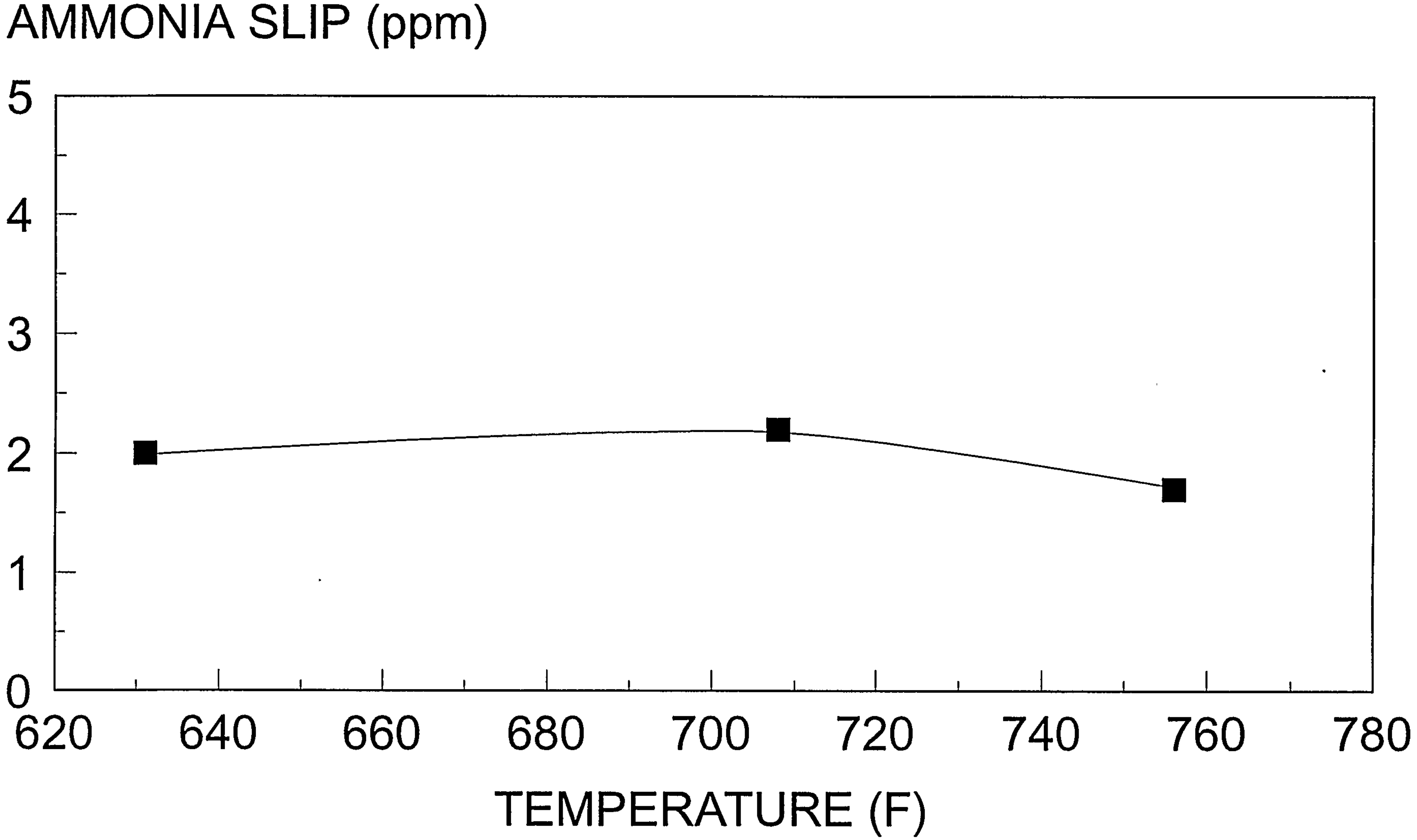
AMMONIA SLIP VS. NH3/NOx RATIO



GRACE NXRM: Design Flow, 620 F

FIGURE 7a

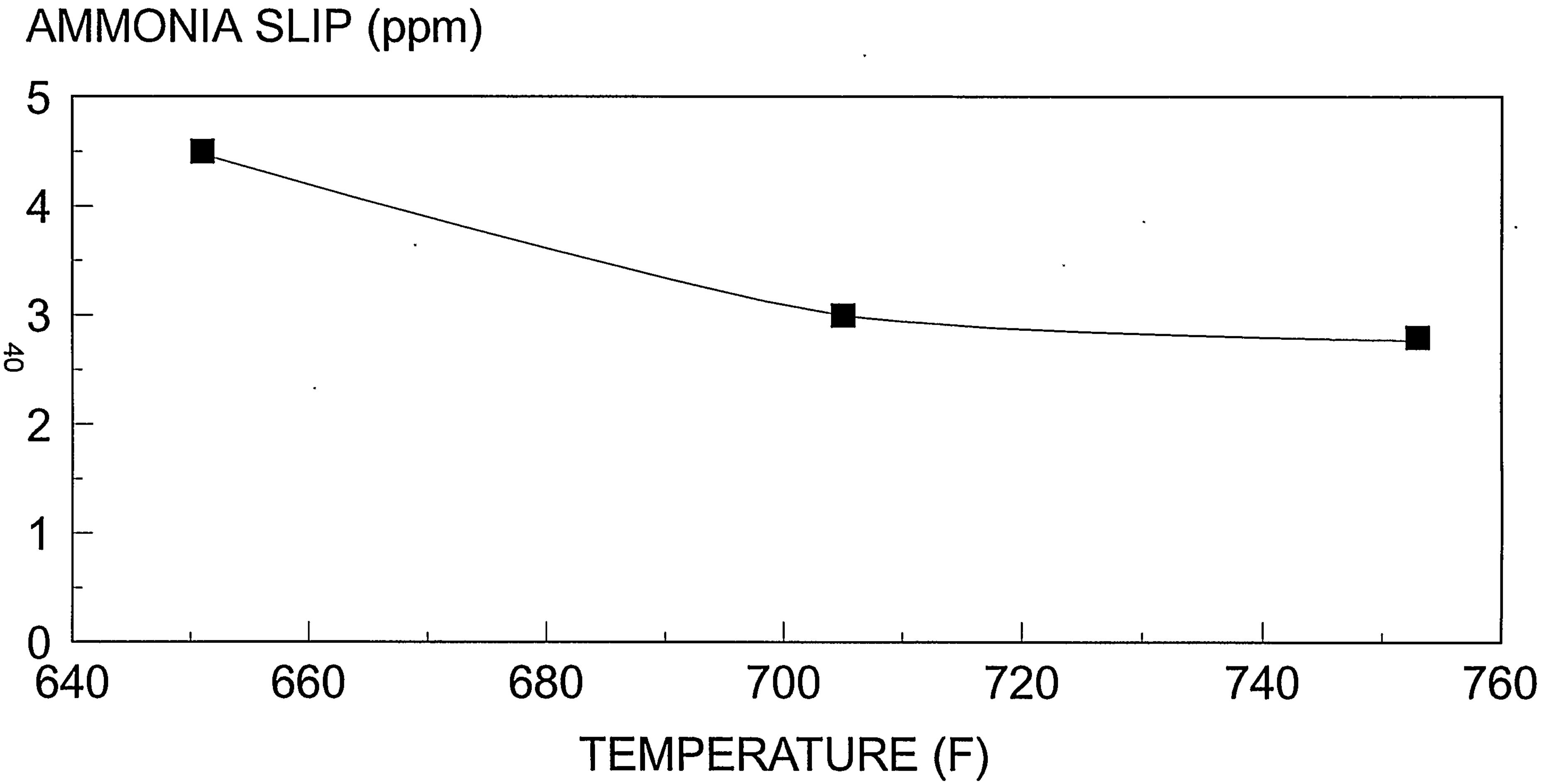
AMMONIA SLIP VS. TEMPERATURE



GRACE NXRM: DESIGN FLOW, NH3/NOx=0.8

FIGURE 7b

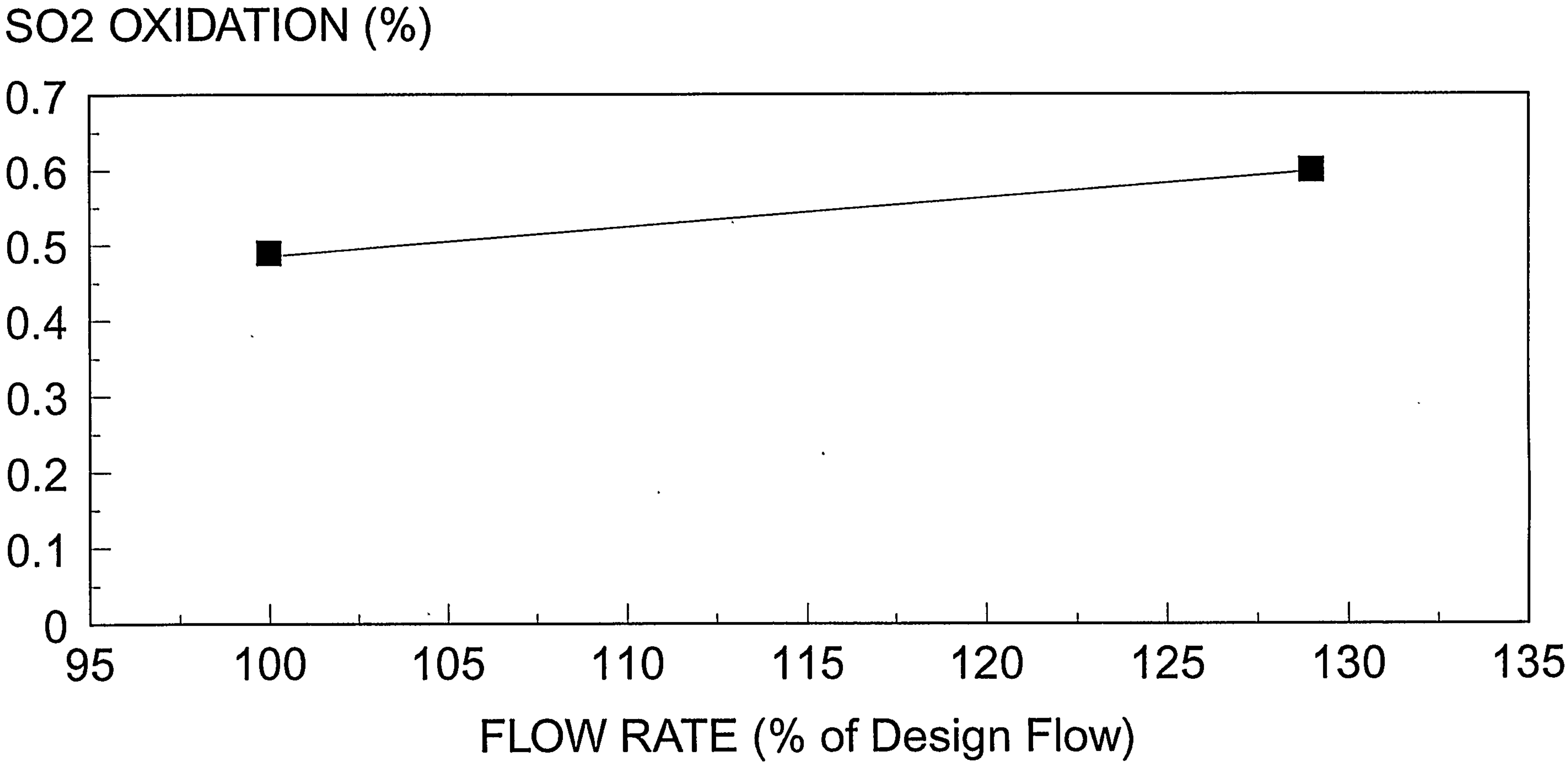
AMMONIA SLIP VS. TEMPERATURE



GRACE NXRM: NH3/NOx=0.80, Design Flow

FIGURE 8

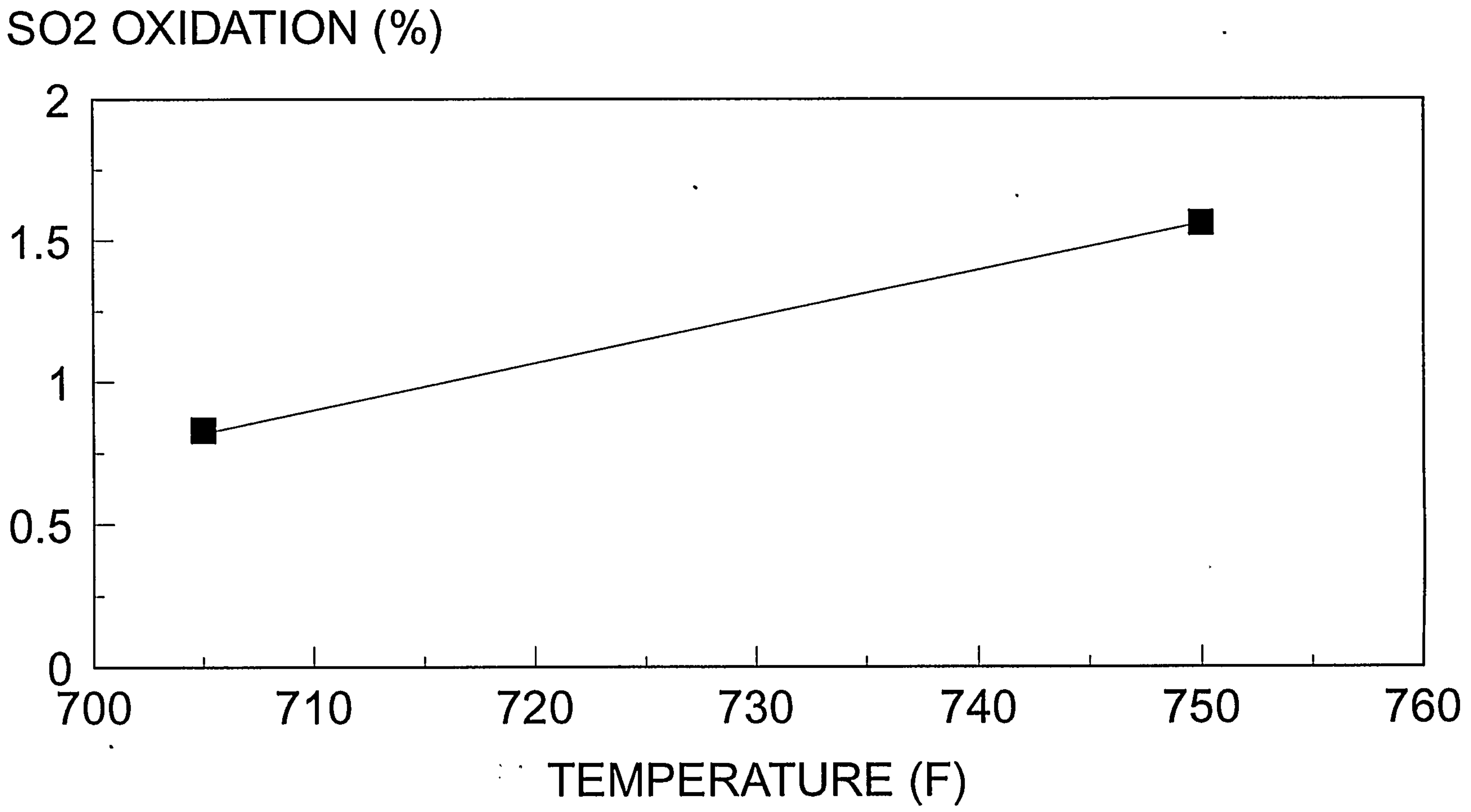
SO2 OXIDATION VS. FLOWRATE



GRACE NXRM: NH3/NOx=0.80, 700 F

FIGURE 9a

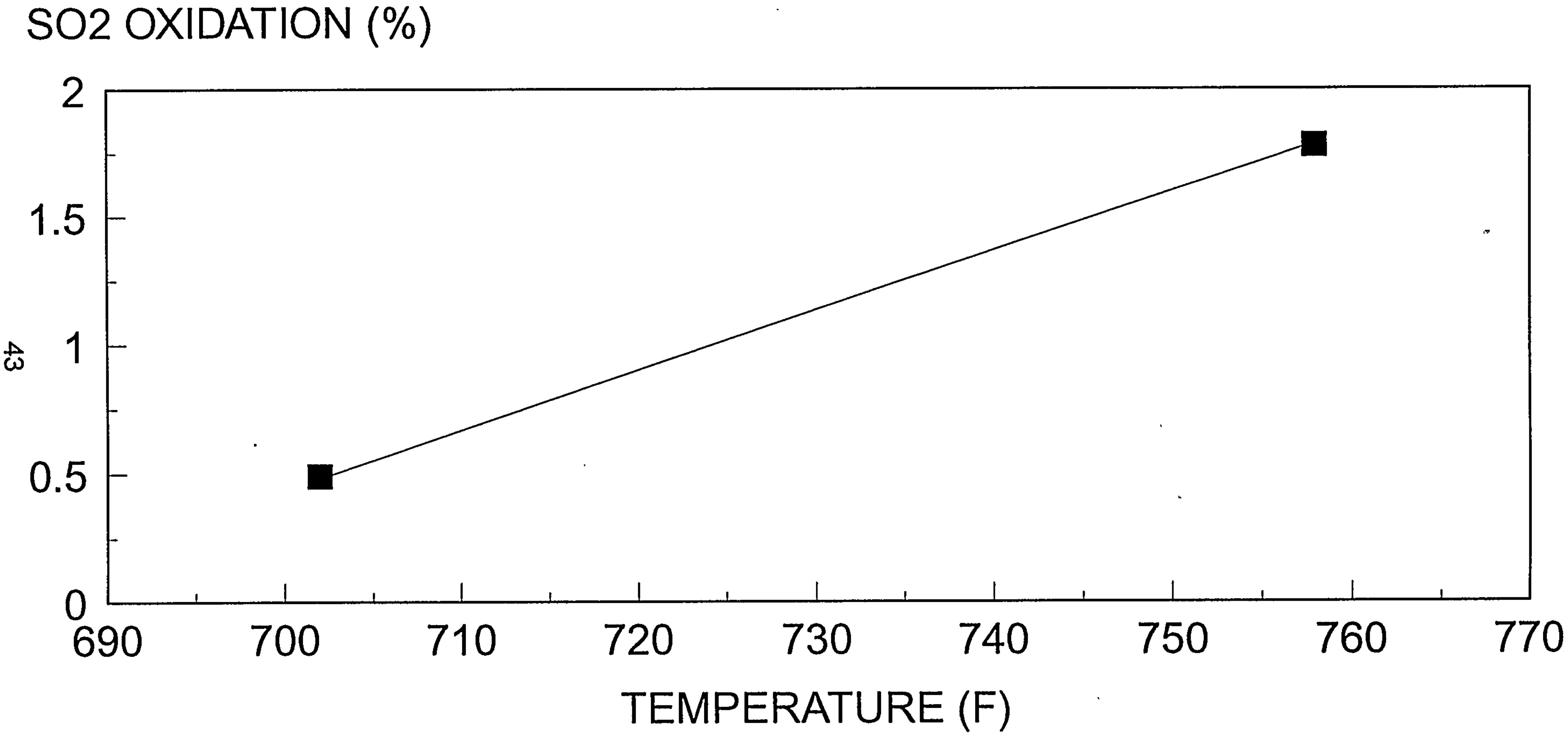
SO2 OXIDATION VS. TEMPERATURE



GRACE NXRM: DESIGN FLOW, NH3/NOx=0.8

FIGURE 9b

SO2 OXIDATION VS. TEMPERATURE



GRACE NXRM: Design Flow, NH3/NOX=0.80

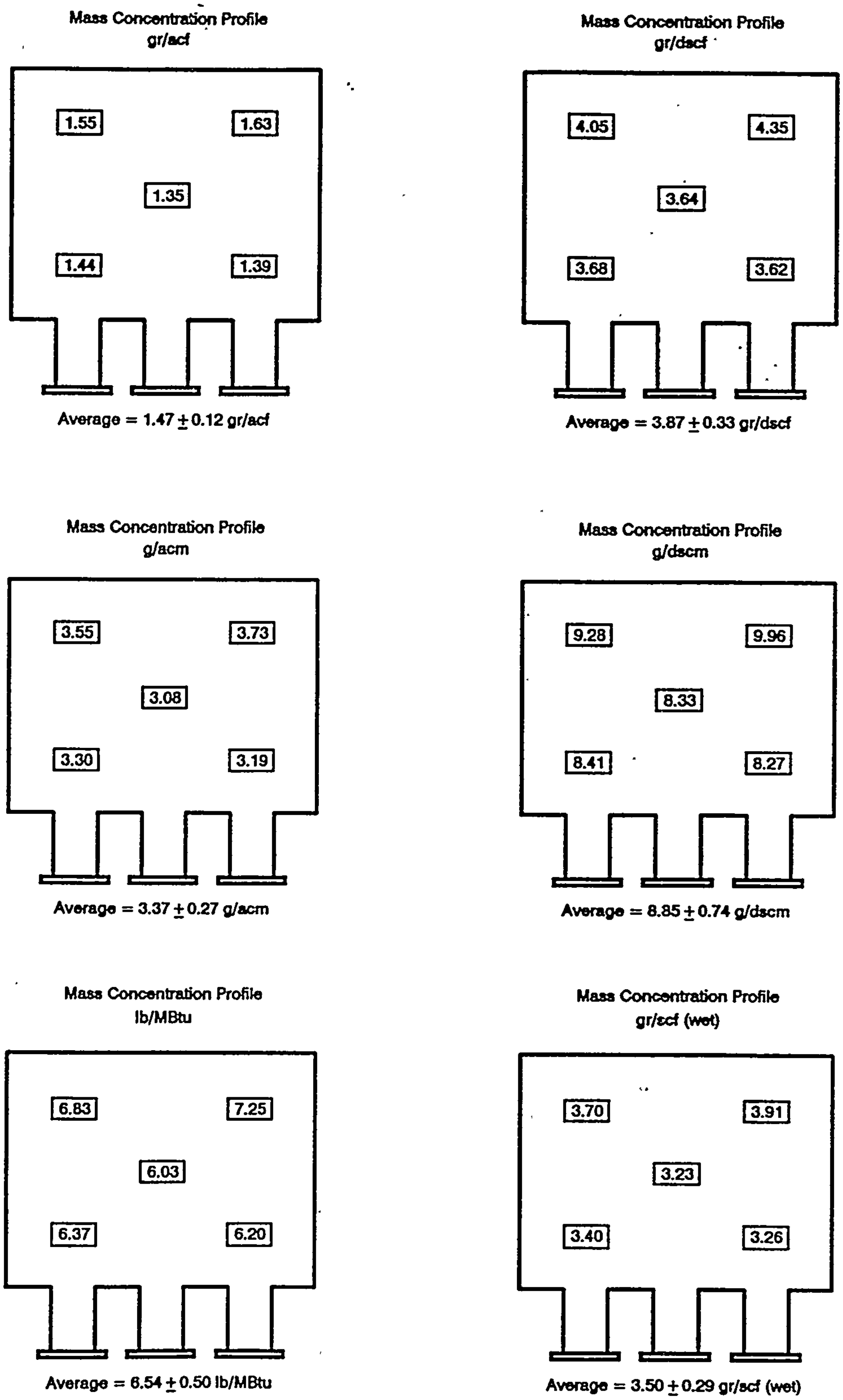


Figure 10. Six presentations of the Reactor A outlet mass concentration/mass emission profile.

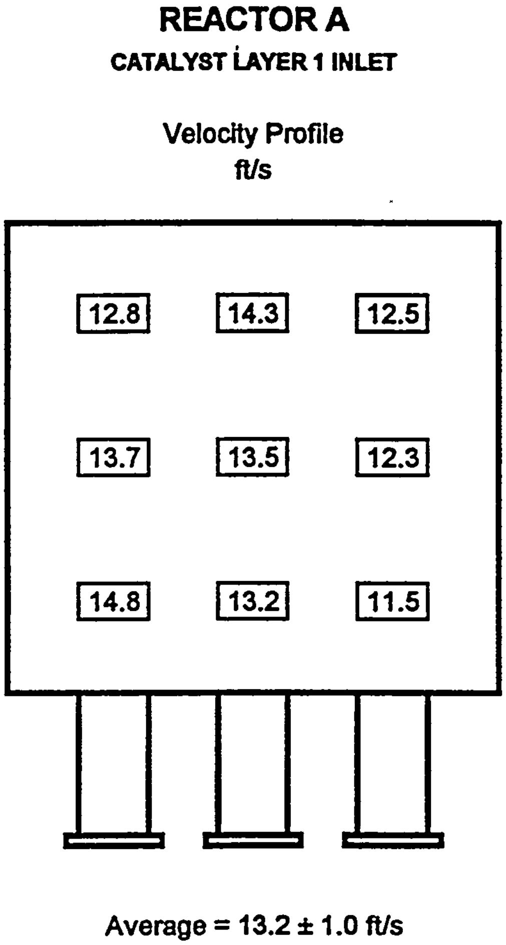
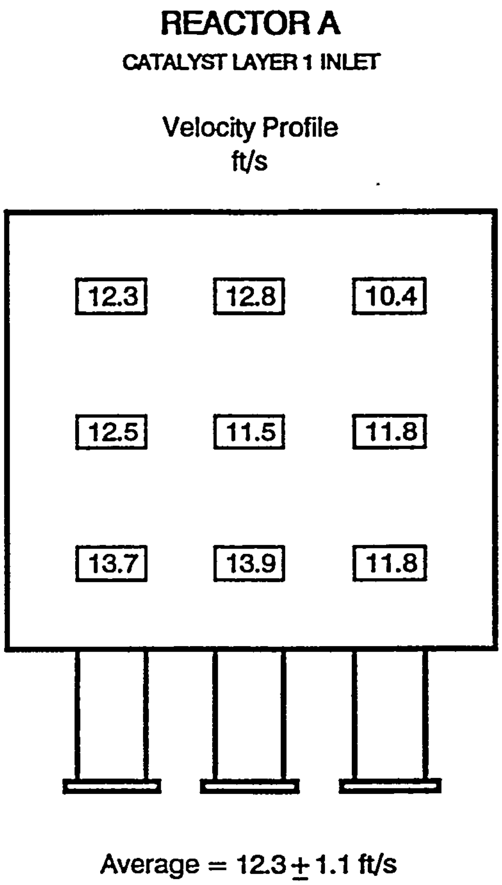


Figure 11a. Reactor A flue gas velocity profile.
Third Parametric Sequence



12.3	12.8	10.4
12.5	11.5	11.8
13.7	13.9	11.8

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 SO_2 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 SO_2 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 SO_2 oxidation decreasing with flow rate. In this case, large measurement variability of up to 0.39% SO_2 oxidation is the most probable cause for the uncharacteristic trend.

Figures 16a and 16b show SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 deposition occur in the test facility reactors. The extremely low oxidation rate of the catalyst further exacerbates this problem. The general trend of increasing SO_2 oxidation is expected, however, and the plots provide a good basis for determining the potential for SO_3 formation across the SCR reactor at various operating temperatures.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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% O_2, dry) were 238 ± 7 ppmv and 222 ± 13 ppmv respectively. The N_2O 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% O_2).[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

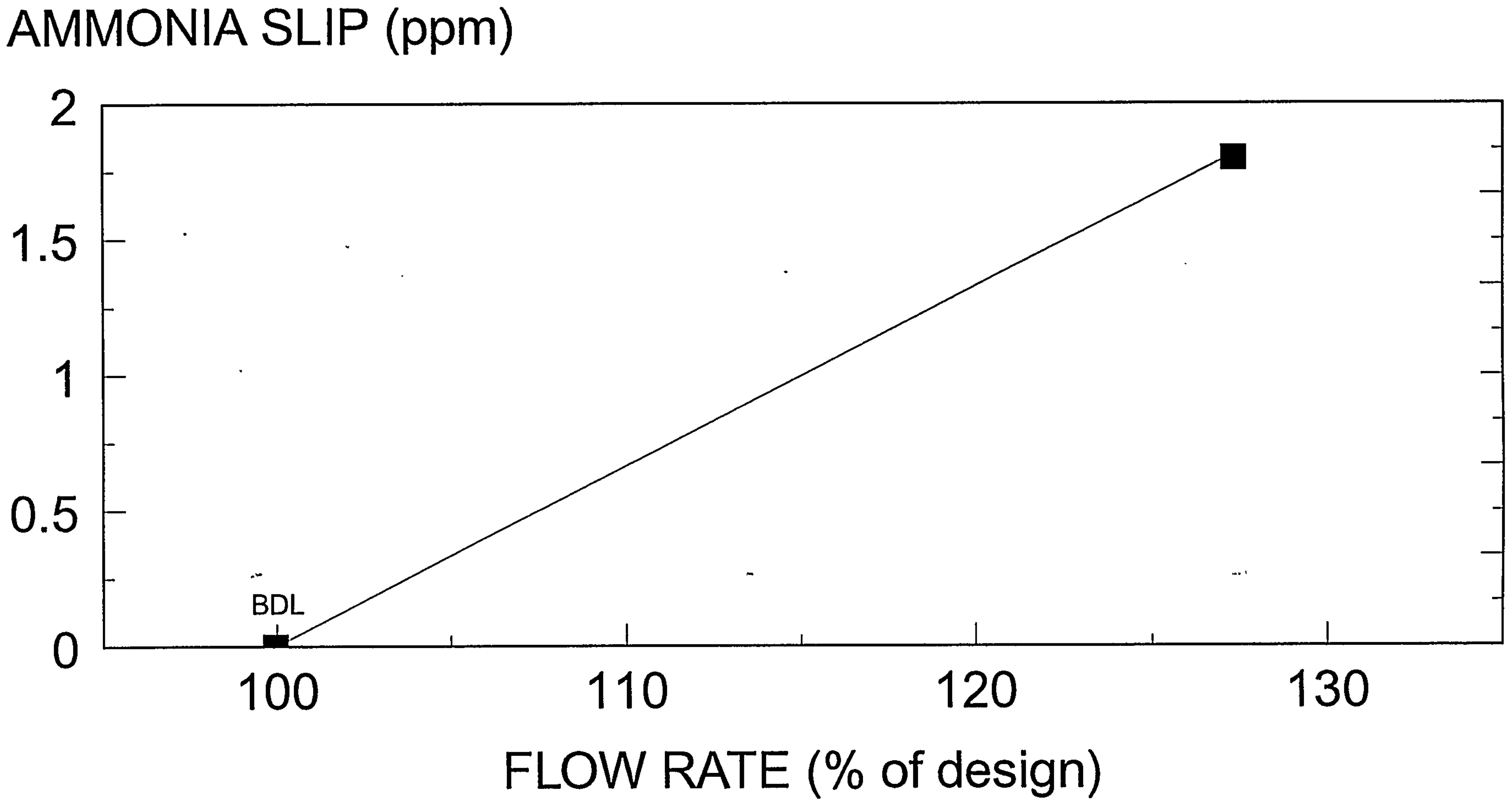
FLOW RATE (SCFM)	TEMP. (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS. SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
5329	704	5.365	2076	0.808	5.6	3.6	-2.0	-0.11
7071	705	4.706	1515	0.798	1.8	2.4	0.6	0.04
5350	756	4.167	1783	0.800	8.9	16.2	7.3	0.41

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

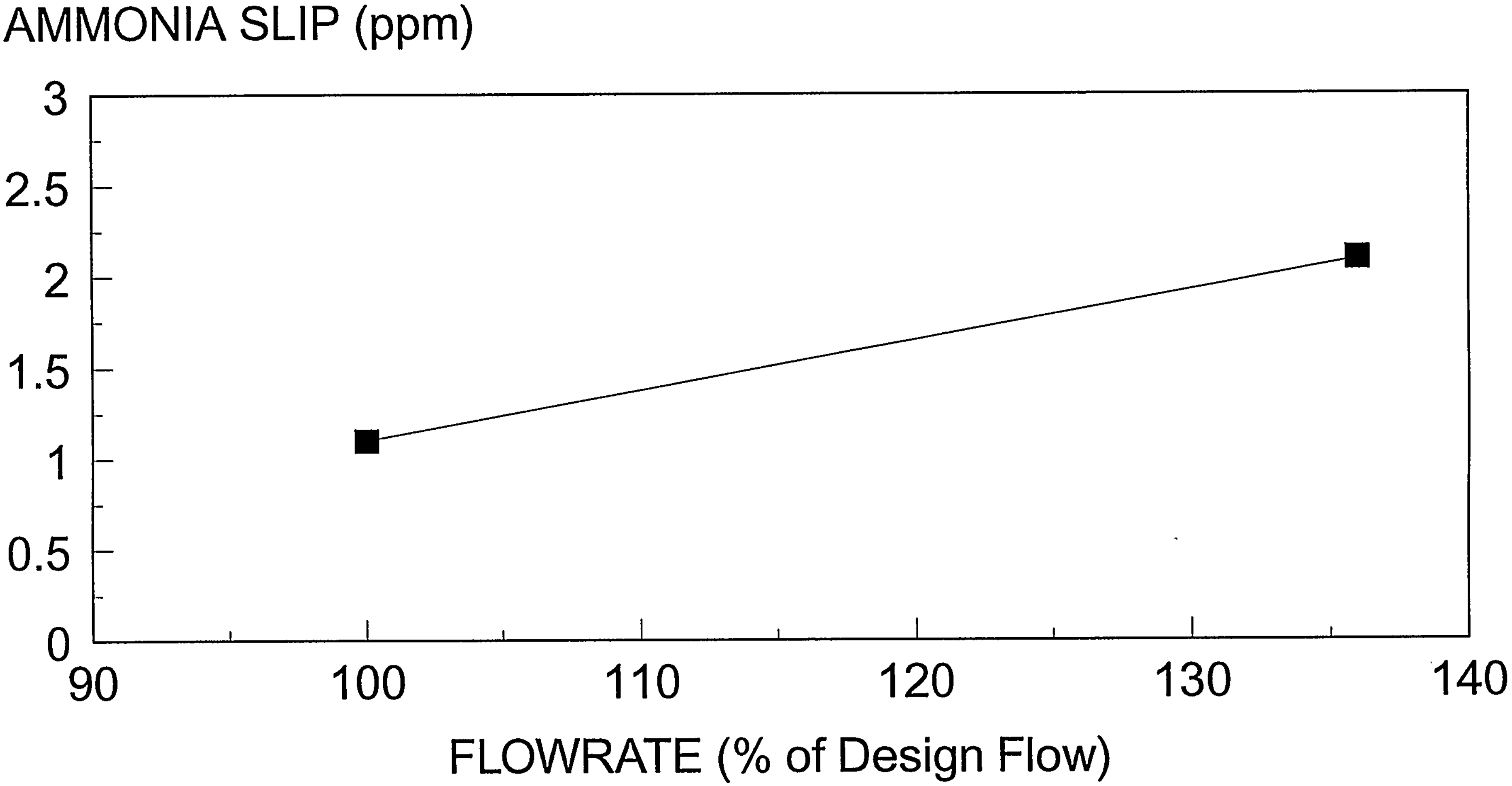


NSKK: 700 F, NH3/NOx=0.8

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

FIGURE 12b

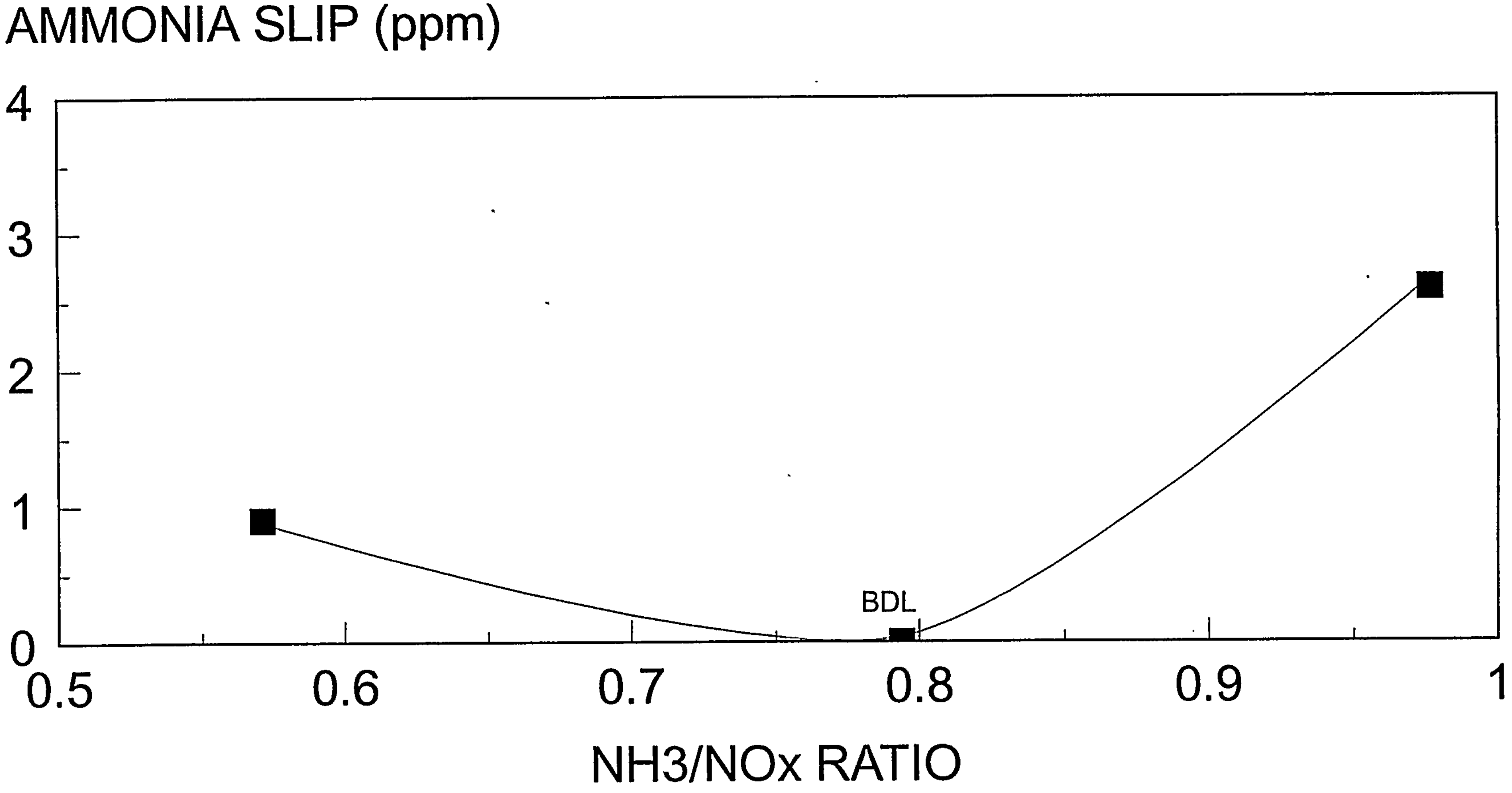
AMMONIA SLIP VS. FLOW RATE



NSKK: NH3/NOx=0.80, 700 F

FIGURE 13a

AMMONIA SLIP VS. NH3/NOx RATIO

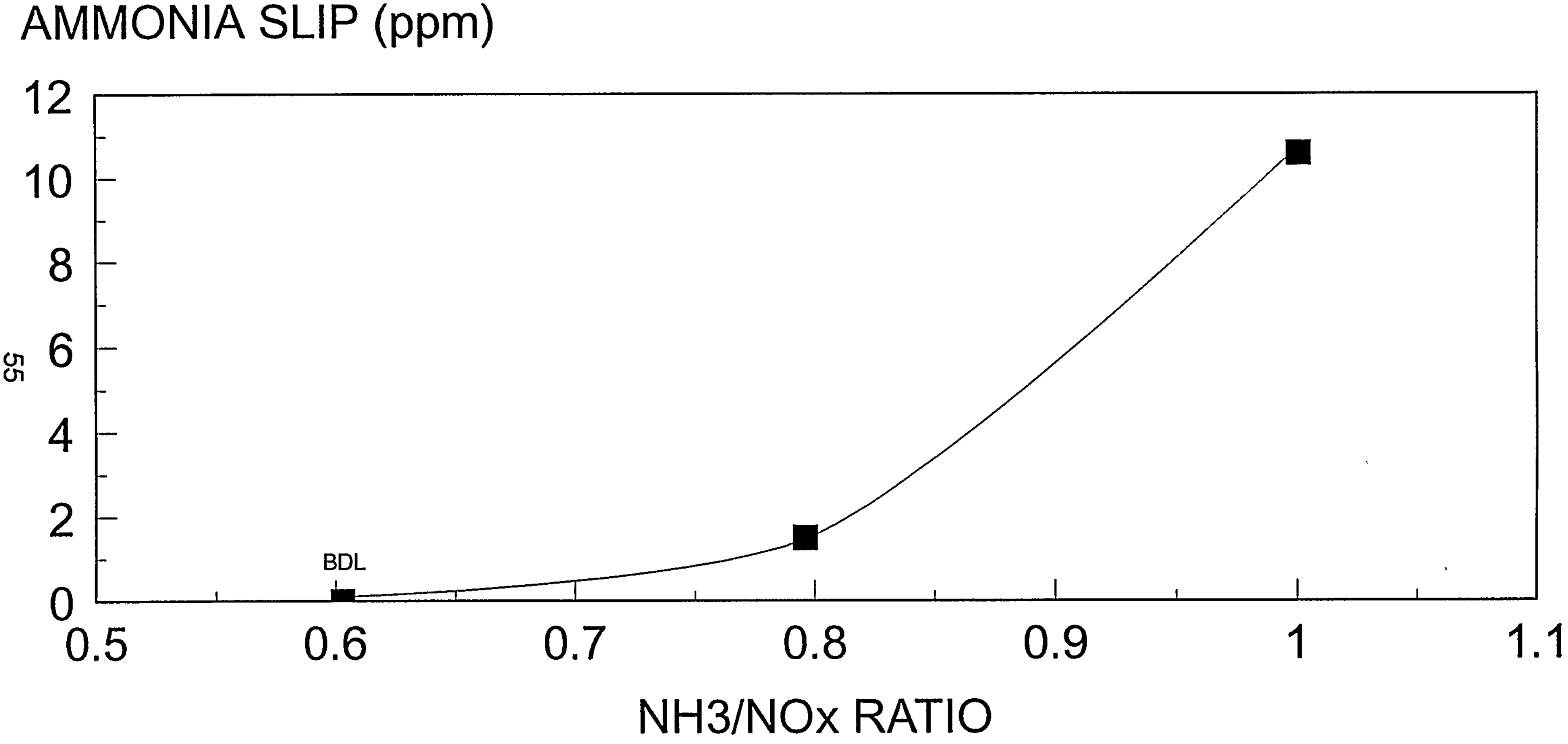


NSKK: DESIGN FLOW, 620F

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

FIGURE 13b

AMMONIA SLIP VS. NH3/NOx RATIO

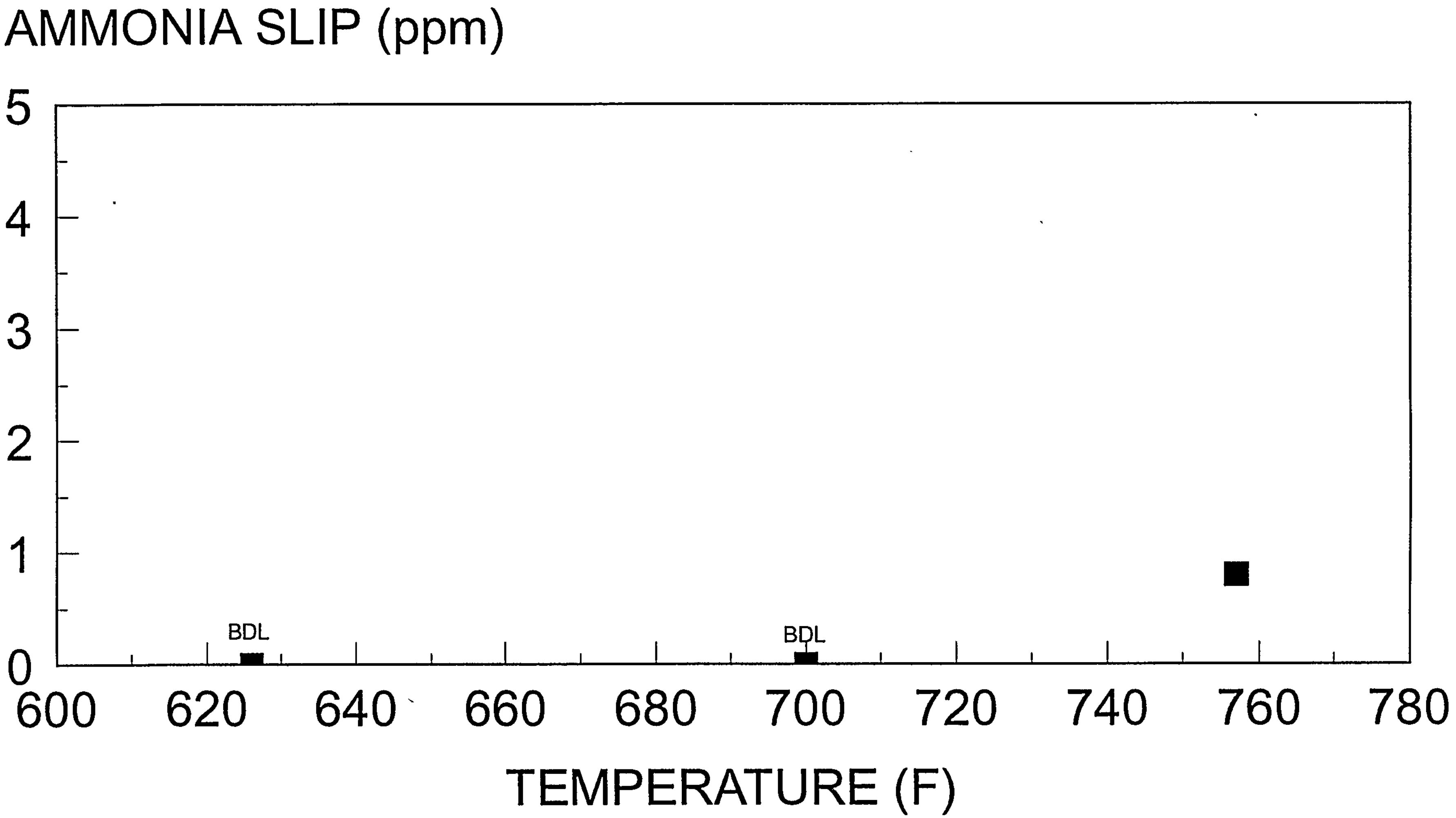


NSKK: Design Flow, 620 F

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

FIGURE 14a

AMMONIA SLIP VS. TEMPERATURE

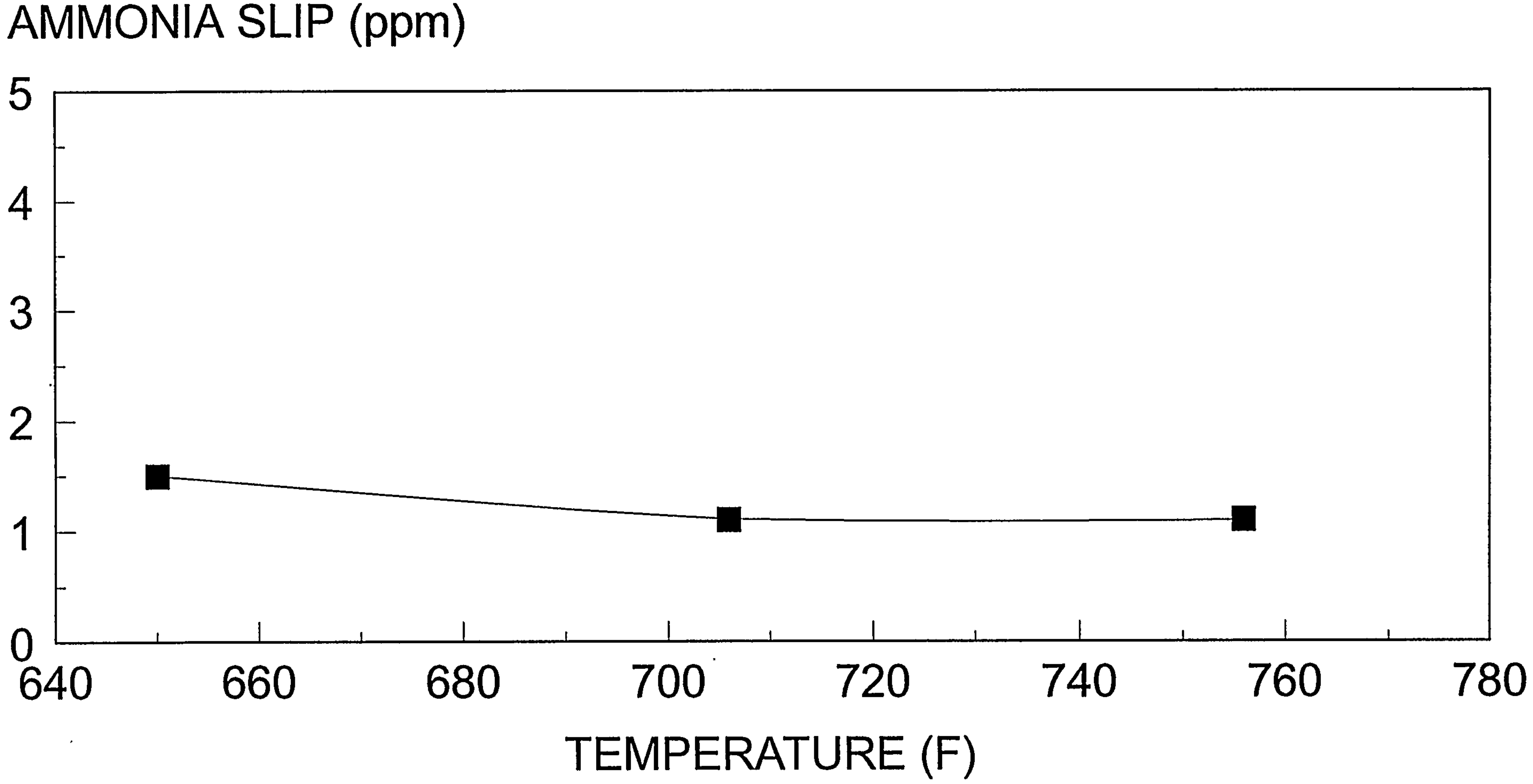


NSKK: DESIGN FLOW, NH3/NOX=0.8

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

FIGURE 14b

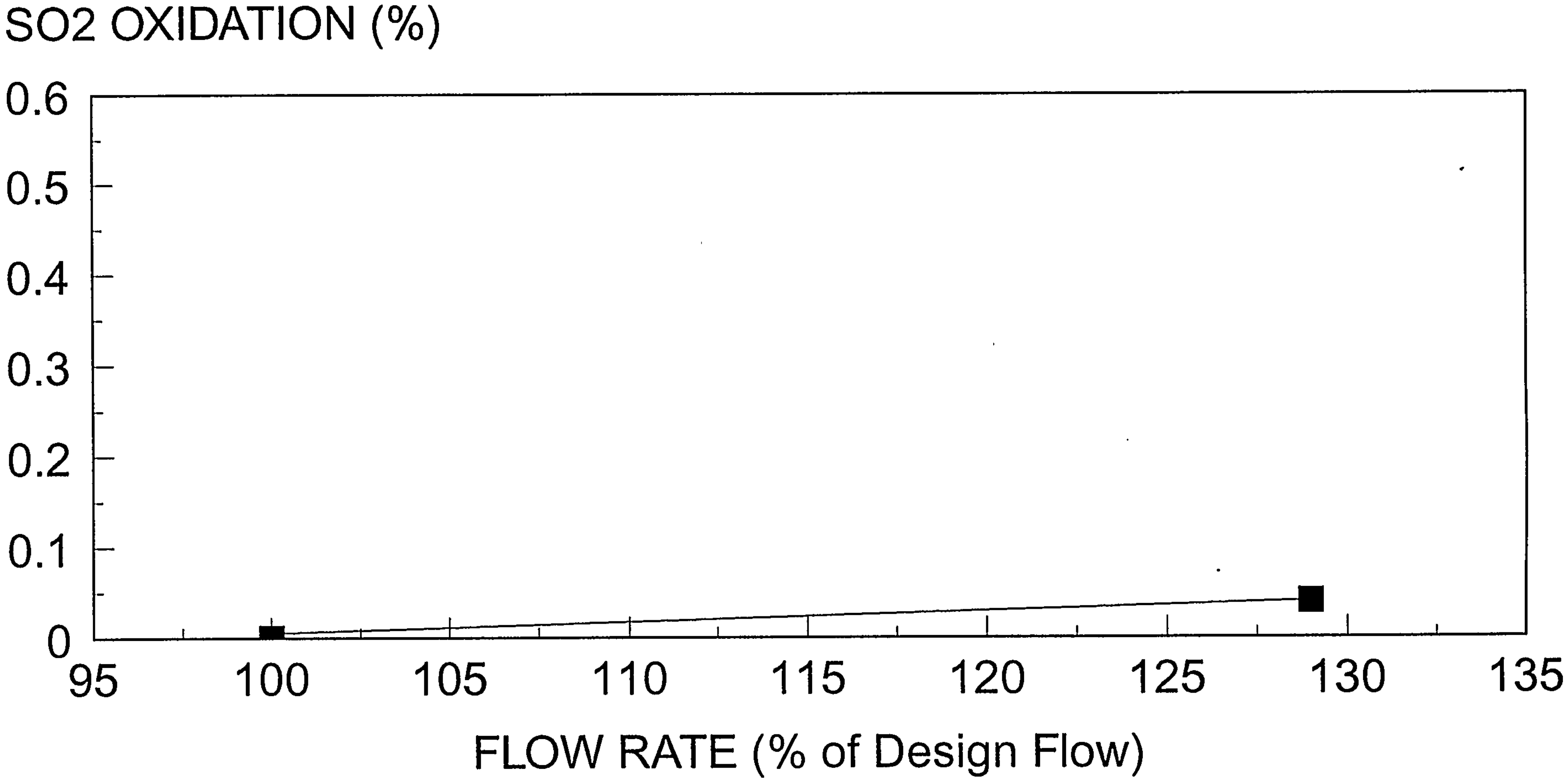
AMMONIA SLIP VS. TEMPERATURE



NSKK: NH3/NOx=0.80, Design Flow

FIGURE 15

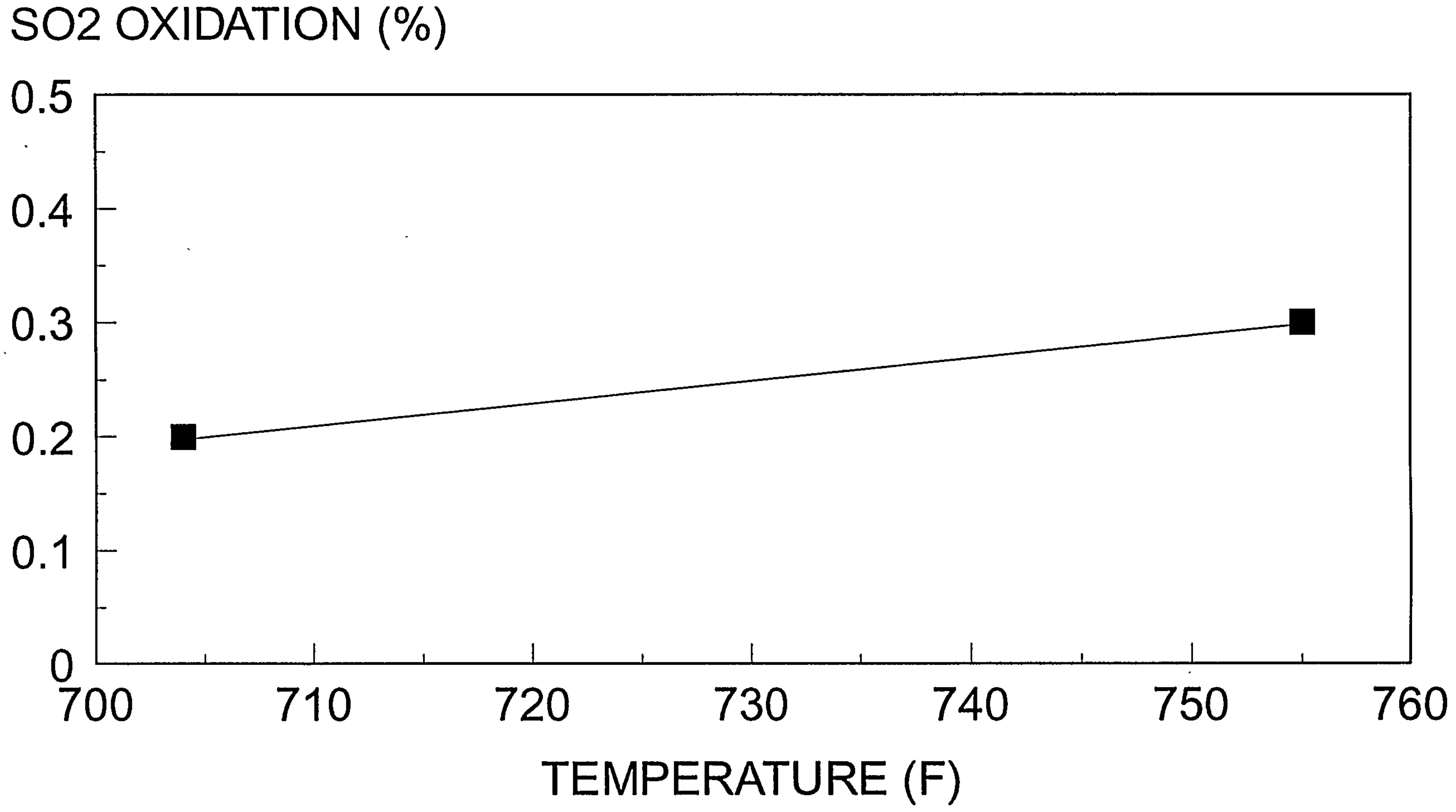
SO2 OXIDATION VS. FLOWRATE



NSKK: NH3/NOx=0.80, 700 F

FIGURE 16a

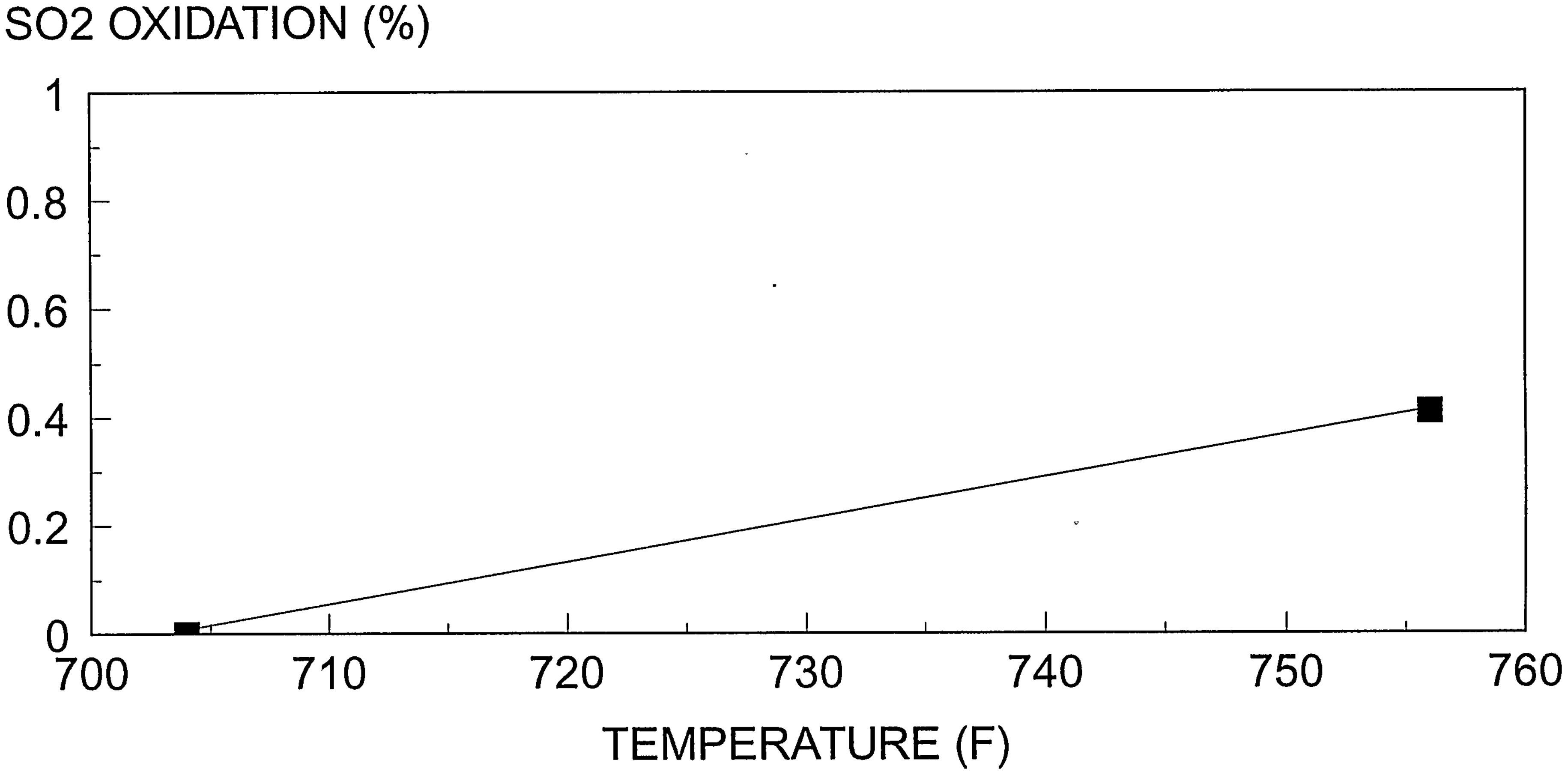
SO2 OXIDATION VS. TEMPERATURE



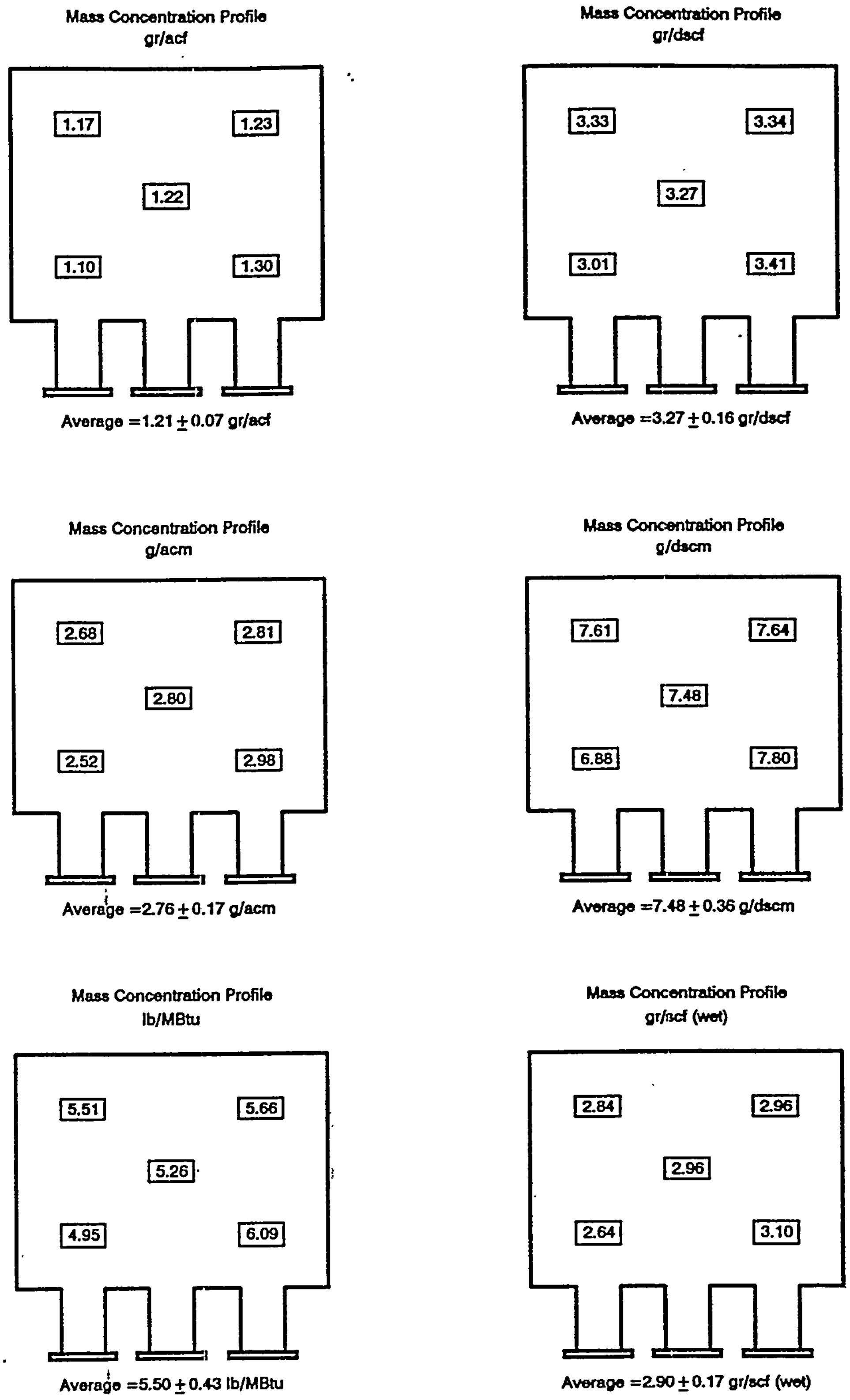
NSKK: DESIGN FLOW, NH3/NOx=0.80

FIGURE 16b

SO2 OXIDATION VS. TEMPERATURE



NSKK: Design Flow, NH3/NOX=0.80



Mass Concentration Profile gr/acf

Average =1.21 ± 0.07 gr/acf

Mass Concentration Profile gr/dscf

Average =3.27 ± 0.16 gr/dscf

Mass Concentration Profile g/acm

Average =2.76 ± 0.17 g/acm

Mass Concentration Profile g/dscm

Average =7.48 ± 0.36 g/dscm

Mass Concentration Profile lb/MBtu

Average =5.50 ± 0.43 lb/MBtu

Mass Concentration Profile gr/scf (wet)

Average =2.90 ± 0.17 gr/scf (wet)

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

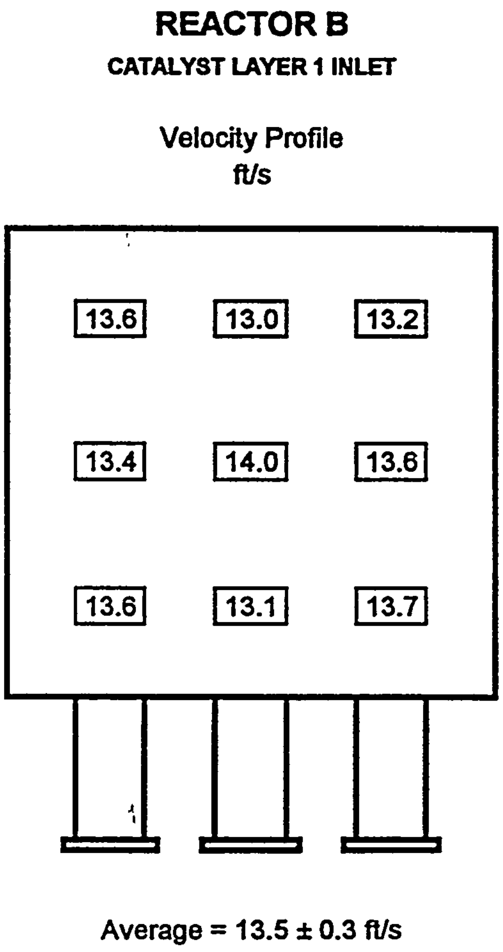


Figure 18a Reactor B flue gas velocity profile.
Third Parametric Sequence

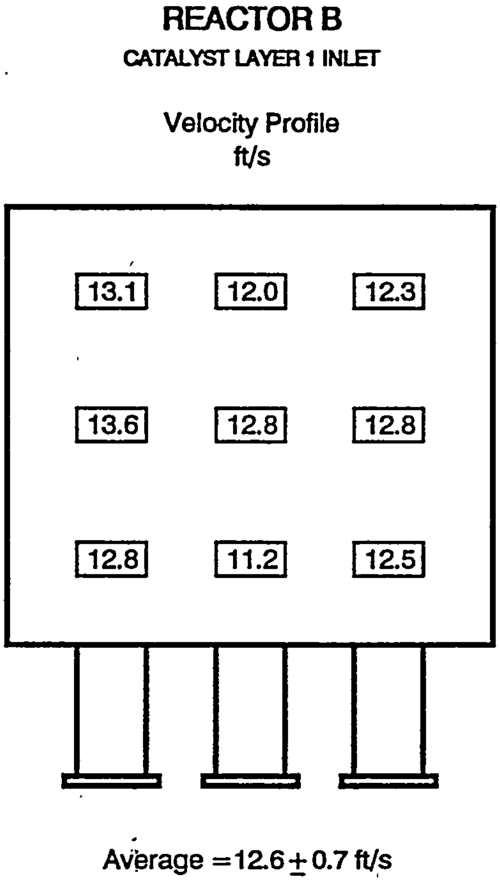


Figure 18b. Reactor B flue gas velocity profile.
Fourth Parametric Sequence

- 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 SO_2 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 SO_2 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 SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 deposition occur in the test facility reactors. The general trend of increasing SO_2 oxidation is expected, however, and the plots provide a good basis for determining the potential for SO_3 formation across the SCR reactor at various operating temperatures.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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 rector) 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% O_2, dry) were 233 ± 8 ppmv and 260 ± 7 ppmv respectively. The N_2O 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% O_2).[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

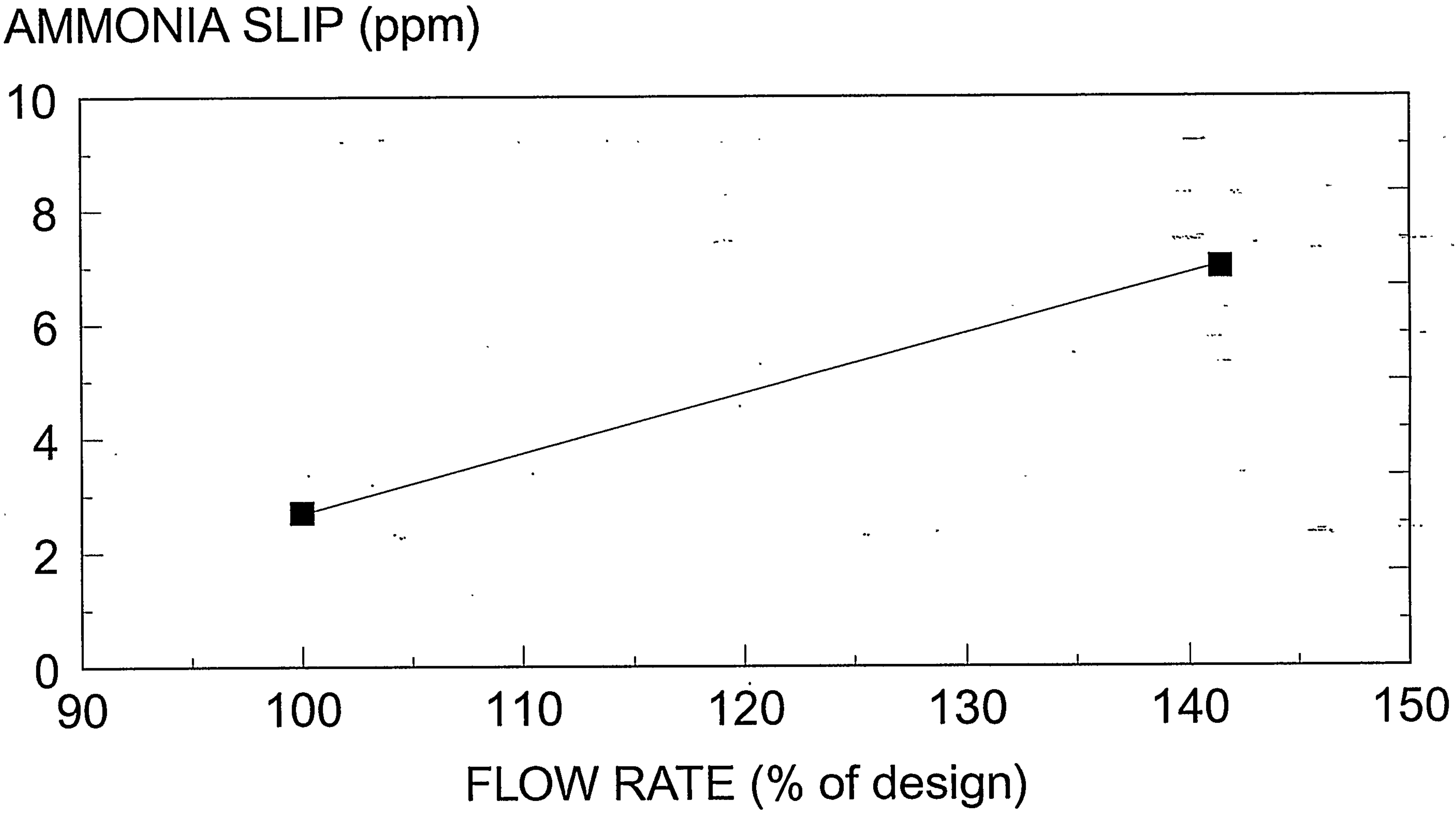
FLOW RATE (SCFM)	TEMP (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS. SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
5293	702	3.193	2019	0.803	9.2	12.8	3.6	0.18
6784	704	5.538	1550	0.802	5.0	2.1	-2.9	-0.18
5354	756	4.122	1960	0.802	11.0	35.2	24.2	1.23

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

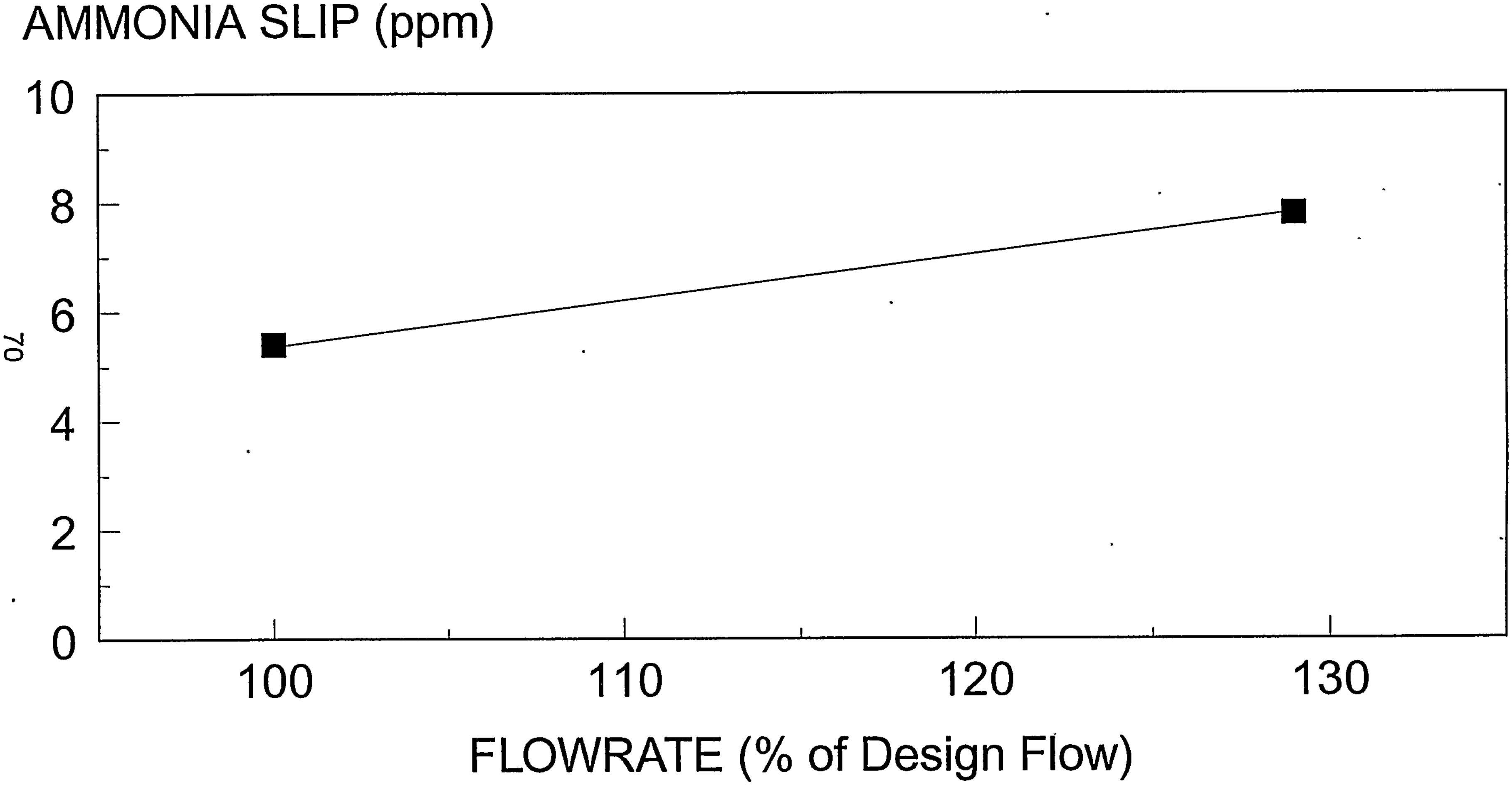
AMMONIA SLIP VS. FLOW RATE



SIEMENS: 700 F, NH3/NOx=0.8

FIGURE 19b

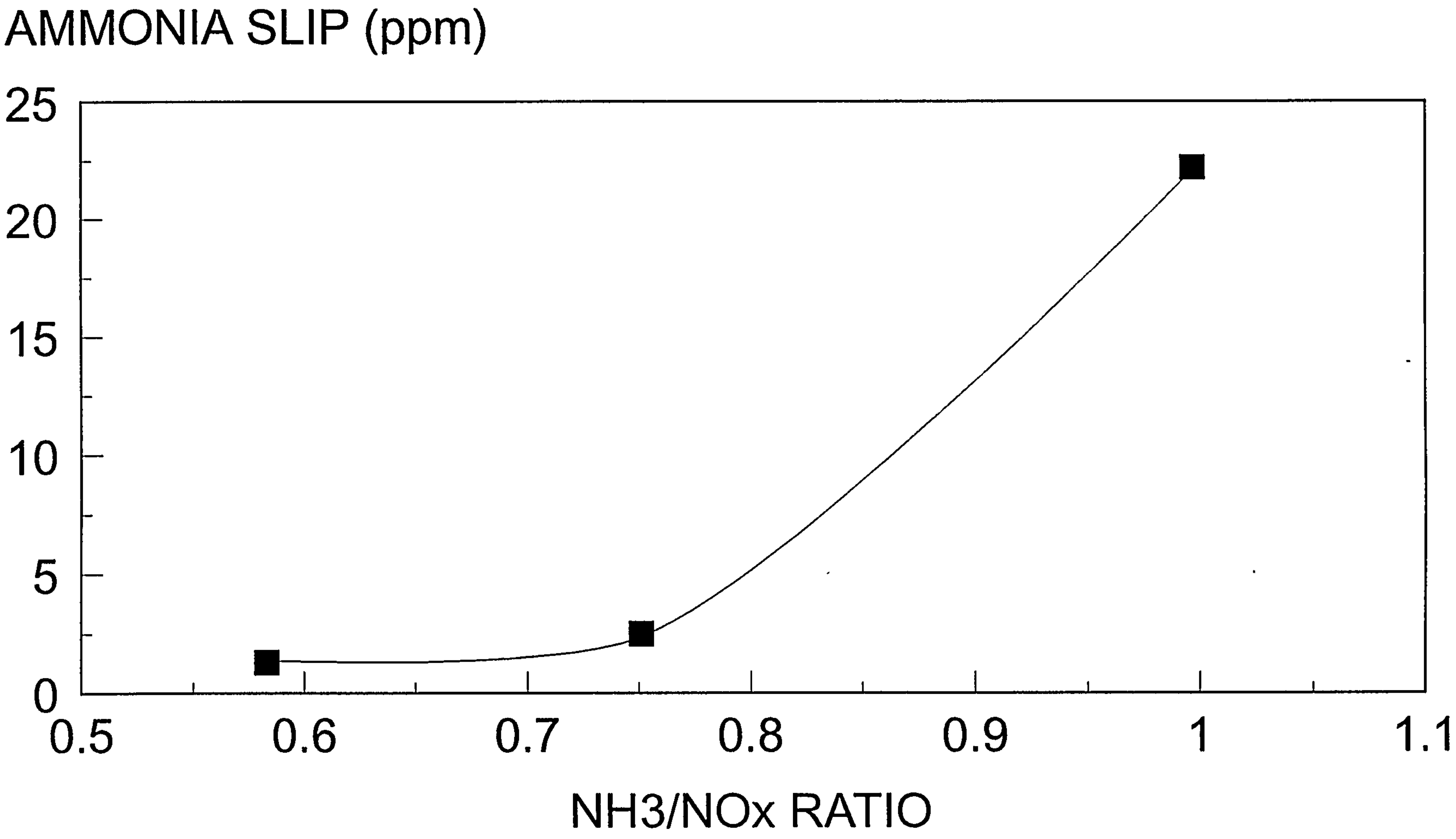
AMMONIA SLIP VS. FLOW RATE



SIEMENS: NH3/NOx=0.80, 700 F

FIGURE 20a

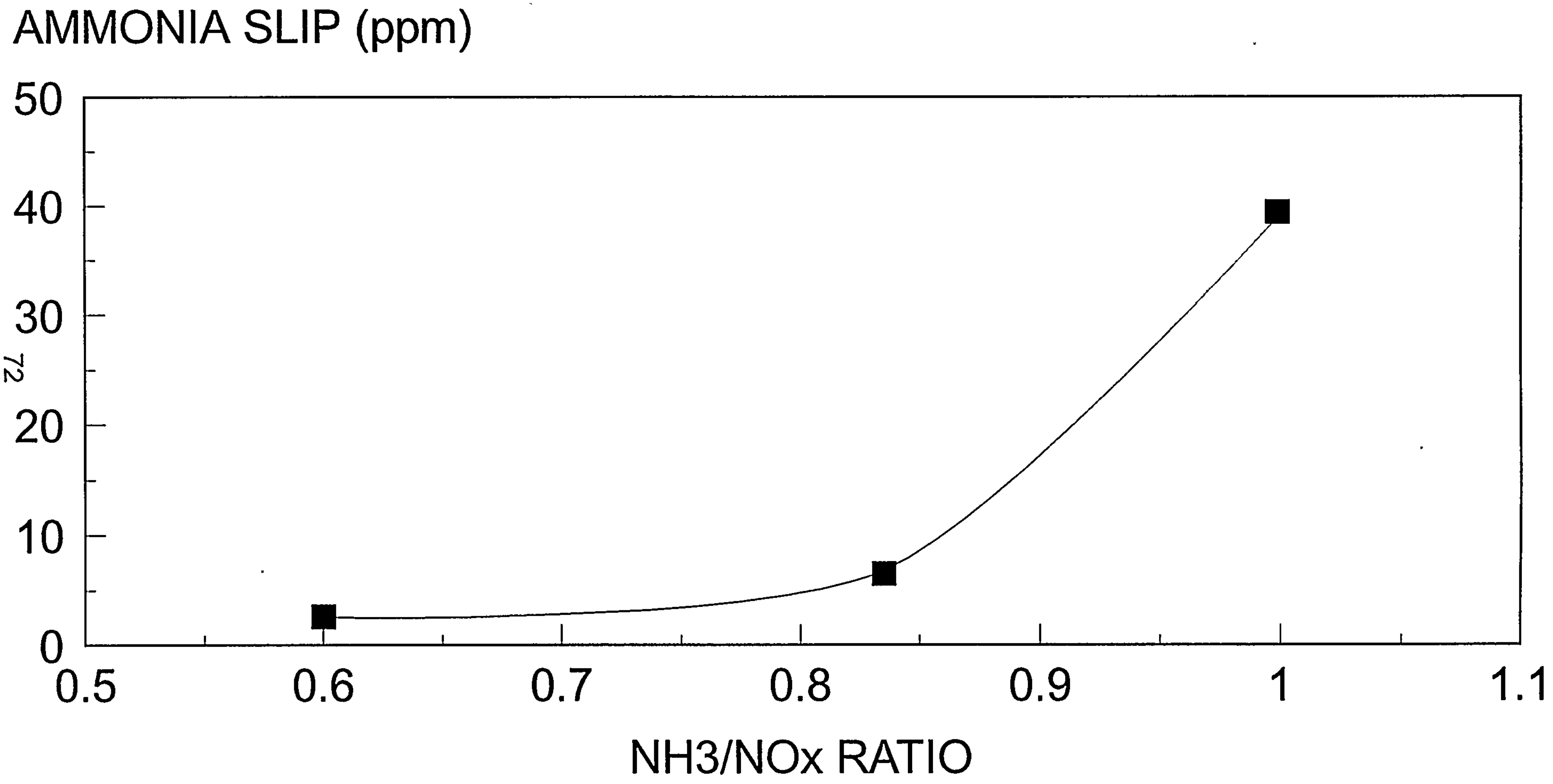
AMMONIA SLIP VS. NH3/NOx RATIO



SIEMENS: DESIGN FLOW, 620F

FIGURE 20b

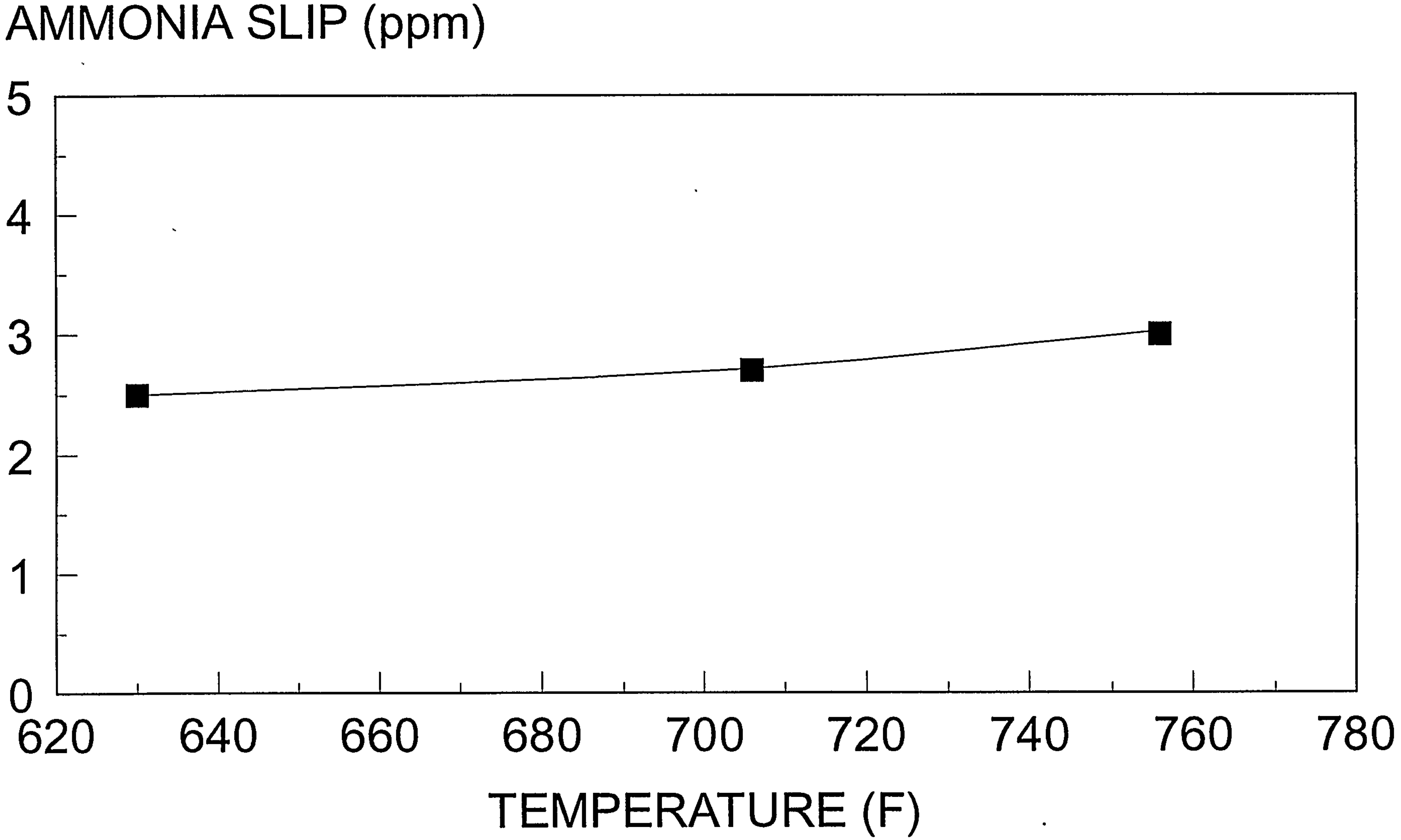
AMMONIA SLIP VS. NH3/NOx RATIO



SIEMENS: Design Flow, 620 F

FIGURE 21a

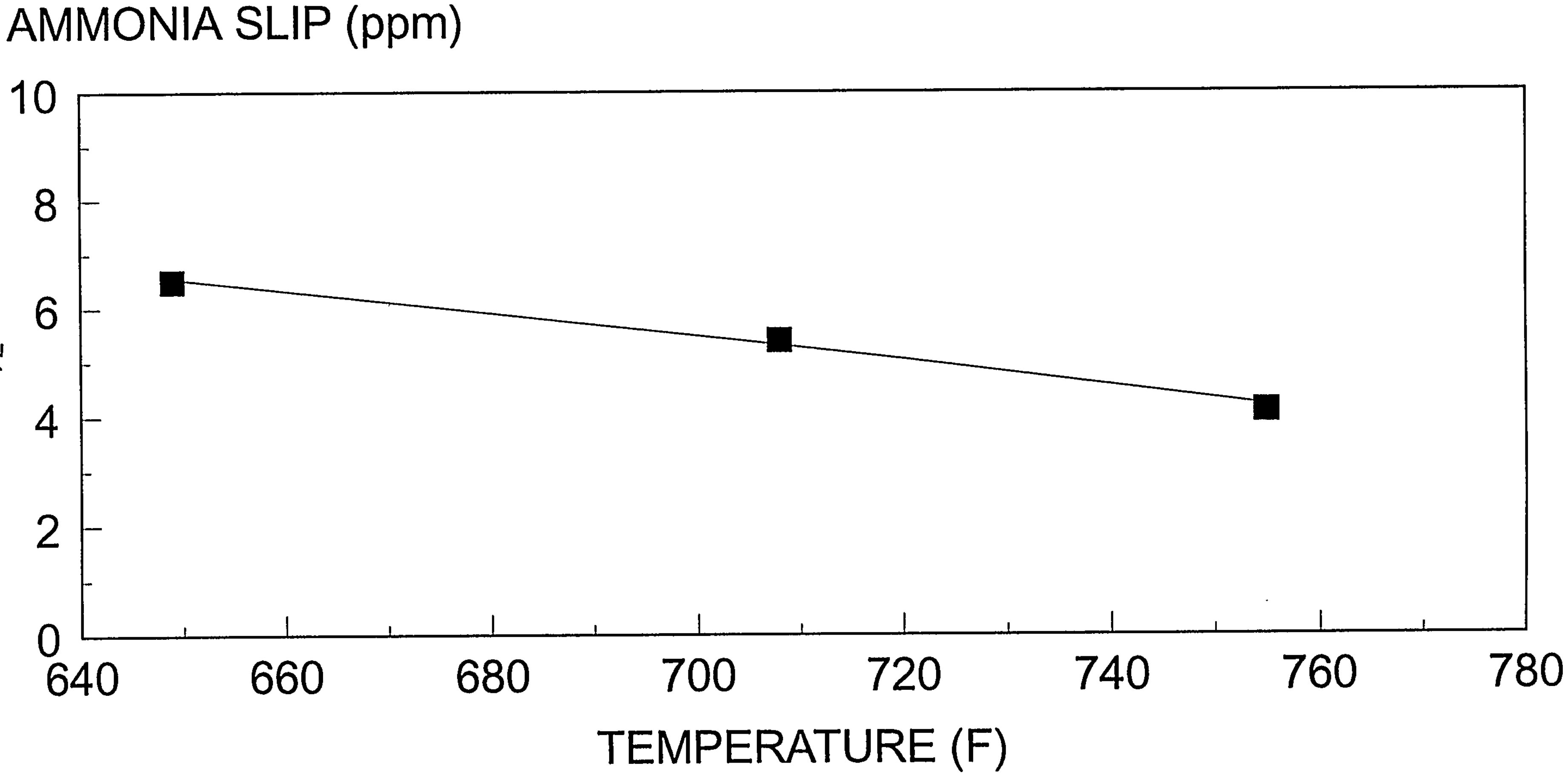
AMMONIA SLIP VS. TEMPERATURE



SIEMENS: DESIGN FLOW, NH3/NOx=0.8

FIGURE 21b

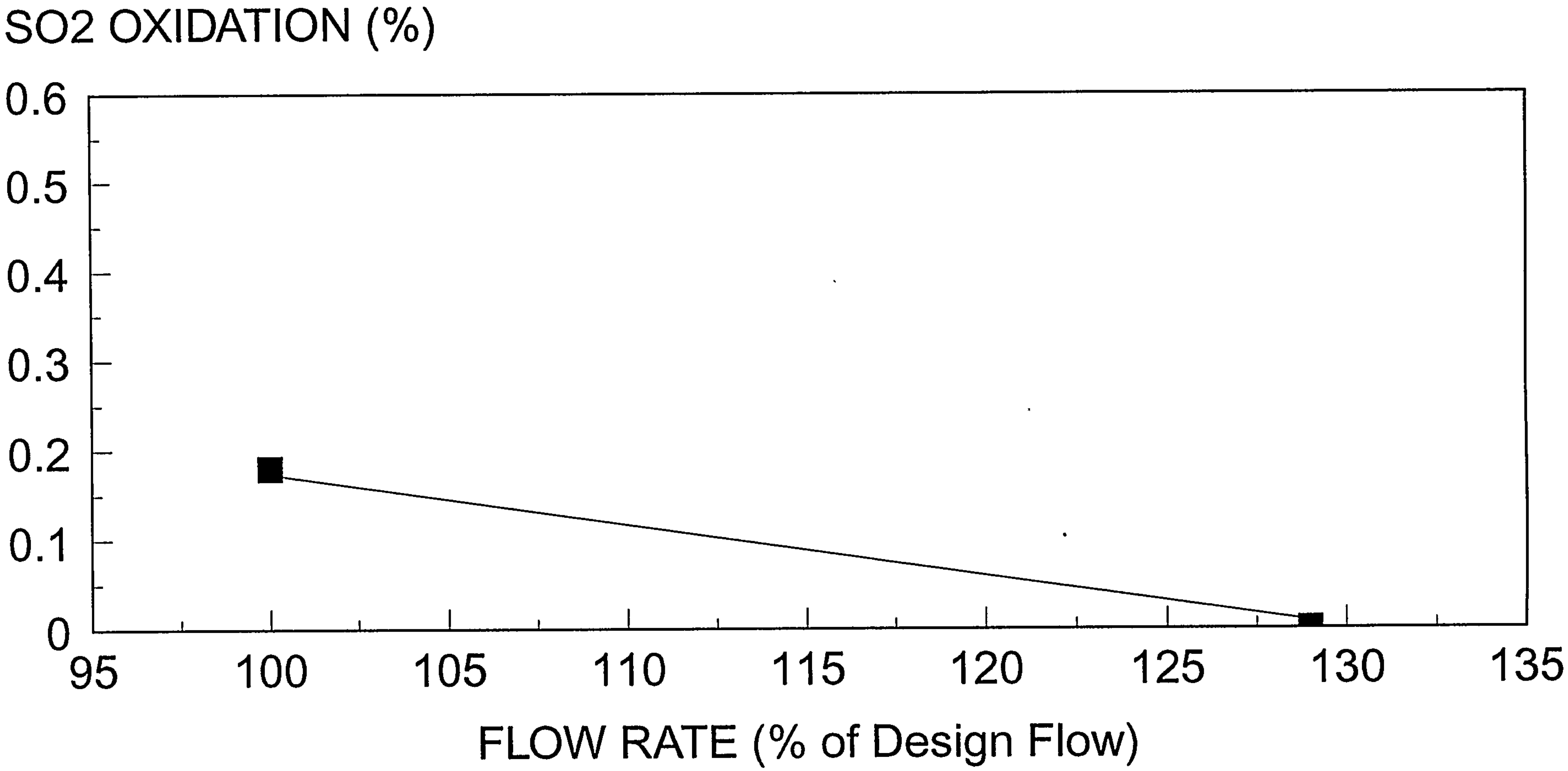
AMMONIA SLIP VS. TEMPERATURE



SIEMENS: NH3/NOx=0.80, Design Flow

FIGURE 22

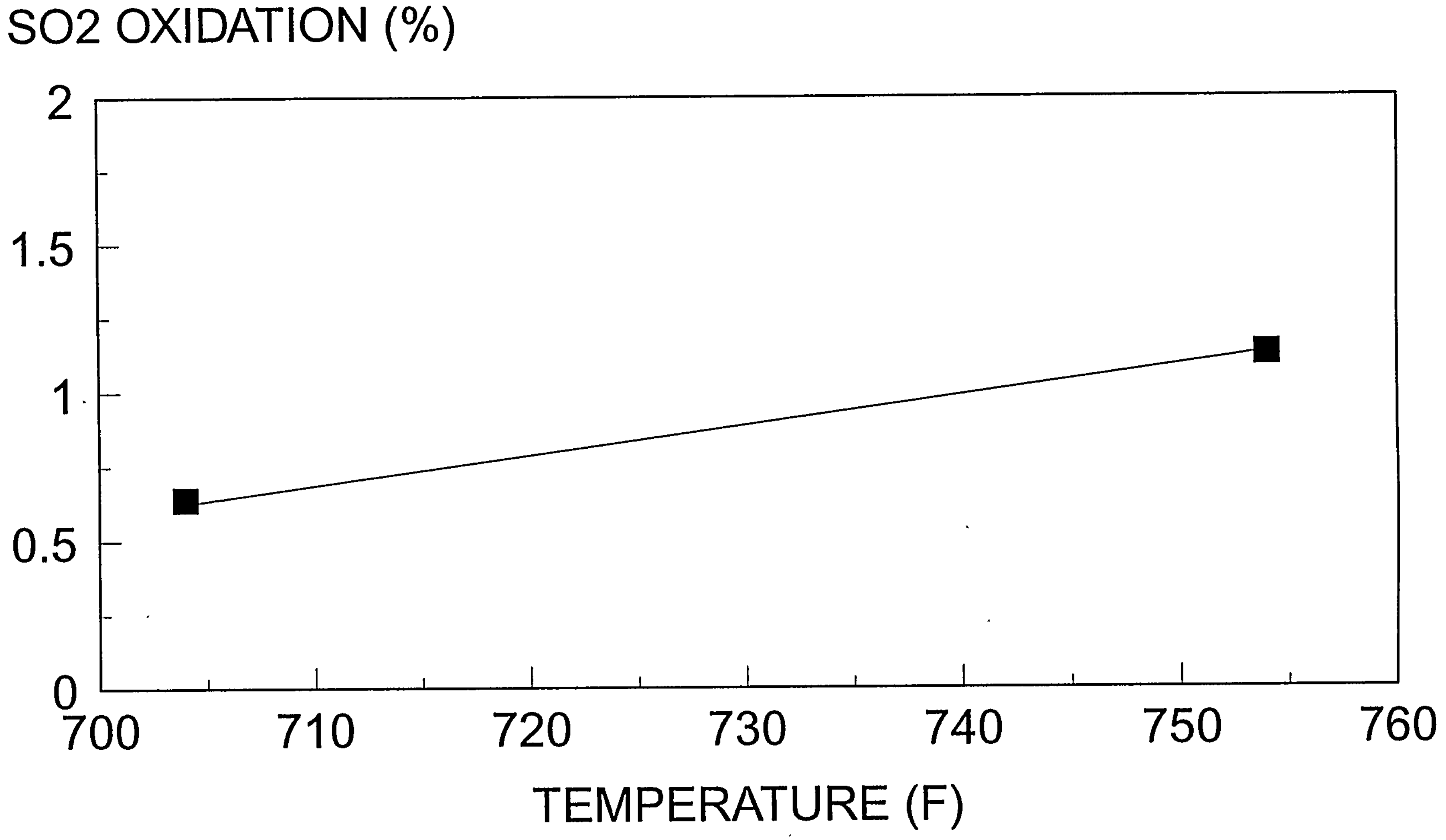
SO2 OXIDATION VS. FLOWRATE



SIEMENS: NH3/NOx=0.80, 700 F

FIGURE 23a

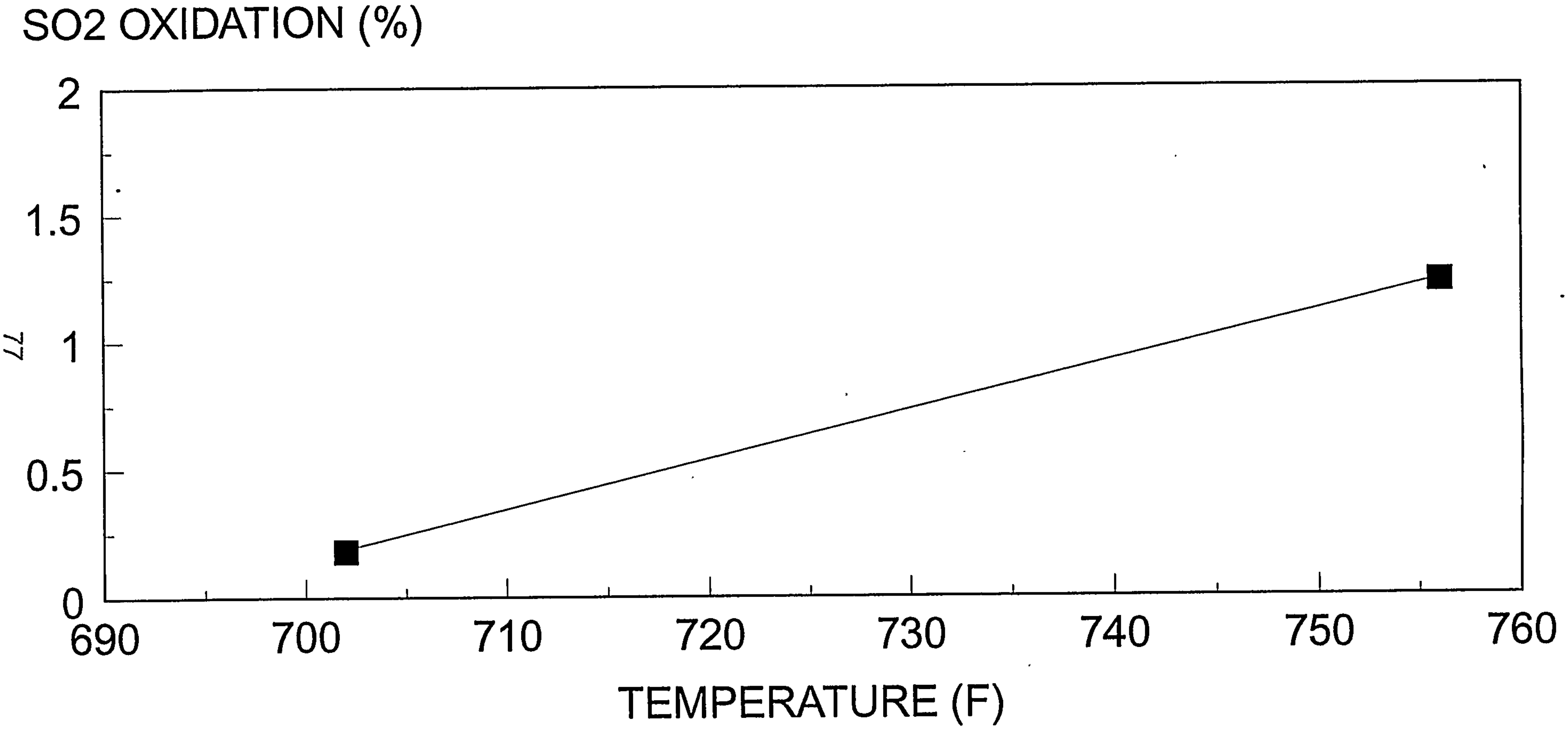
SO2 OXIDATION VS. TEMPERATURE



SIEMENS: DESIGN FLOW, NH3:NOx=0.8

FIGURE 23b

SO2 OXIDATION VS. TEMPERATURE



SIEMENS: Design Flow, NH3/NOX=0.80

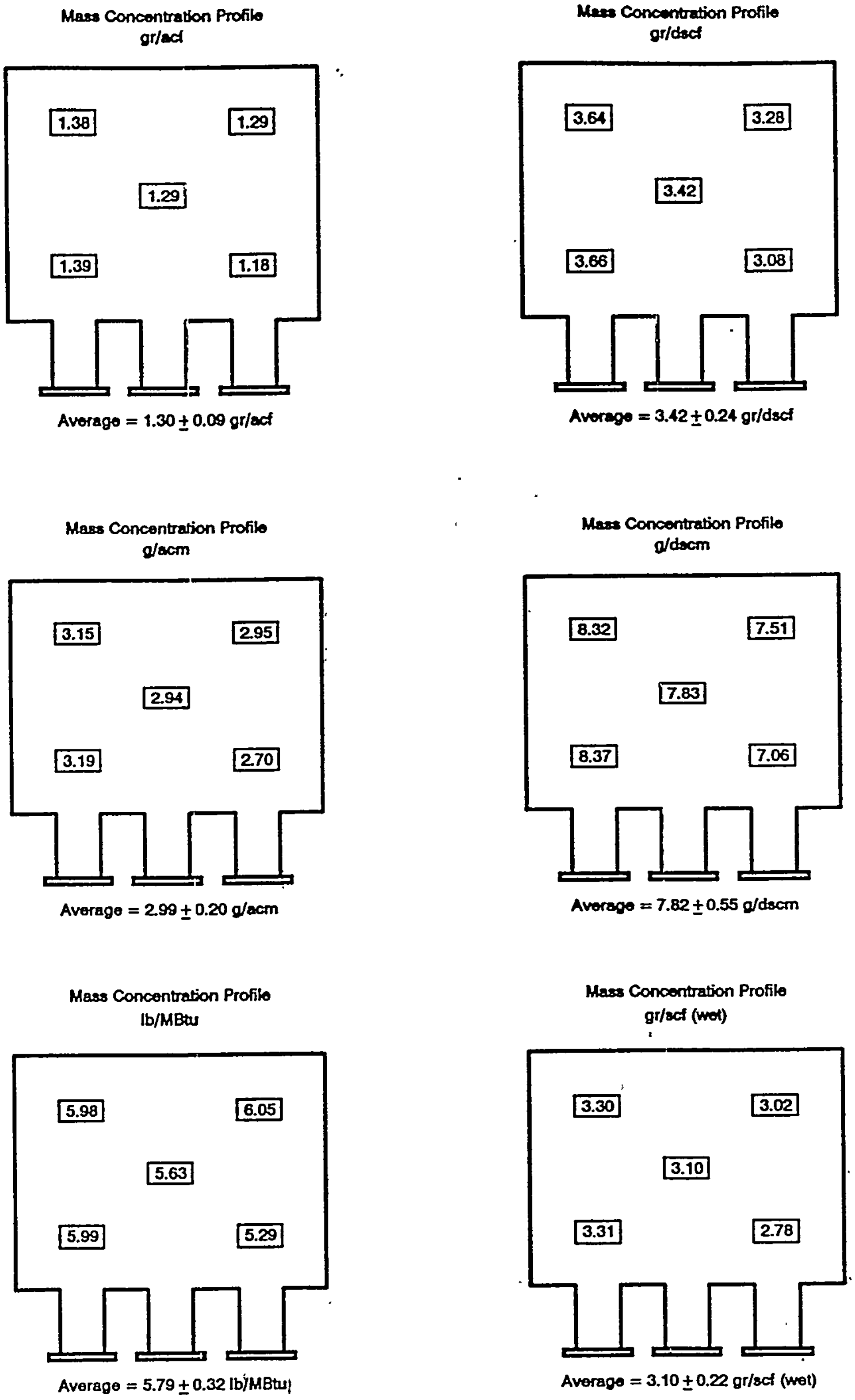
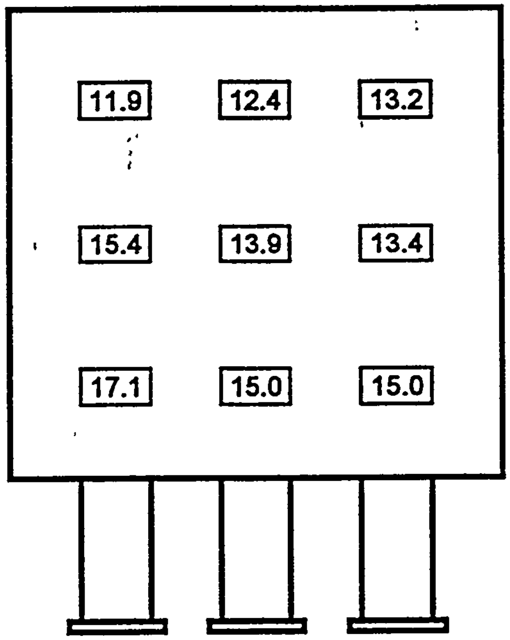


Figure 24. Six presentations of the Reactor C outlet mass concentration/mass emission profile.



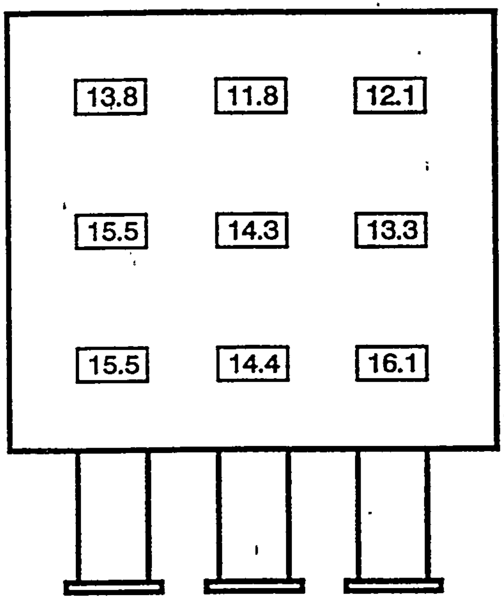
REACTOR C

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 SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 deposition occur in the test facility reactors. The general trend of increasing SO_2 oxidation is expected, however, and the plots provide a good basis for determining the potential for SO_3 formation across the SCR reactor at various operating temperatures.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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% O_2, dry) were 232 ± 4 ppmv and 223 ± 17 ppmv respectively. The N_2O 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% O_2).[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

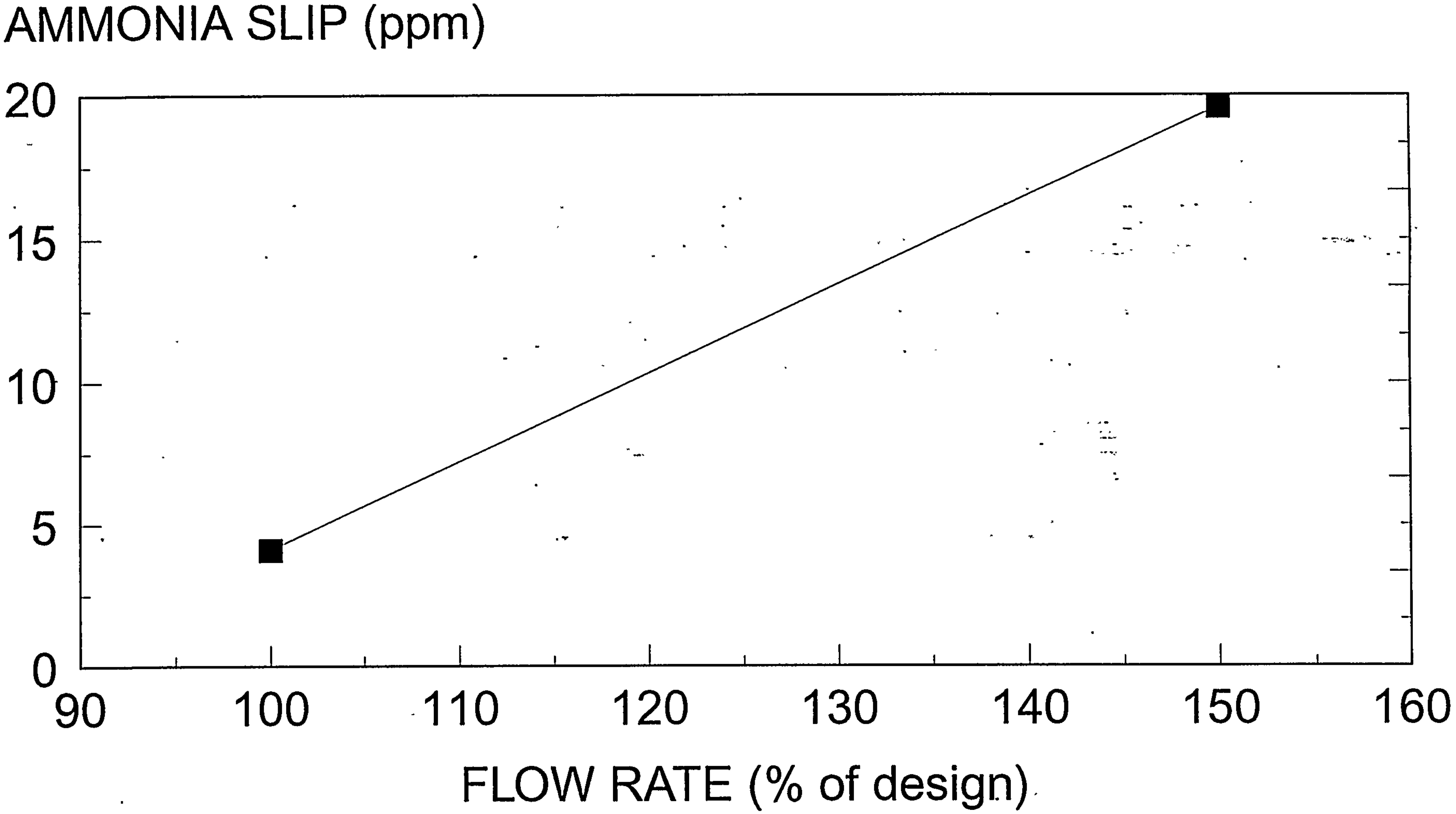
FLOW RATE (SCFM)	TEMP (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS. SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
416	704	4.830	1554	0.800	4.2	12.0	7.8	0.50
416	705	3.984	1600	0.803	0.7	0.2	-0.5	-0.03
399	755	4.012	1639	0.806	1.1	10.4	9.3	0.57

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

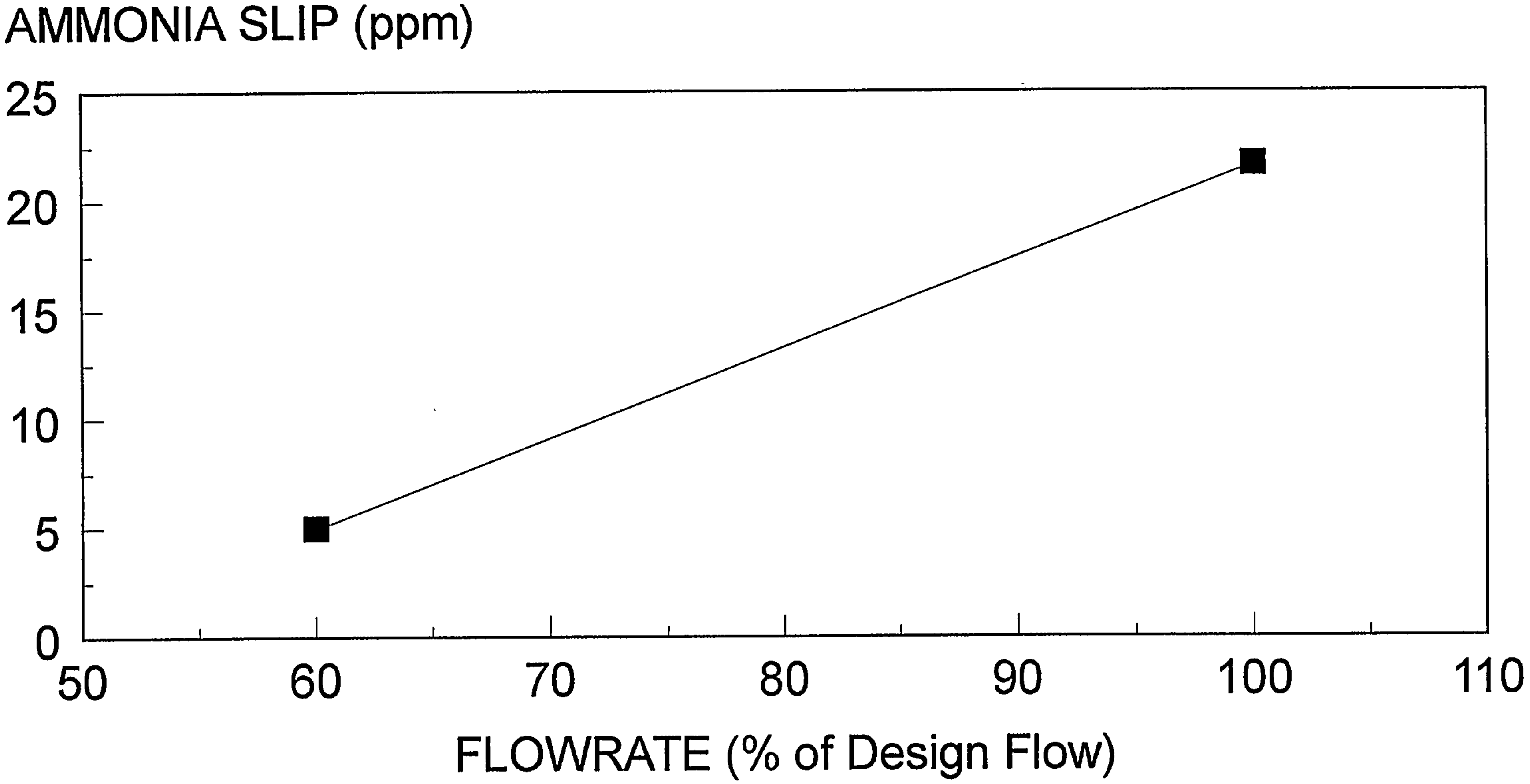
AMMONIA SLIP VS. FLOW RATE



GRACE SYNOX: 700 F, NH3/NOx=0.8

FIGURE 26b

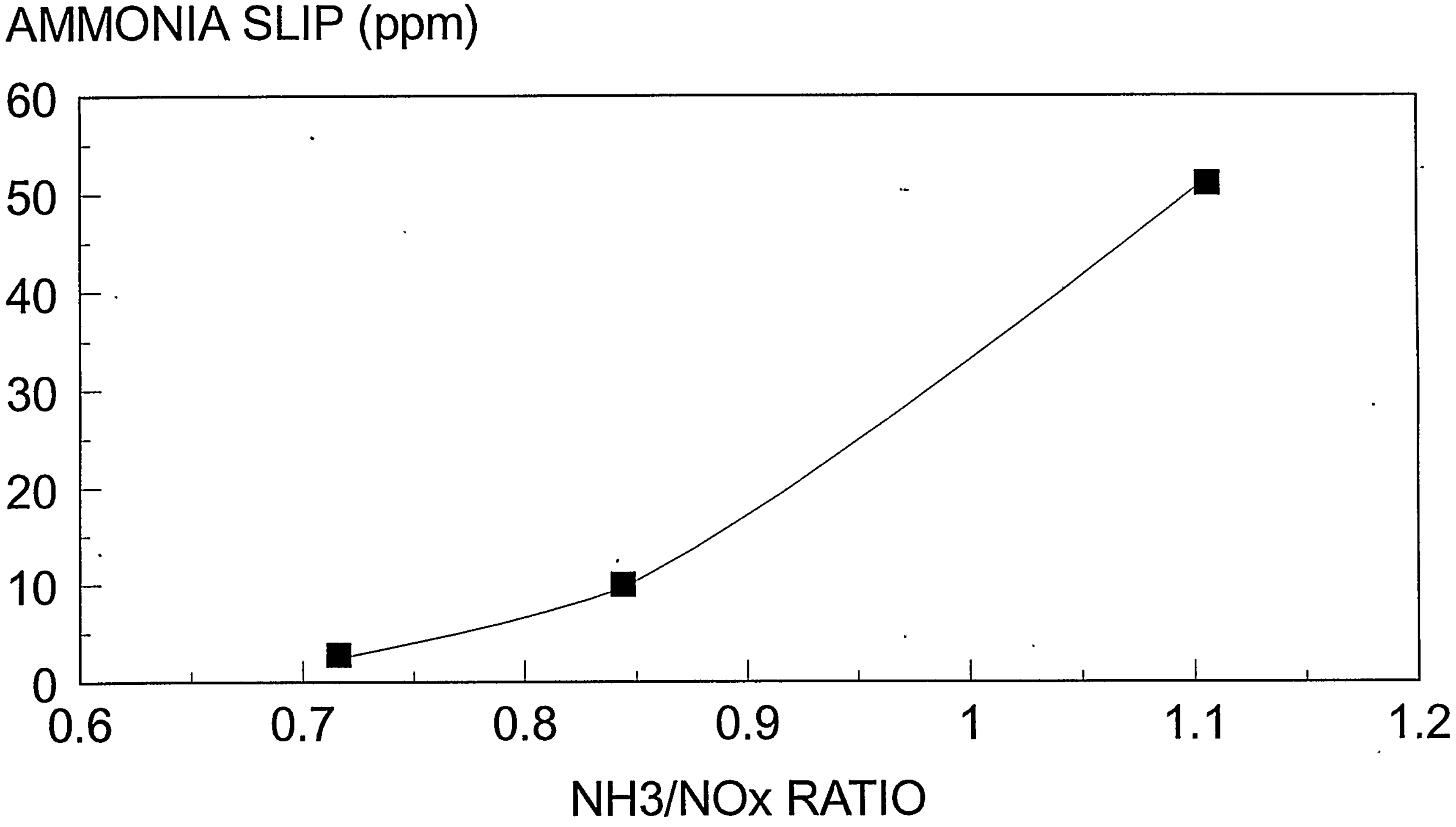
AMMONIA SLIP VS. FLOW RATE



GRACE SNX: NH3/NOx=0.80, 620 F

FIGURE 27a

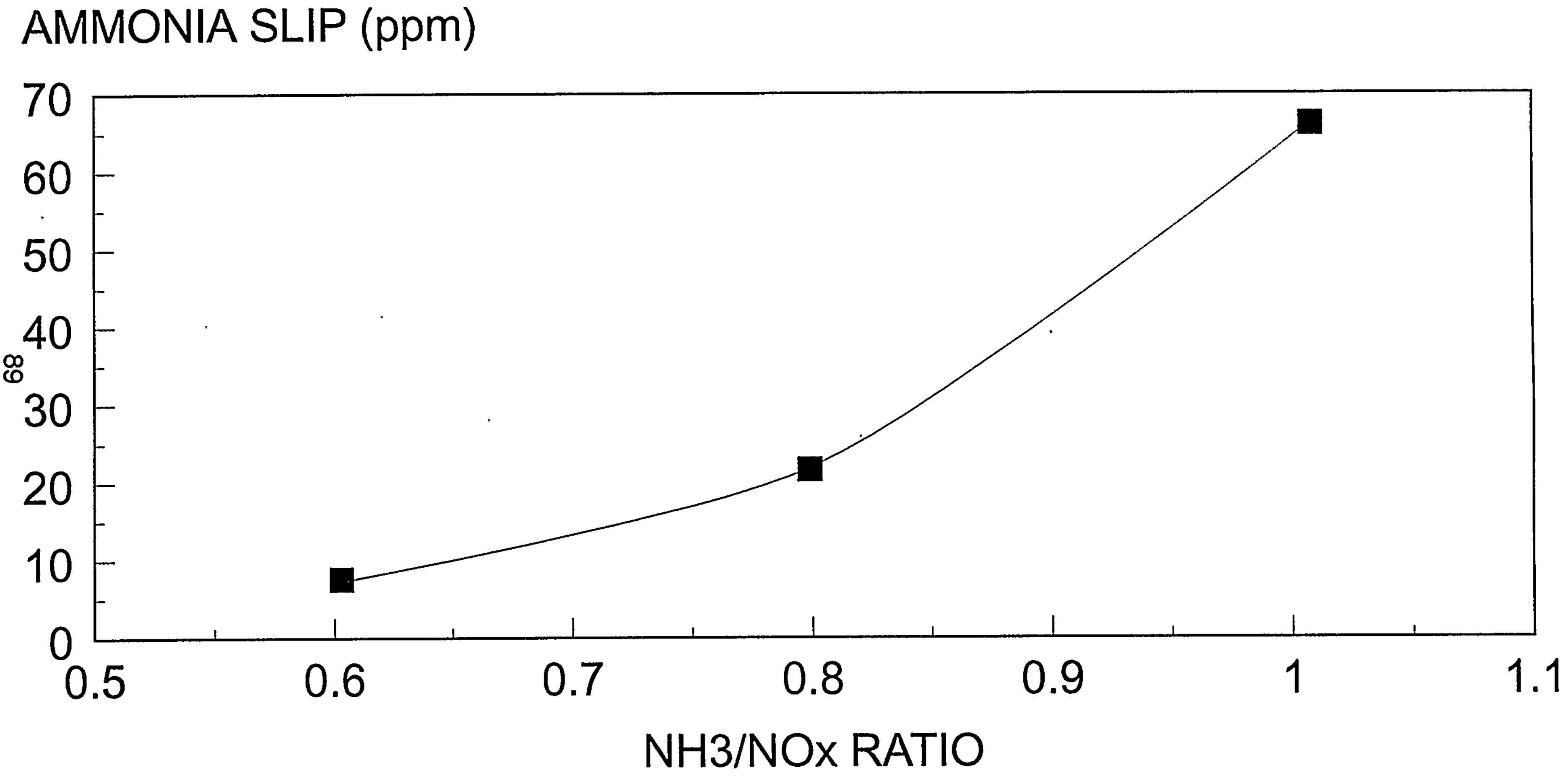
AMMONIA SLIP VS. NH3/NOx RATIO



GRACE SYNOX: DESIGN FLOW, 620F

FIGURE 27b

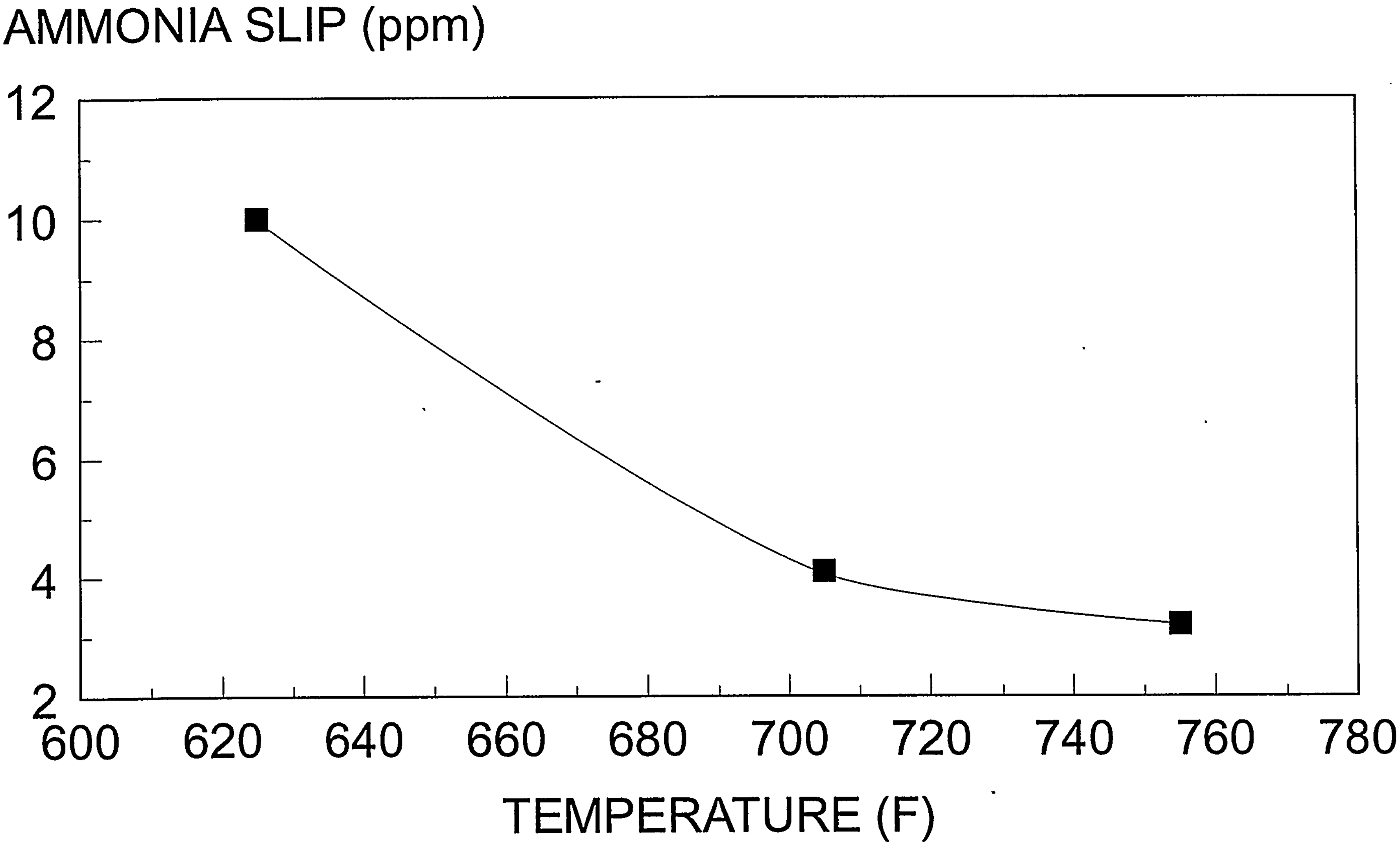
AMMONIA SLIP VS. NH3/NOx RATIO



GRACE SNX: Design Flow, 620 F

FIGURE 28a

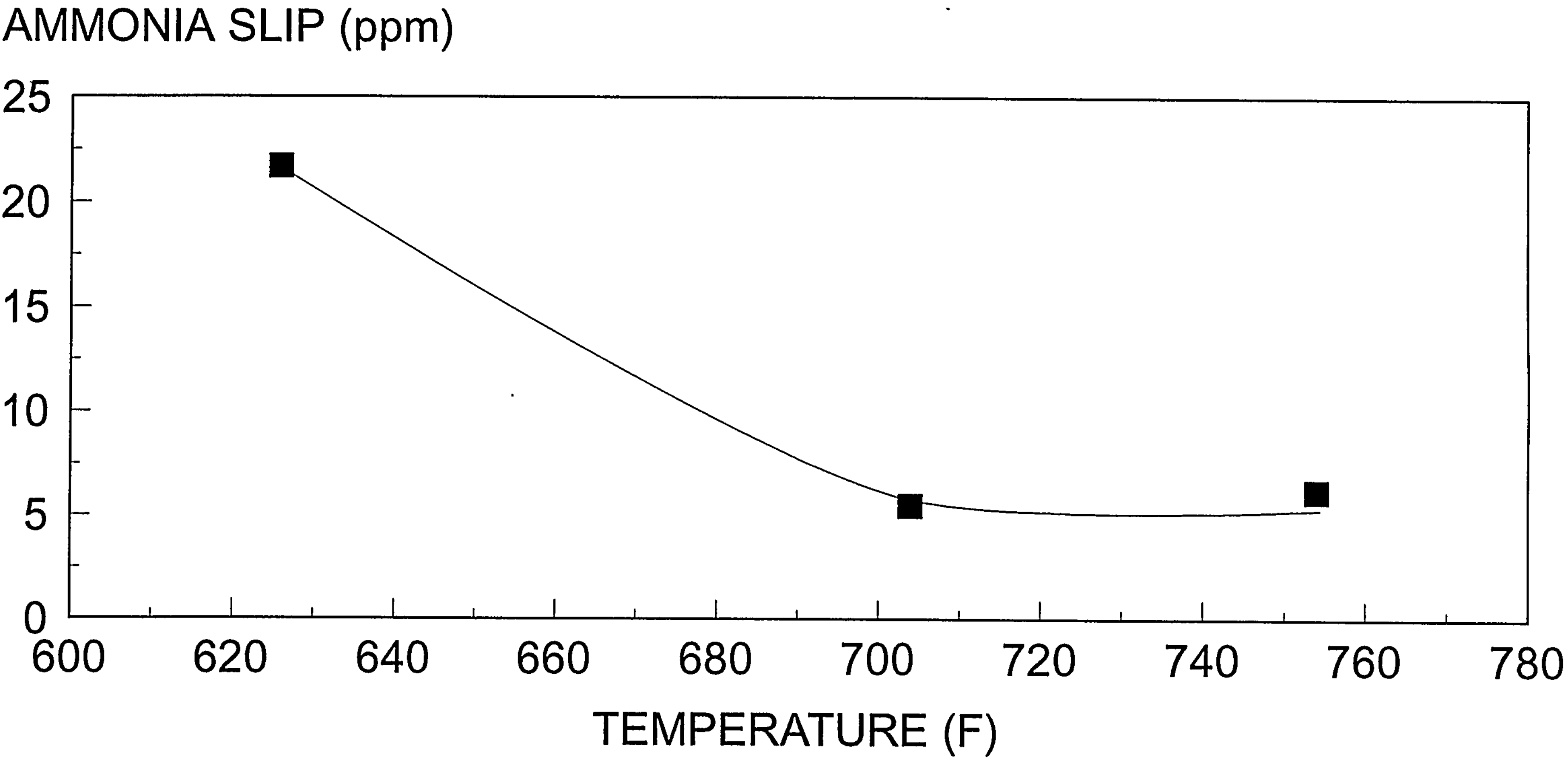
AMMONIA SLIP VS. TEMPERATURE



GRACE SYNOX: DESIGN FLOW, NH3/NOx=0.8

FIGURE 28b

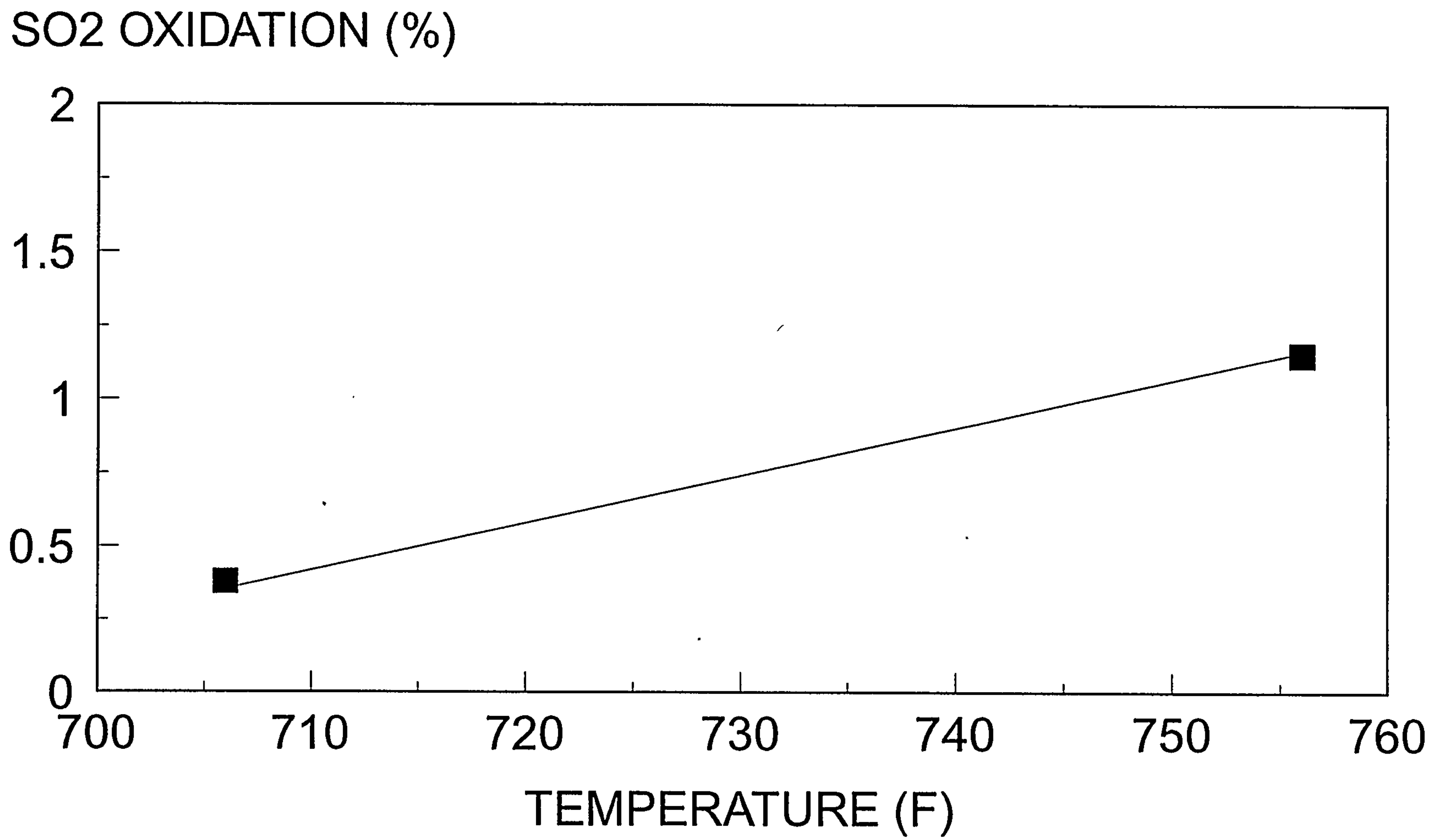
AMMONIA SLIP VS. TEMPERATURE



GRACE SNX: NH3/NOx=0.80, Design Flow

FIGURE 29a

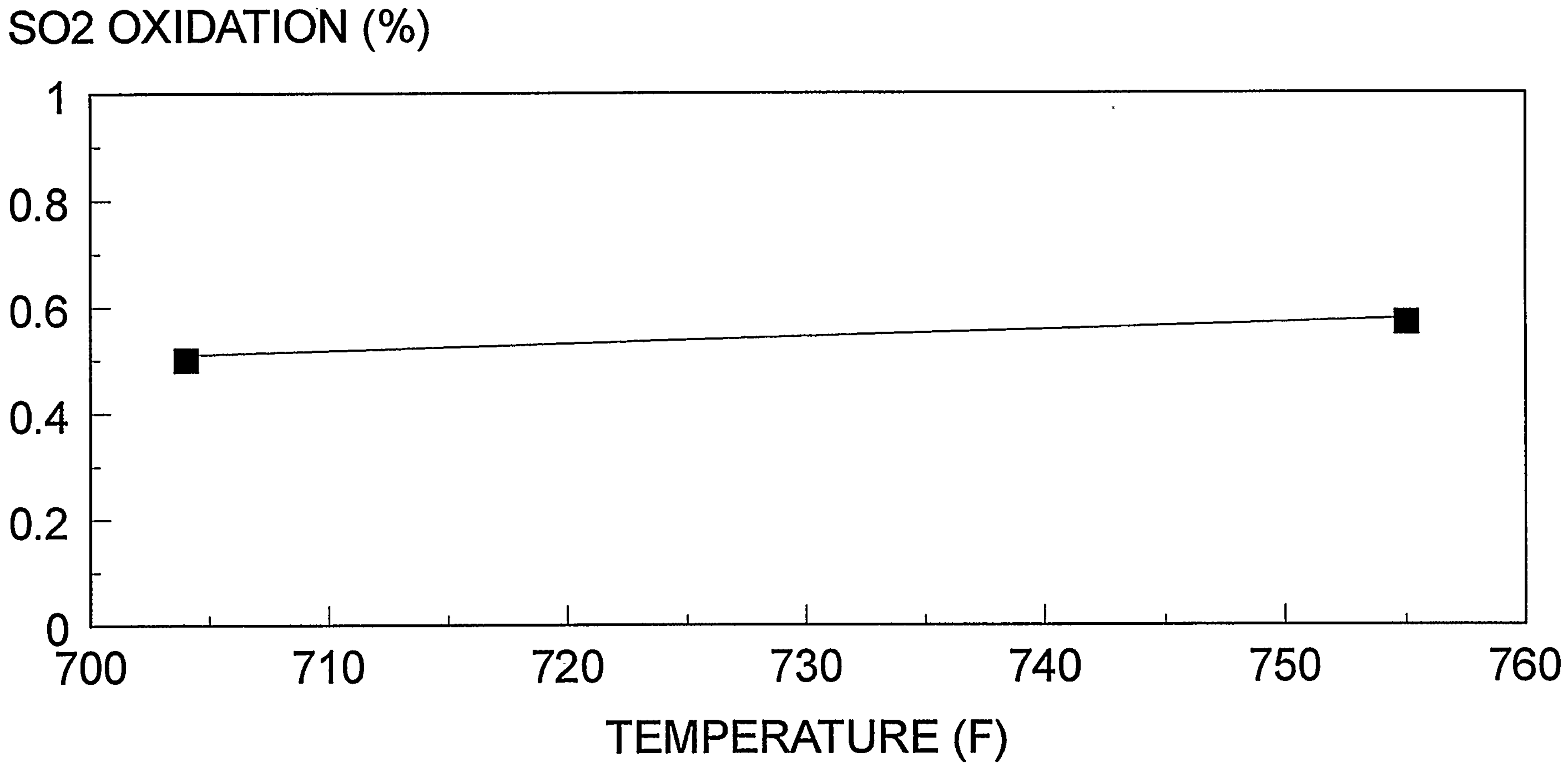
SO2 OXIDATION VS. TEMPERATURE



GRACE SNX: DESIGN FLOW, NH3/NOx=0.8

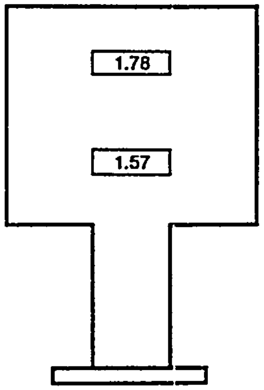
FIGURE 29b

SO2 OXIDATION VS. TEMPERATURE



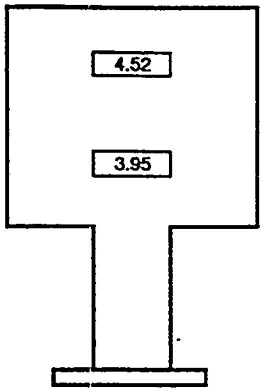
GRACE SNX: Design Flow, NH3/NOX=0.80

Mass Concentration Profile
gr/acf



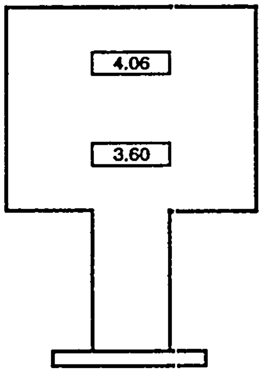
Average = 1.67 ± 0.14 gr/acf

Mass Concentration Profile
gr/dscf



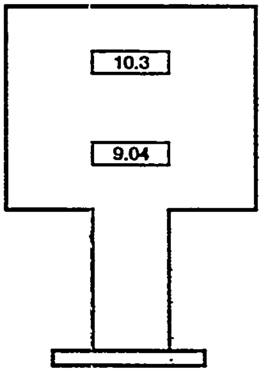
Average = 4.24 ± 0.40 gr/dscf

Mass Concentration Profile
g/acm



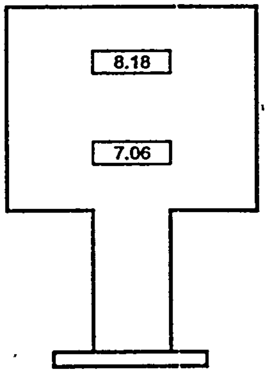
Average = 3.83 ± 0.33 g/acm

Mass Concentration Profile
g/dscm



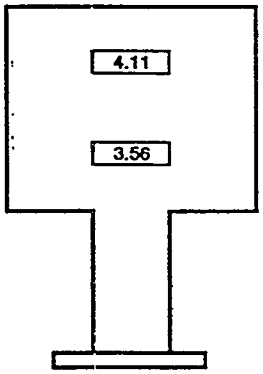
Average = 9.70 ± 0.92 g/dscm

Mass Concentration Profile
lb/MBtu



Average = 7.62 ± 0.79 lb/MBtu

Mass Concentration Profile
gr/scf (wet)

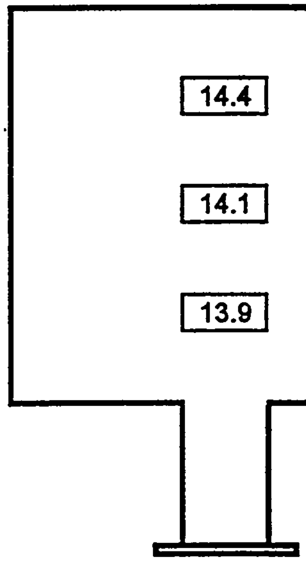


Average = 3.83 ± 0.39 gr/scf (wet)

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

REACTOR D
CATALYST LAYER 1 INLET

Velocity Profile
ft/s



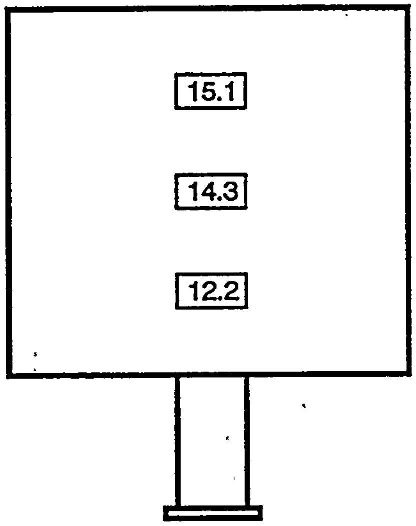
Average = 14.1 ± 0.3 ft/s

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 SO_2 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 SO_2 oxidation rate. Published rate equations and catalyst supplier information indicate that the general form of the plot should be linear with SO_2 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 SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 deposition occur in the test facility reactors. The general trend of increasing SO_2 oxidation is expected, however, and the plots provide a good basis for determining the potential for SO_3 formation across the SCR reactor at various operating temperatures.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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% O_2, dry) were 226 ± 4 ppmv and 233 ± 5 ppmv respectively. The N_2O 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% O_2).[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

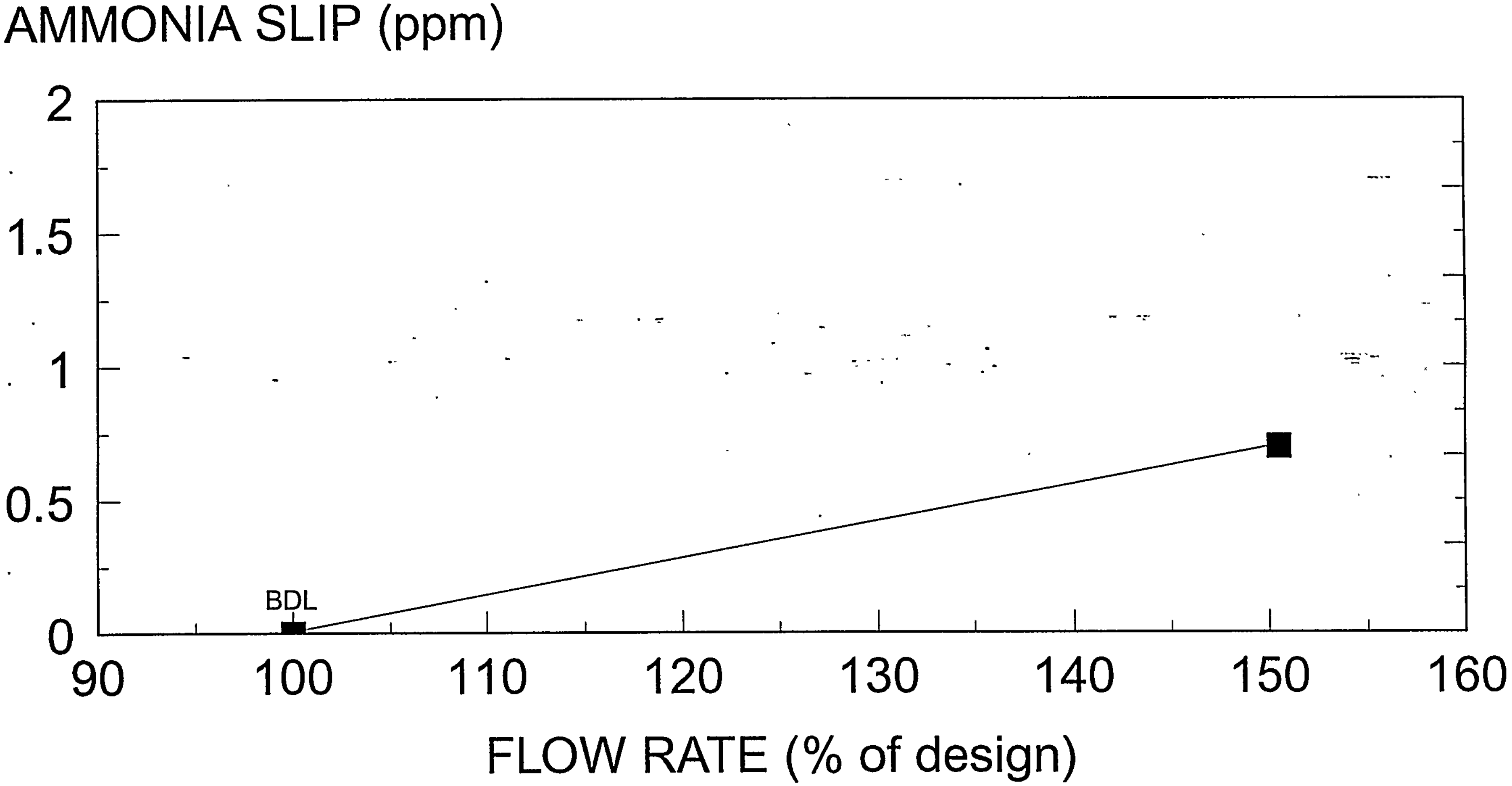
FLOW RATE (SCFM)	TEMP . (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS. SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
408	704	3.283	1751	0.802	2.8	9.2	6.4	0.36
624	704	4.101	1678	0.804	0.3	5.7	5.4	0.32
408	749	3.377	1720	0.807	1.2	10.5	9.3	0.54

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

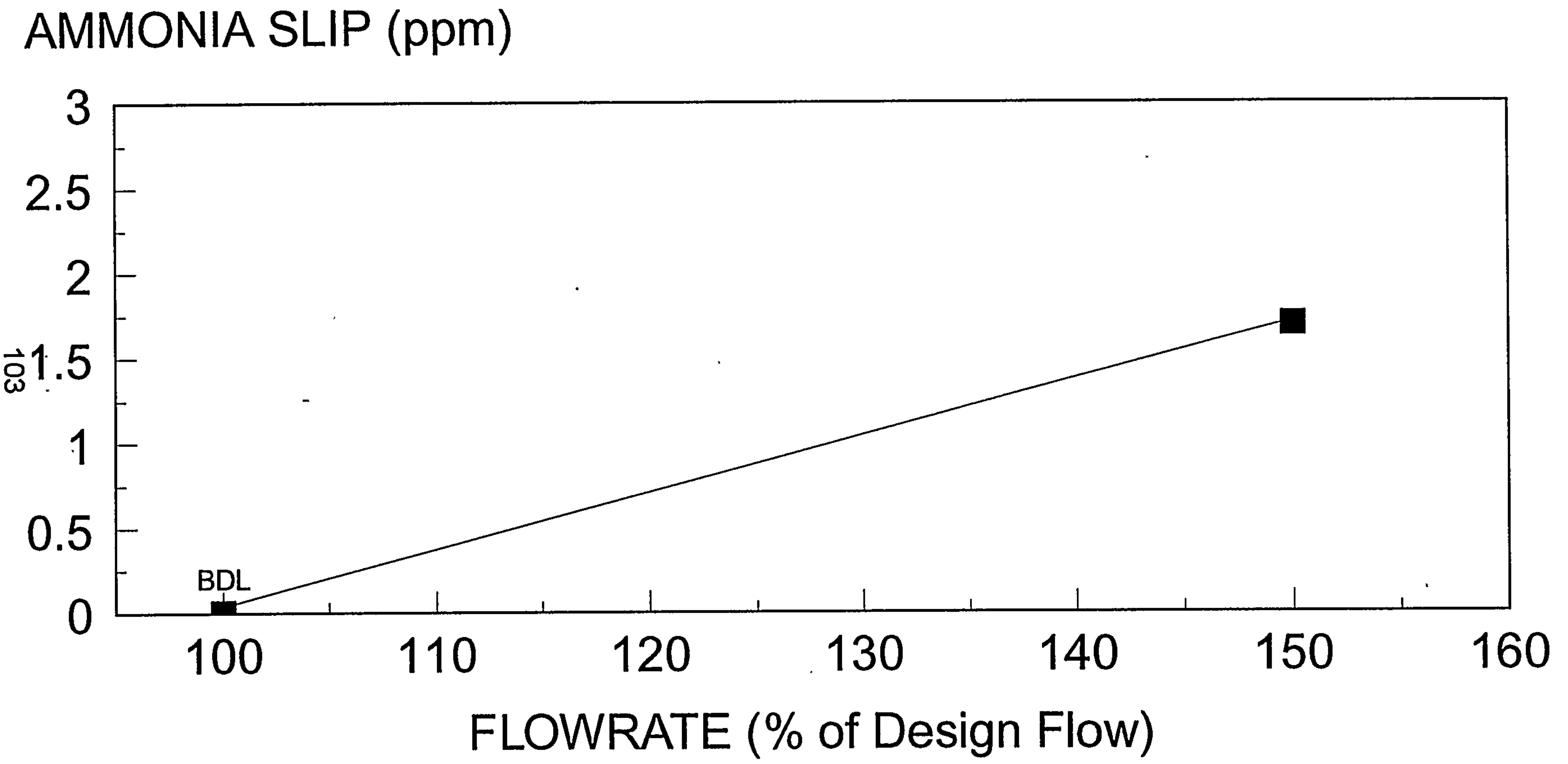


CORM. HD: 700 F, NH3/NOx=0.8

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

FIGURE 32b

AMMONIA SLIP VS. FLOW RATE

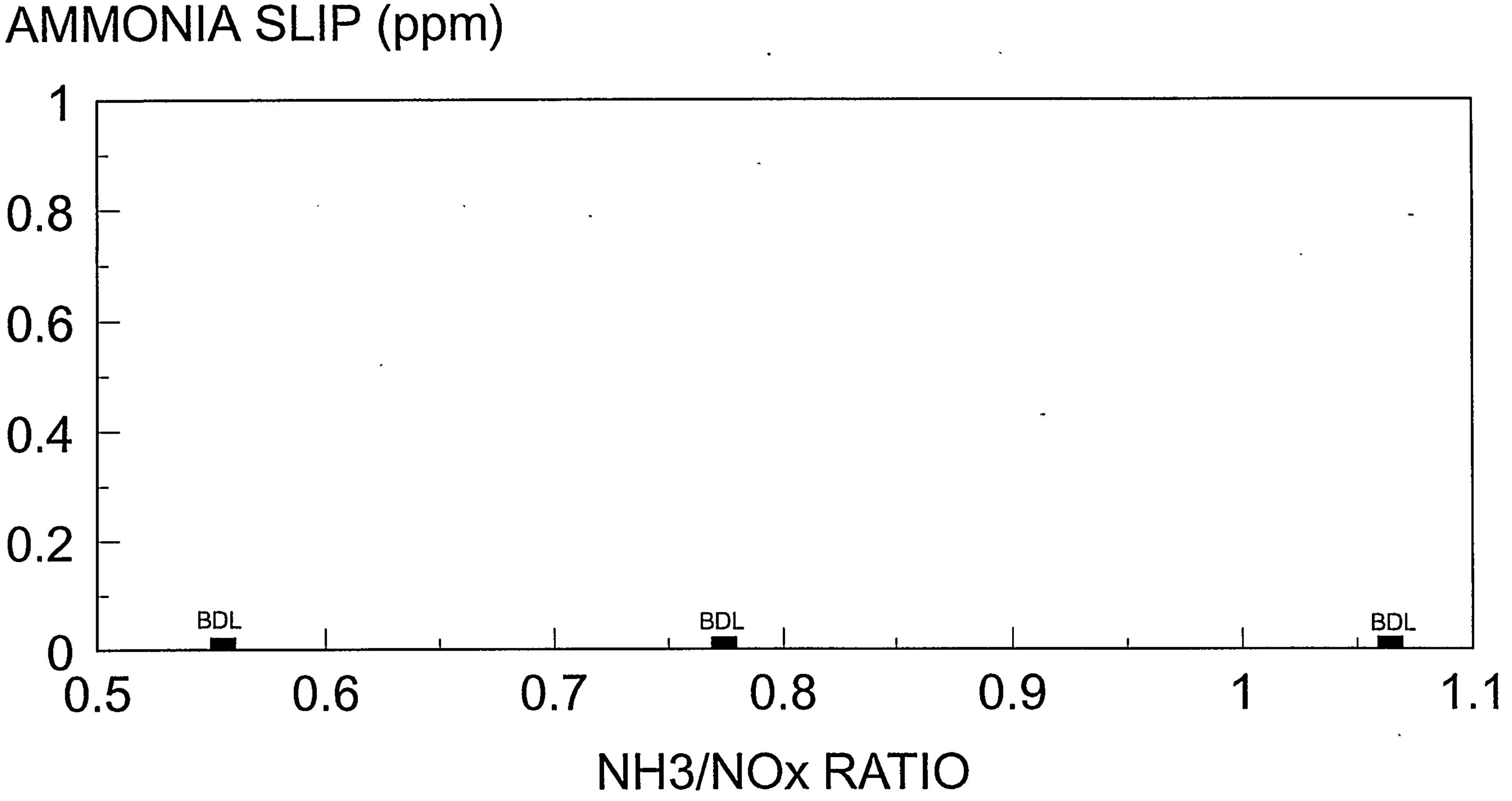


CORM HD: NH3/NOx=0.80, 700 F

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

FIGURE 33a

AMMONIA SLIP VS. NH3/NOx RATIO

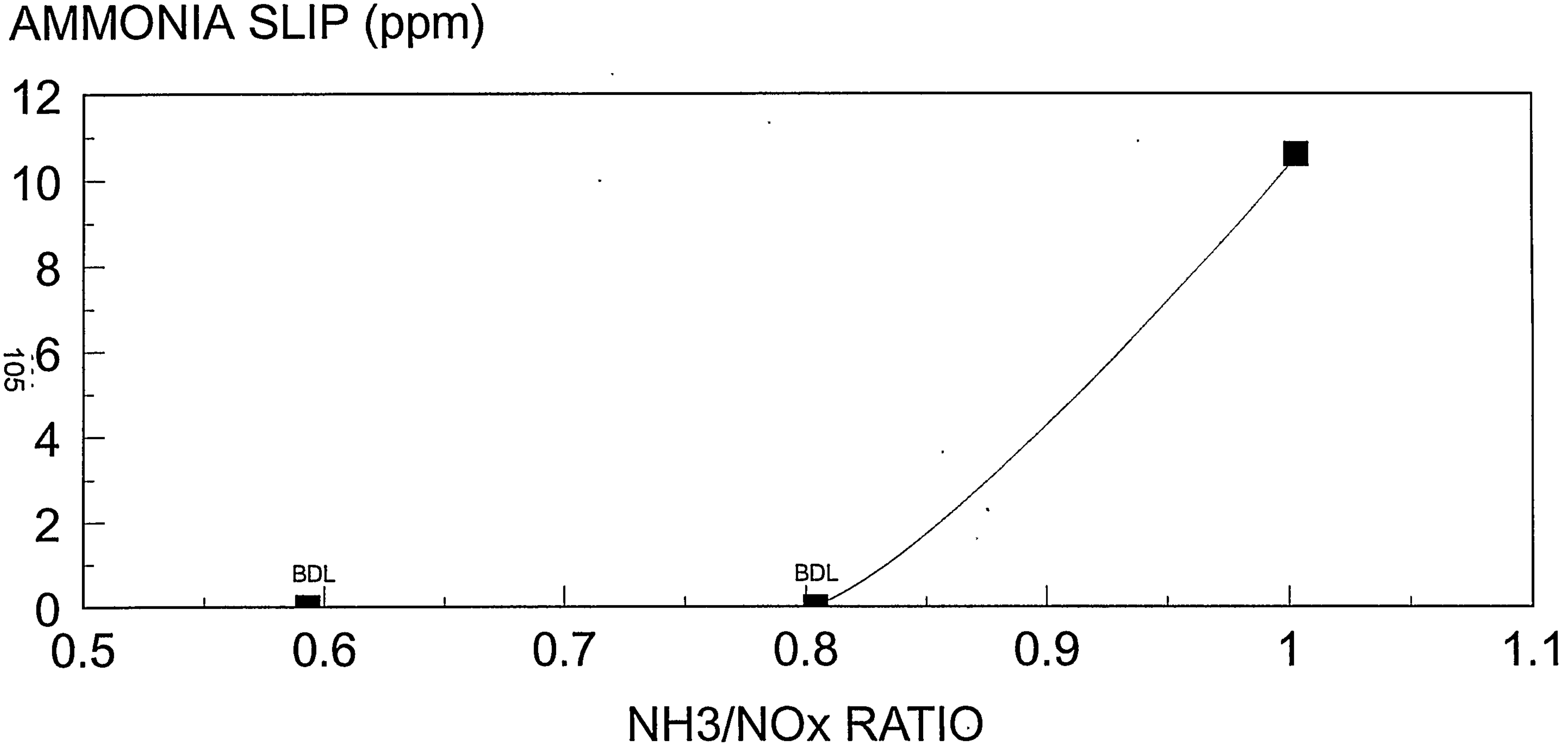


CORM HD: DESIGN FLOW, 620F

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

FIGURE 33b

AMMONIA SLIP VS. NH3/NOx RATIO

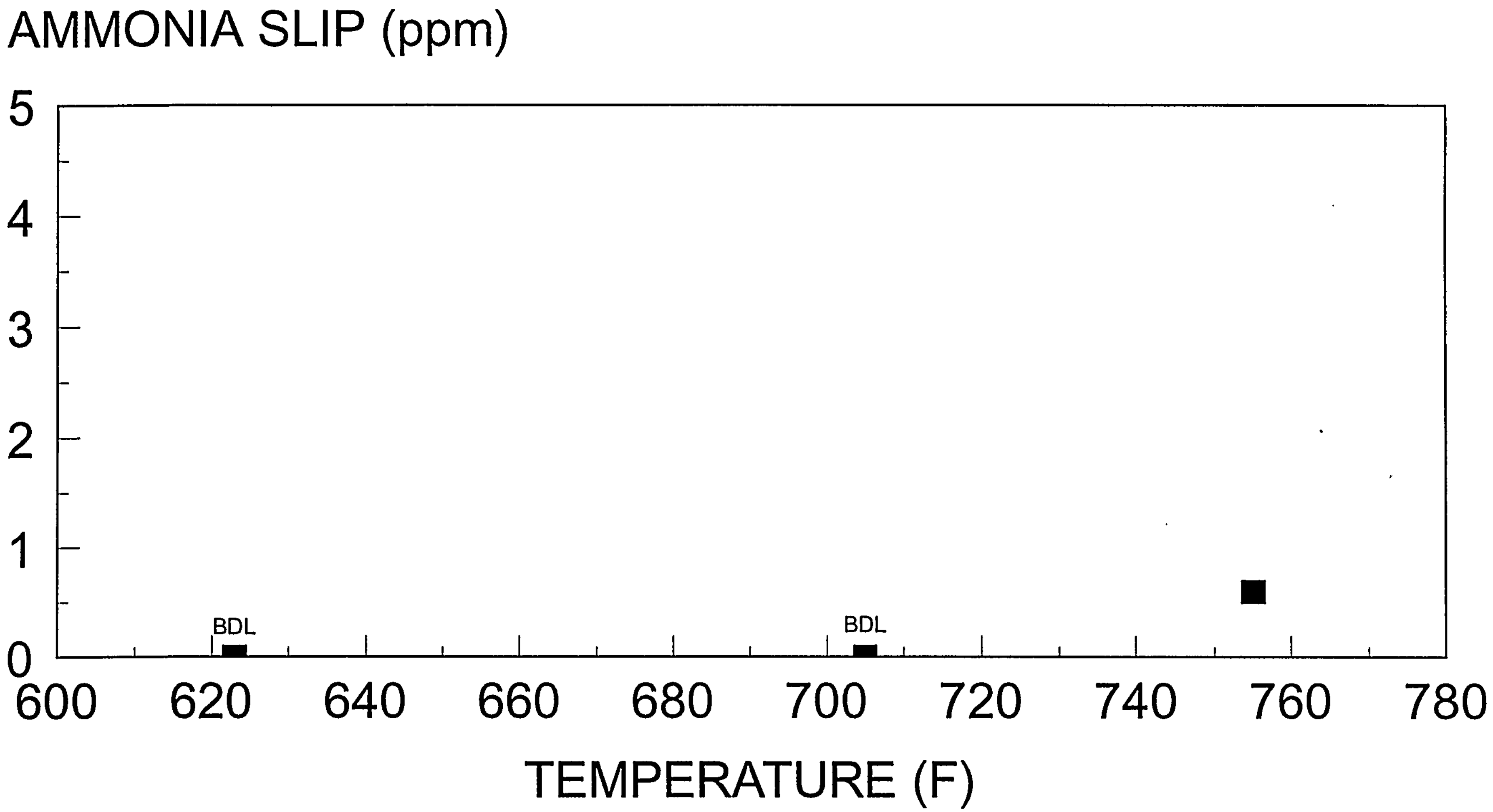


CORM HD: Design Flow, 620 F

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

FIGURE 34a

AMMONIA SLIP VS. TEMPERATURE

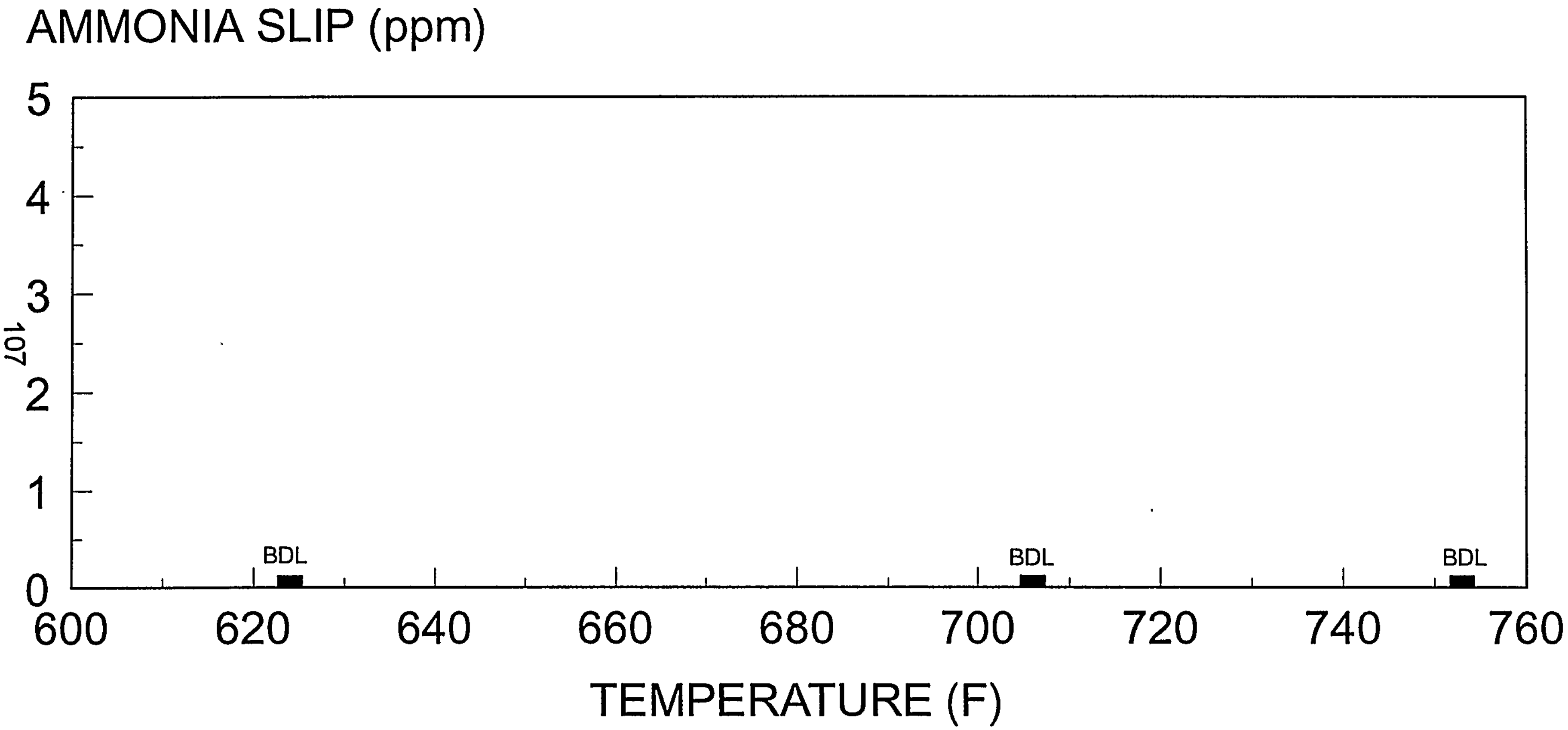


CORM HD: DESIGN FLOW, NH3/NOx=0.8

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

FIGURE 34b

AMMONIA SLIP VS. TEMPERATURE

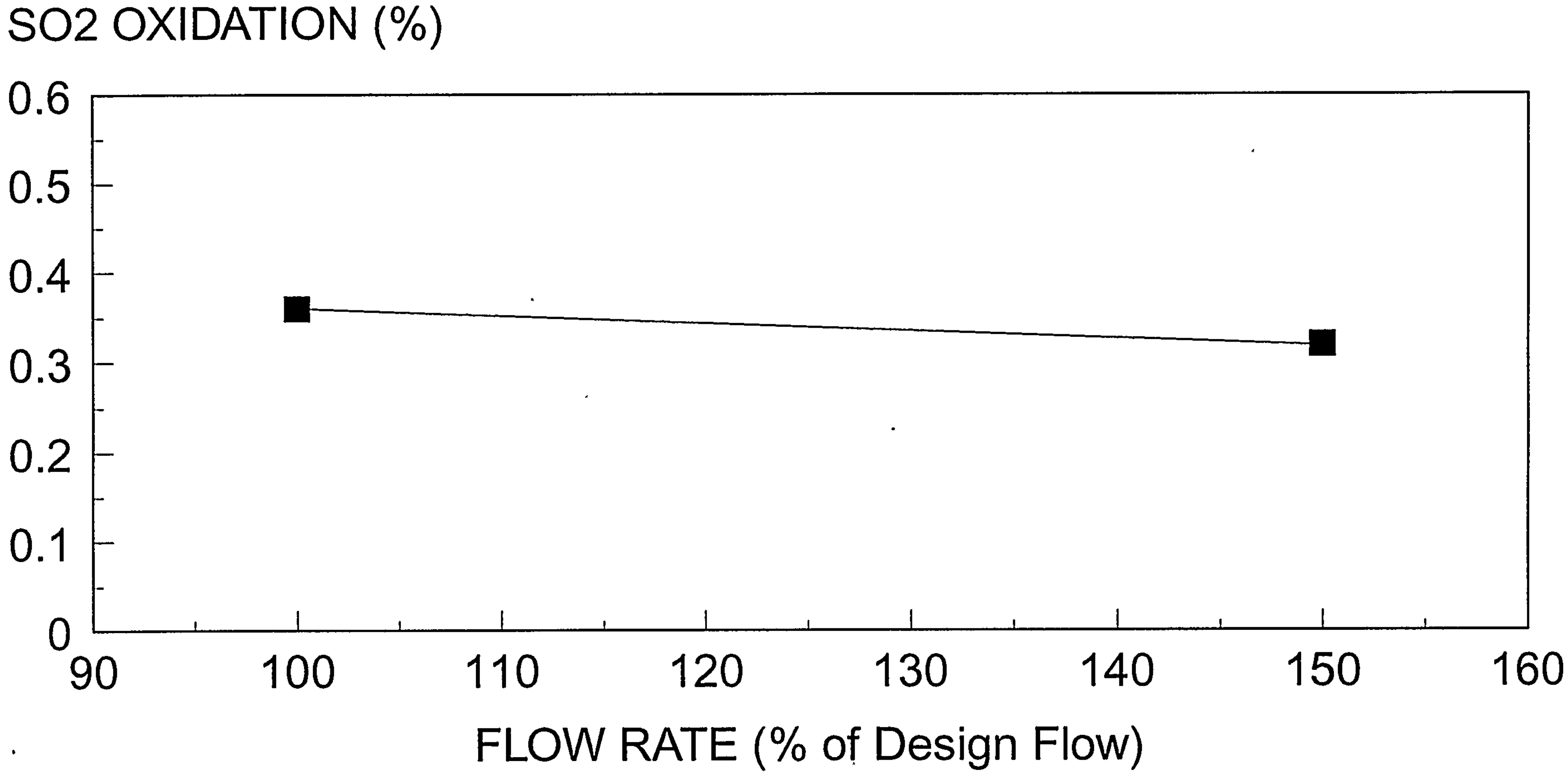


CORM HD: NH3/NOx=0.80, Design Flow

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

FIGURE 35

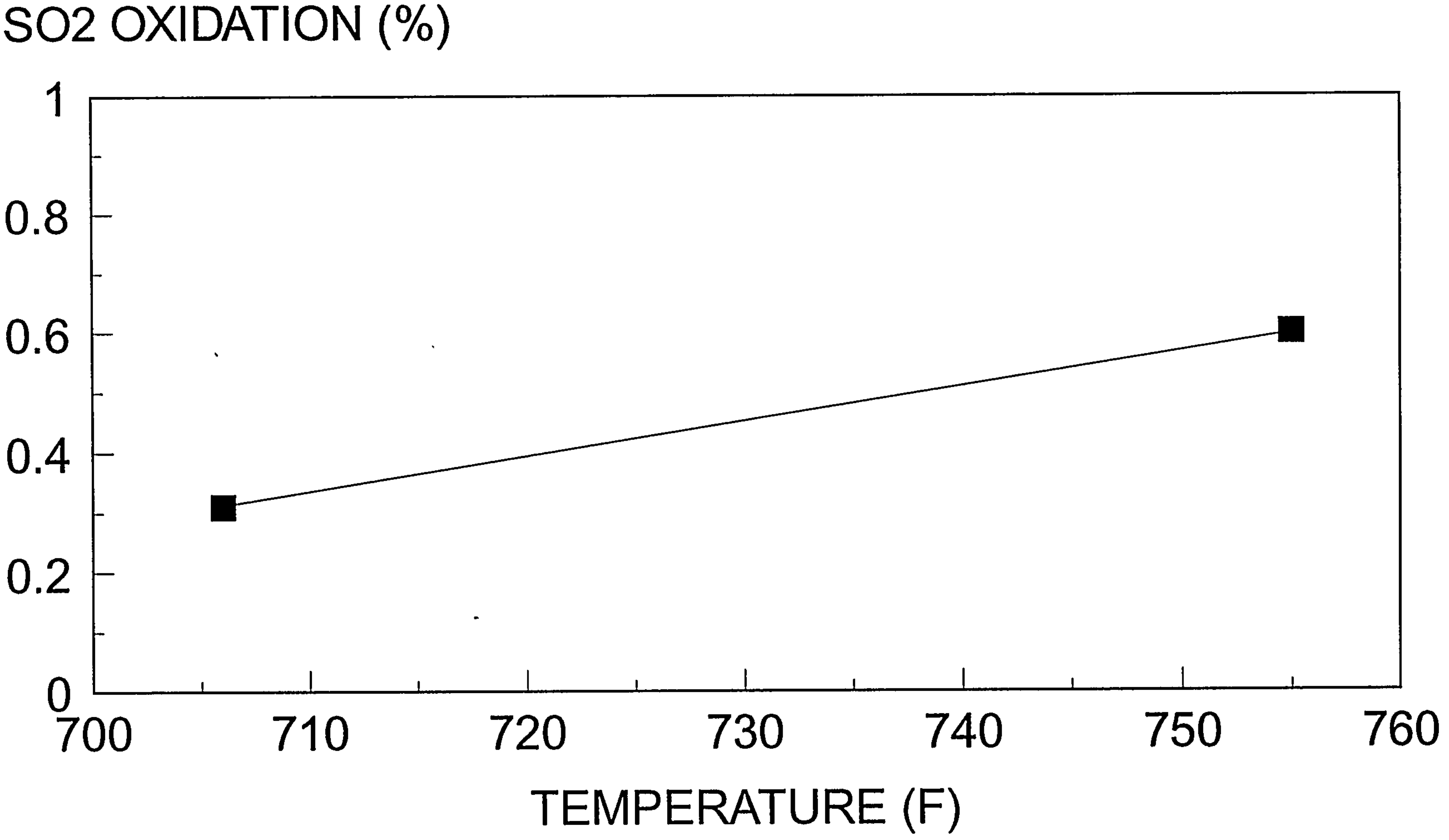
SO2 OXIDATION VS. FLOWRATE



CORM HD: NH3/NOx=0.80, 700 F

FIGURE 36a

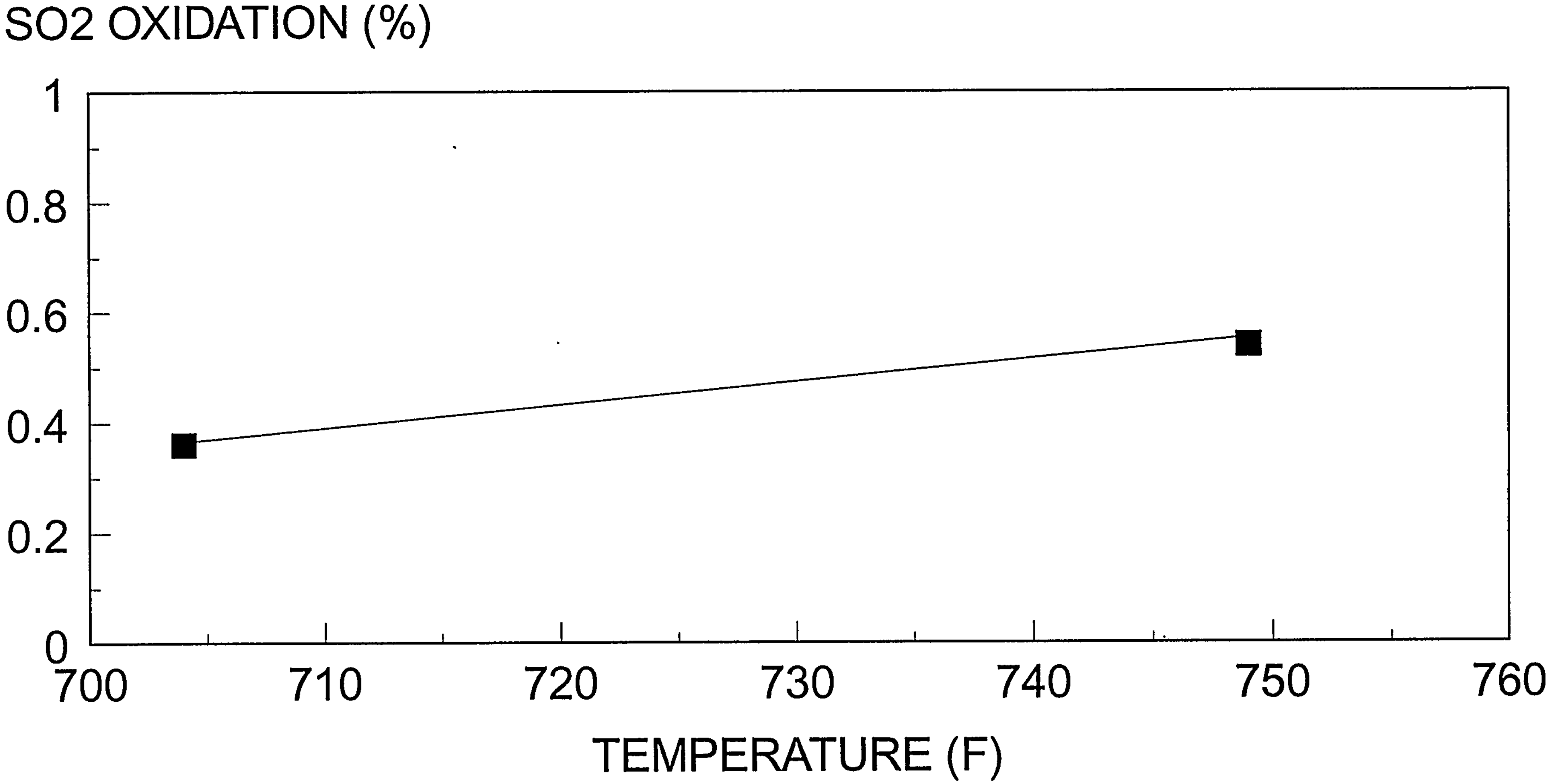
SO2 OXIDATION VS. TEMPERATURE



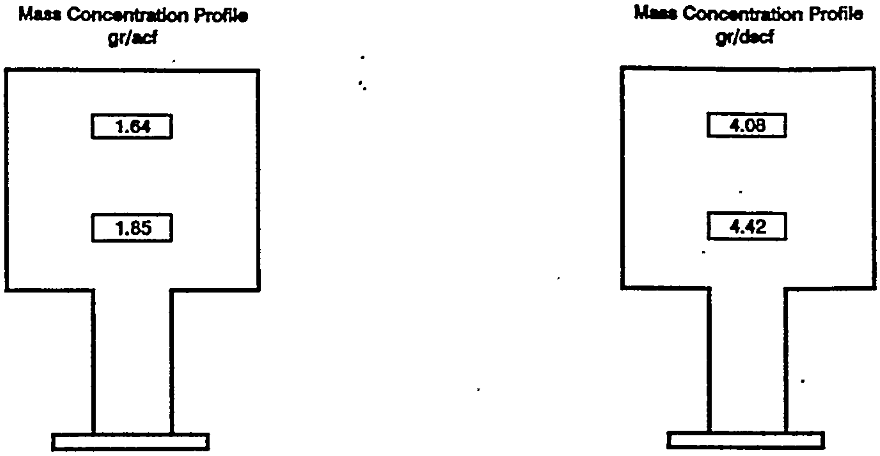
CORM HD: DESIGN FLOW, NH3/NOx=0.8

FIGURE 36b

SO2 OXIDATION VS. TEMPERATURE



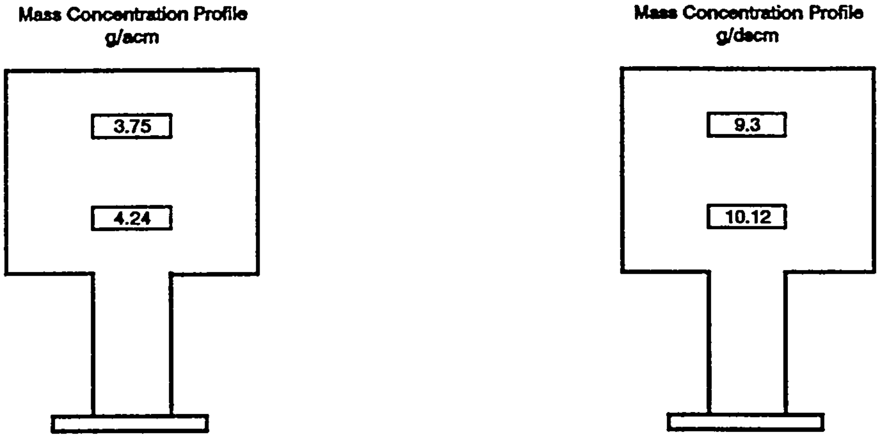
CORM HD: Design Flow, NH3/NOX=0.80


Mass Concentration Profile gr/acf

Mass Concentration Profile gr/dscf

Average = 1.75 ± 0.15 gr/acf

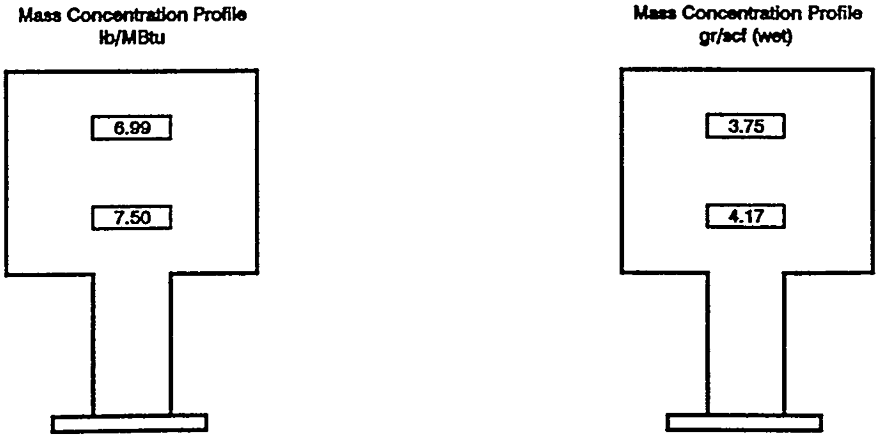
Average = 4.25 ± 0.25 gr/dscf


Mass Concentration Profile g/acm

Mass Concentration Profile g/dscm

Average = 4.00 ± 0.35 g/acm

Average = 9.73 ± 0.56 g/dscm


Mass Concentration Profile lb/MBtu

Mass Concentration Profile gr/acf (wet)

Average = 7.25 ± 0.36 lb/MBtu

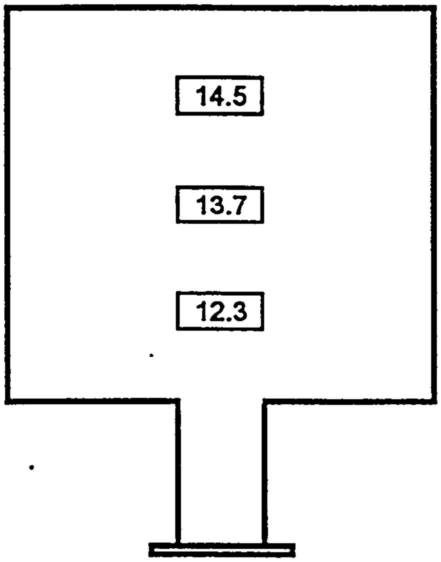
Average = 3.96 ± 0.30 gr/scf (wet)

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

REACTOR E

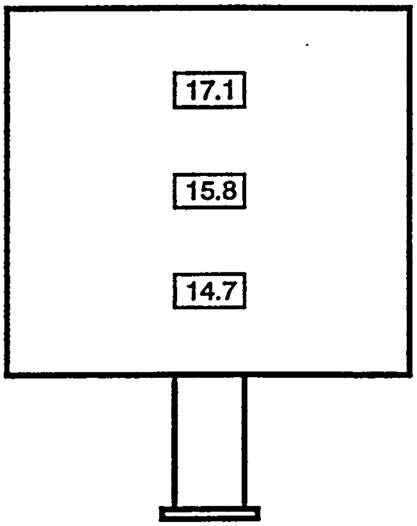
CATALYST LAYER 1 INLET

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 SO_2 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 SO_2 oxidation rate. Published rate equations and catalyst supplier information indicate that the general form of the plot should be linear with SO_2 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 SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 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 SO_2 oxidation potential.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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% O_2, dry) were 241 ± 13 ppmv and 250 ± 9 ppmv respectively. The N_2O 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% O_2).[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

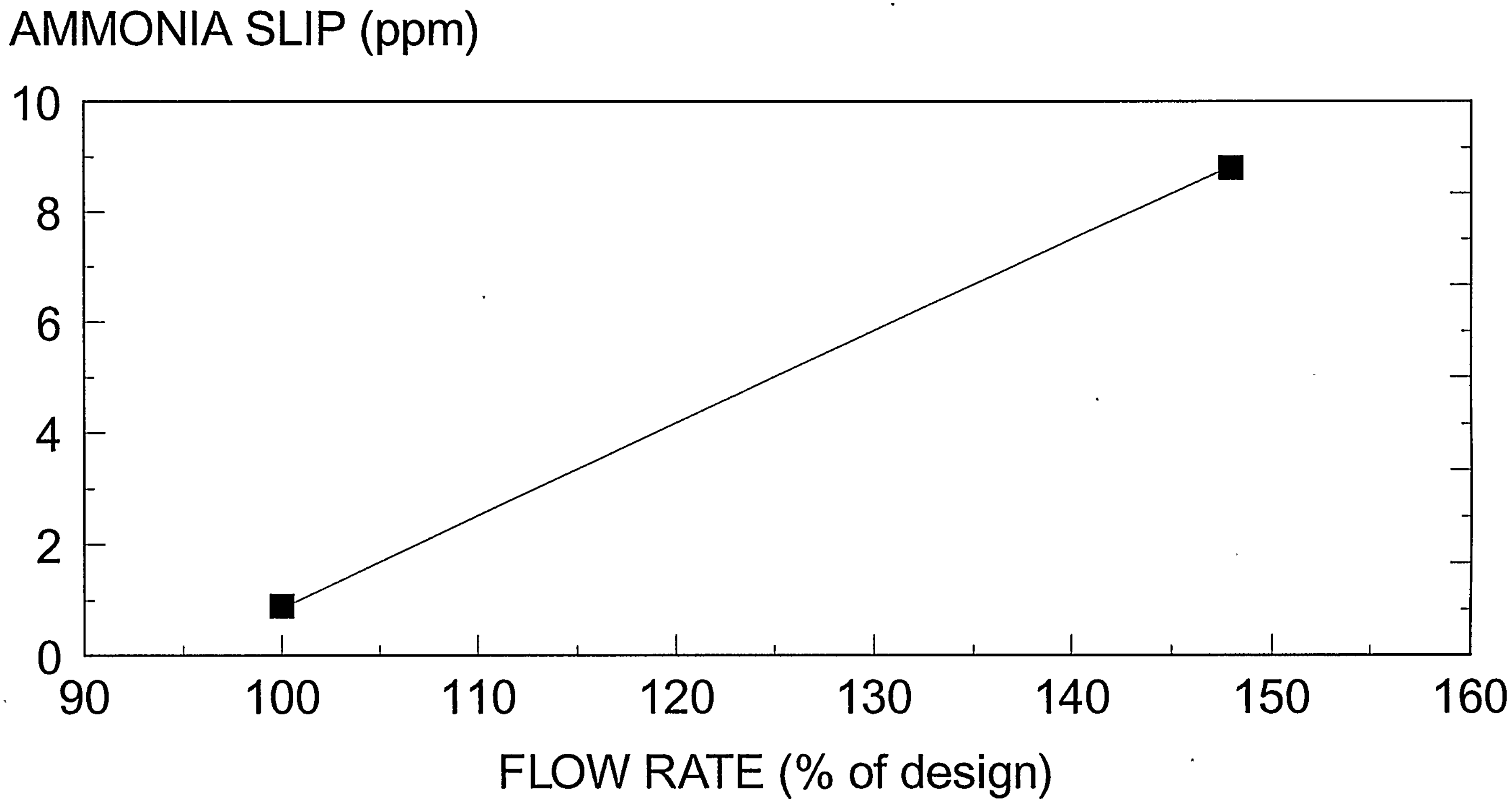
FLOW RATE (SCFM)	TEMP (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS. SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
432	706	4.236	1784	0.804	0.7	0.9	0.2	0.01
631	705	5.616	1554	0.800	1.2	0.2	-1.0	-0.07
431	758	3.994	1779	0.804	0.7	0.7	0.0	0.00

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



HALDOR: 700 F, NH3/NOx=0.8

FIGURE 39b

AMMONIA SLIP VS. FLOW RATE

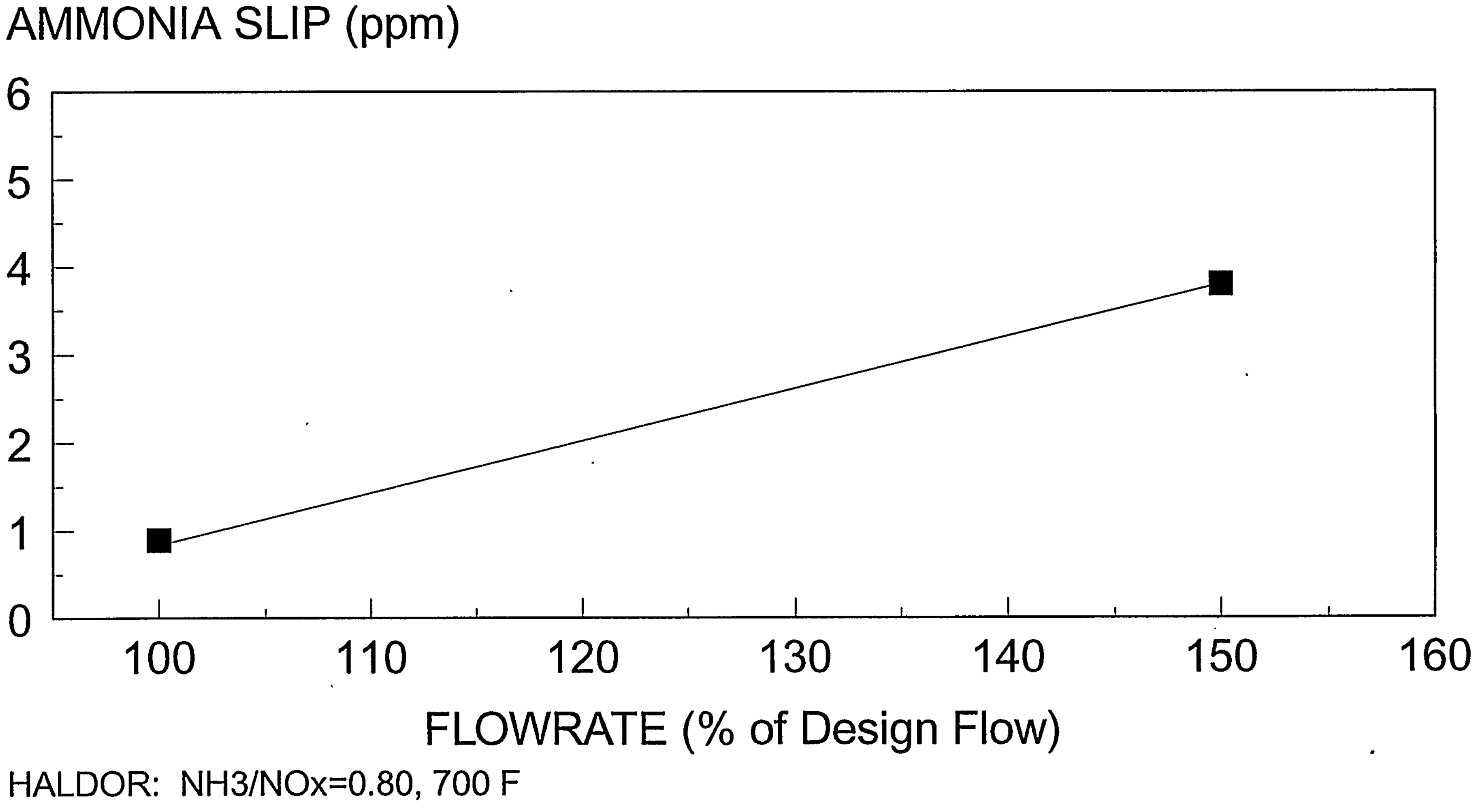
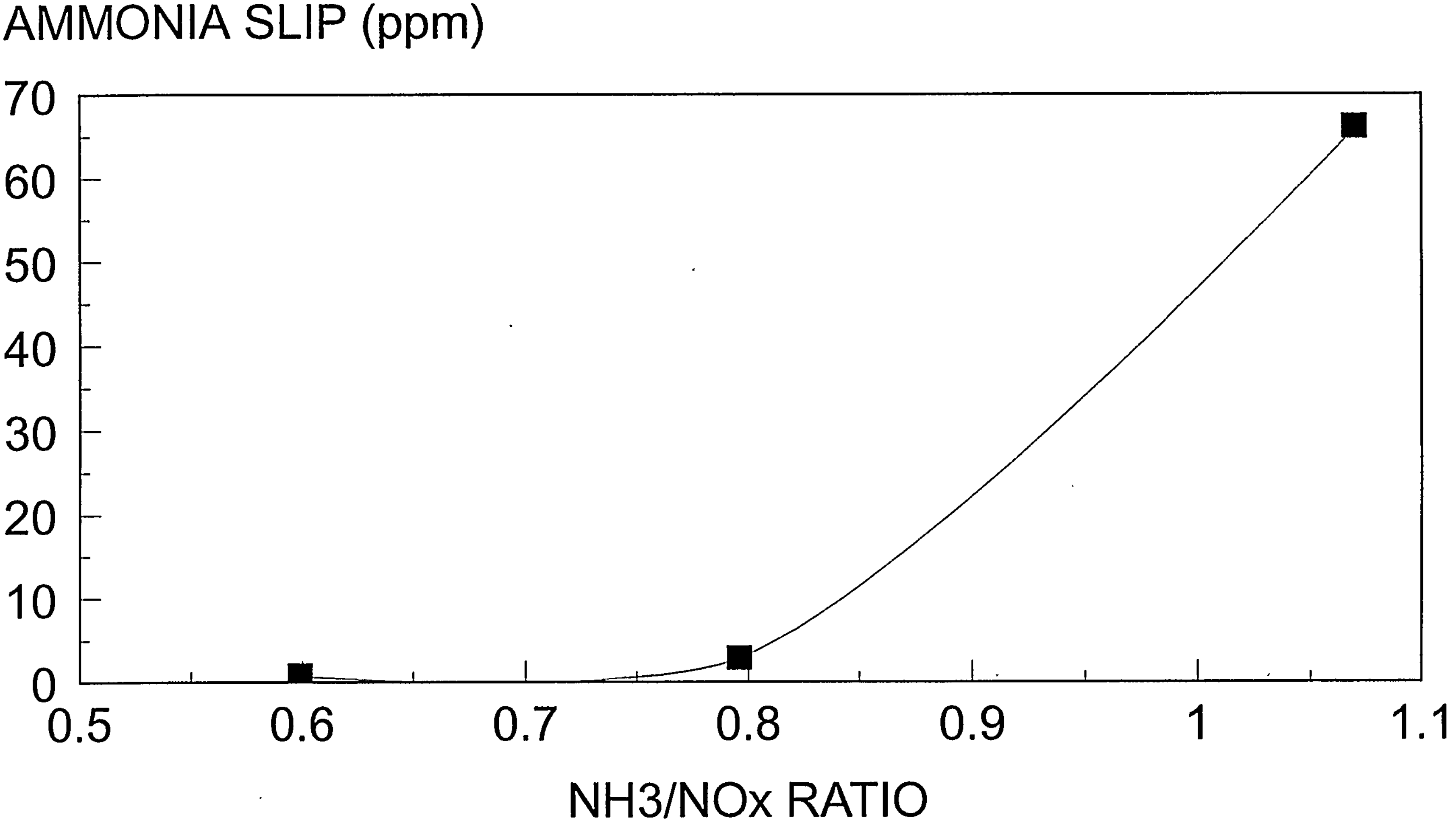


FIGURE 40a

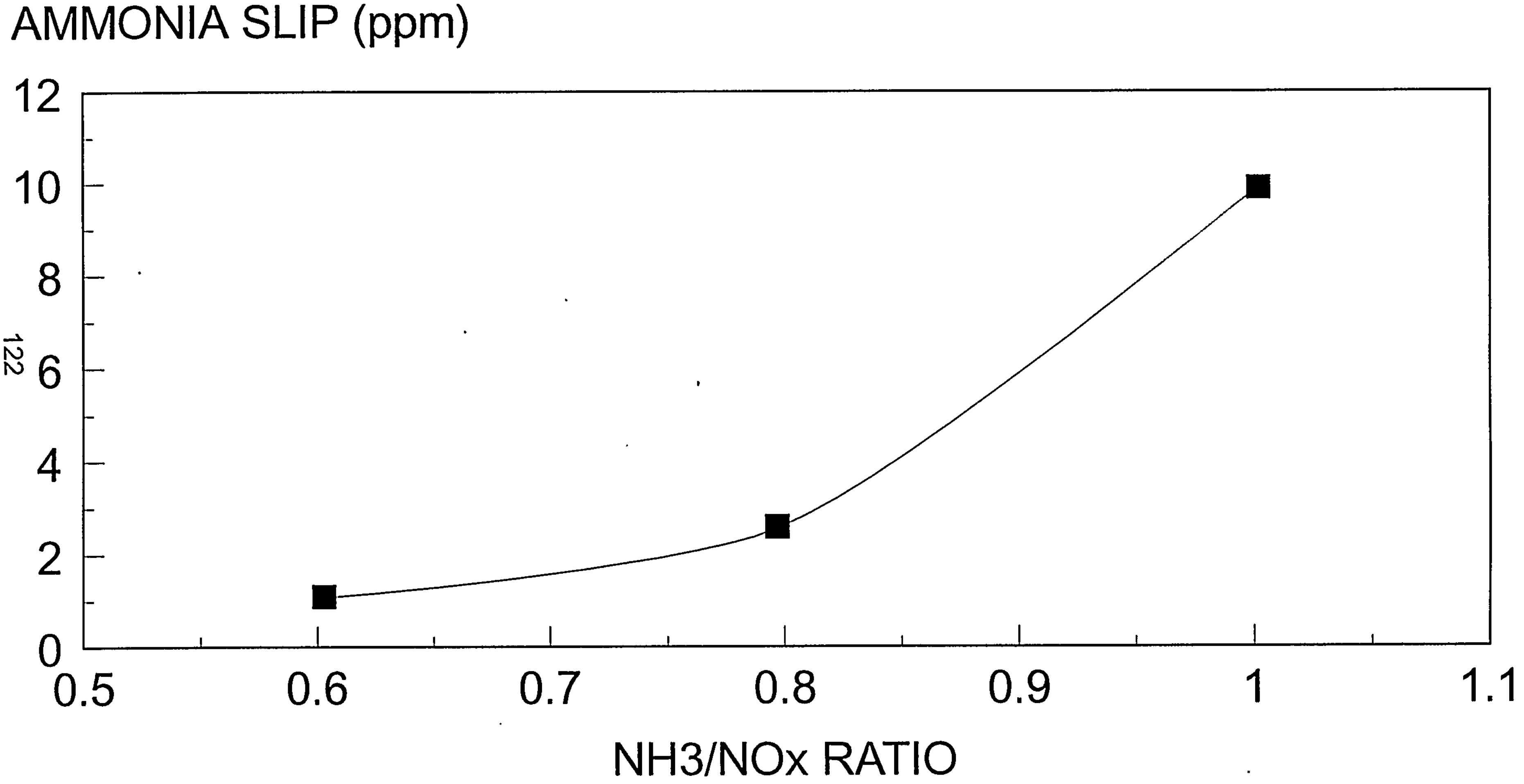
AMMONIA SLIP VS. NH3/NOx RATIO



HALDOR: DESIGN FLOW, 620F

FIGURE 40b

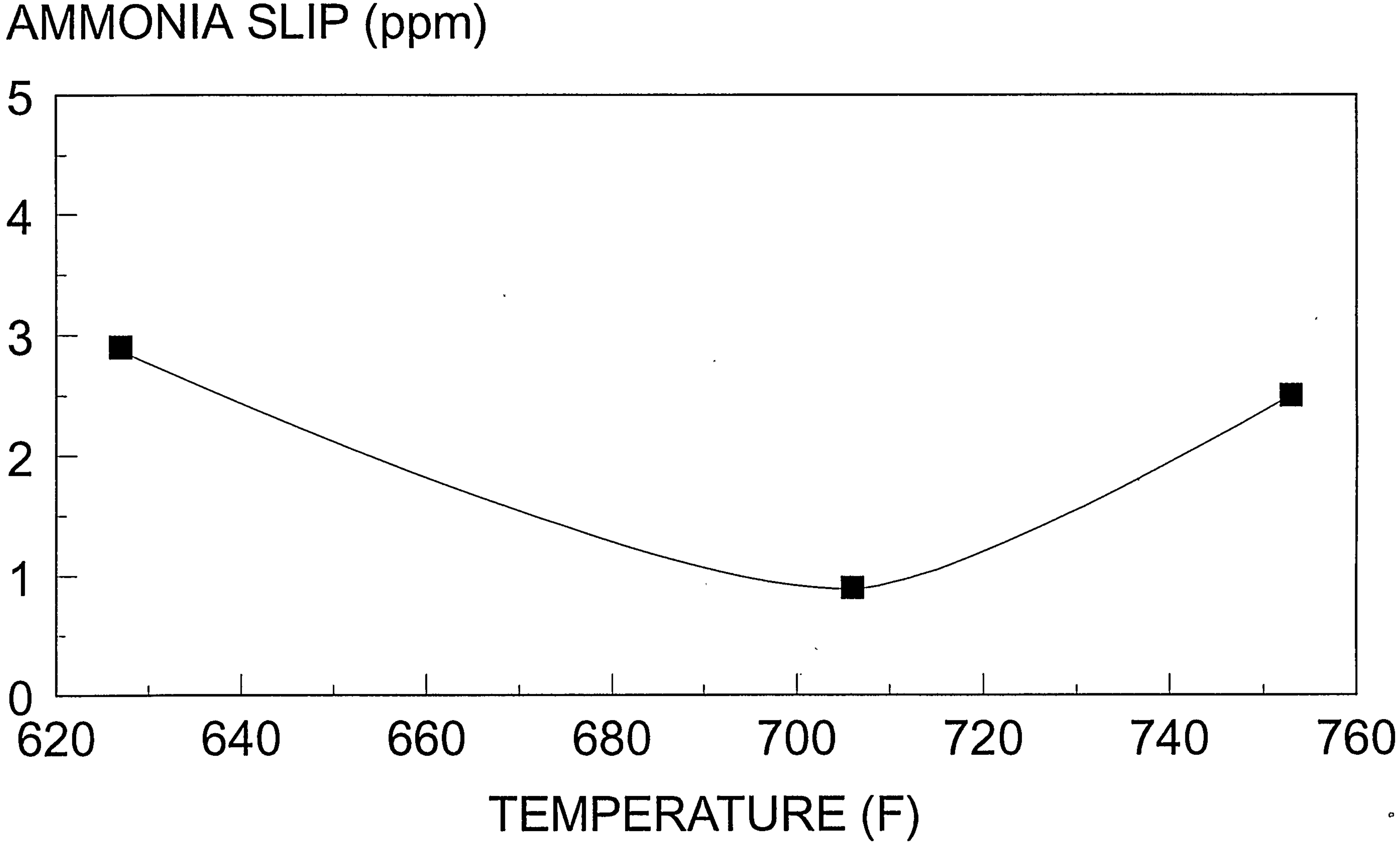
AMMONIA SLIP VS. NH3/NOx RATIO



HALDOR: Design Flow, 620 F

FIGURE 41a

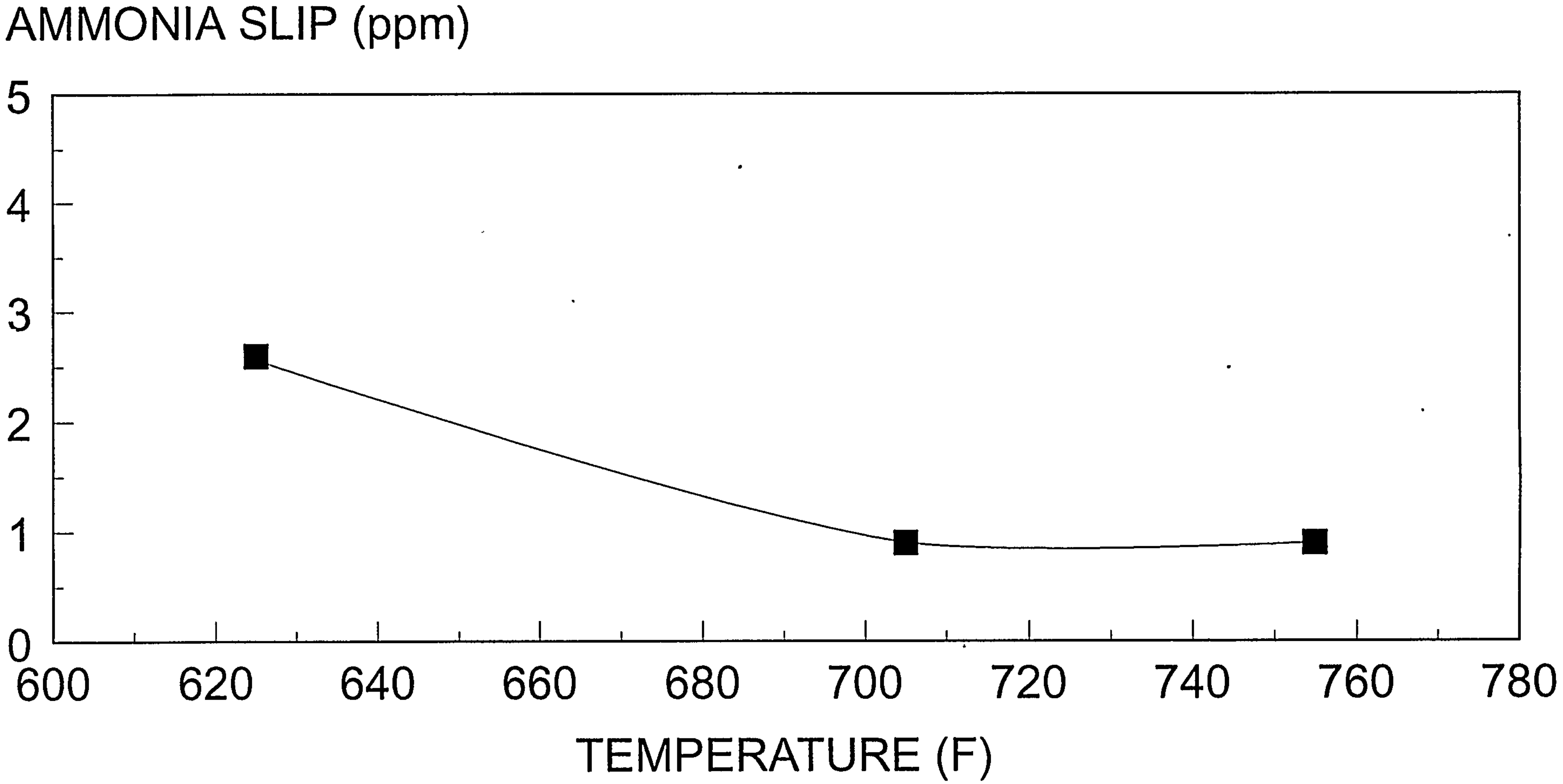
AMMONIA SLIP VS. TEMPERATURE



HALDOR: DESIGN FLOW, NH3/NOx=0.8

FIGURE 41b

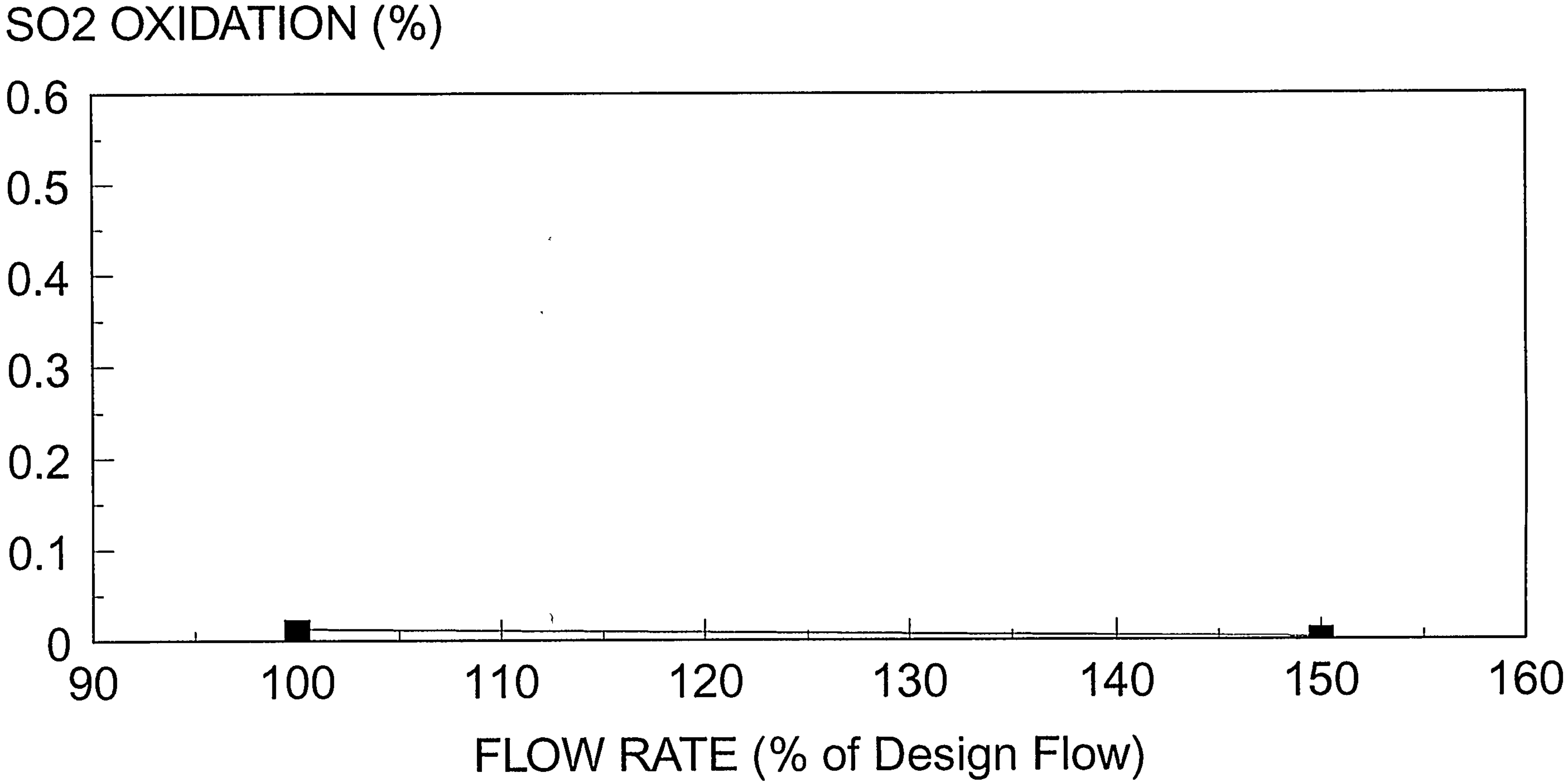
AMMONIA SLIP VS. TEMPERATURE



HALDOR: NH3/NOx=0.80, Design Flow

FIGURE 42

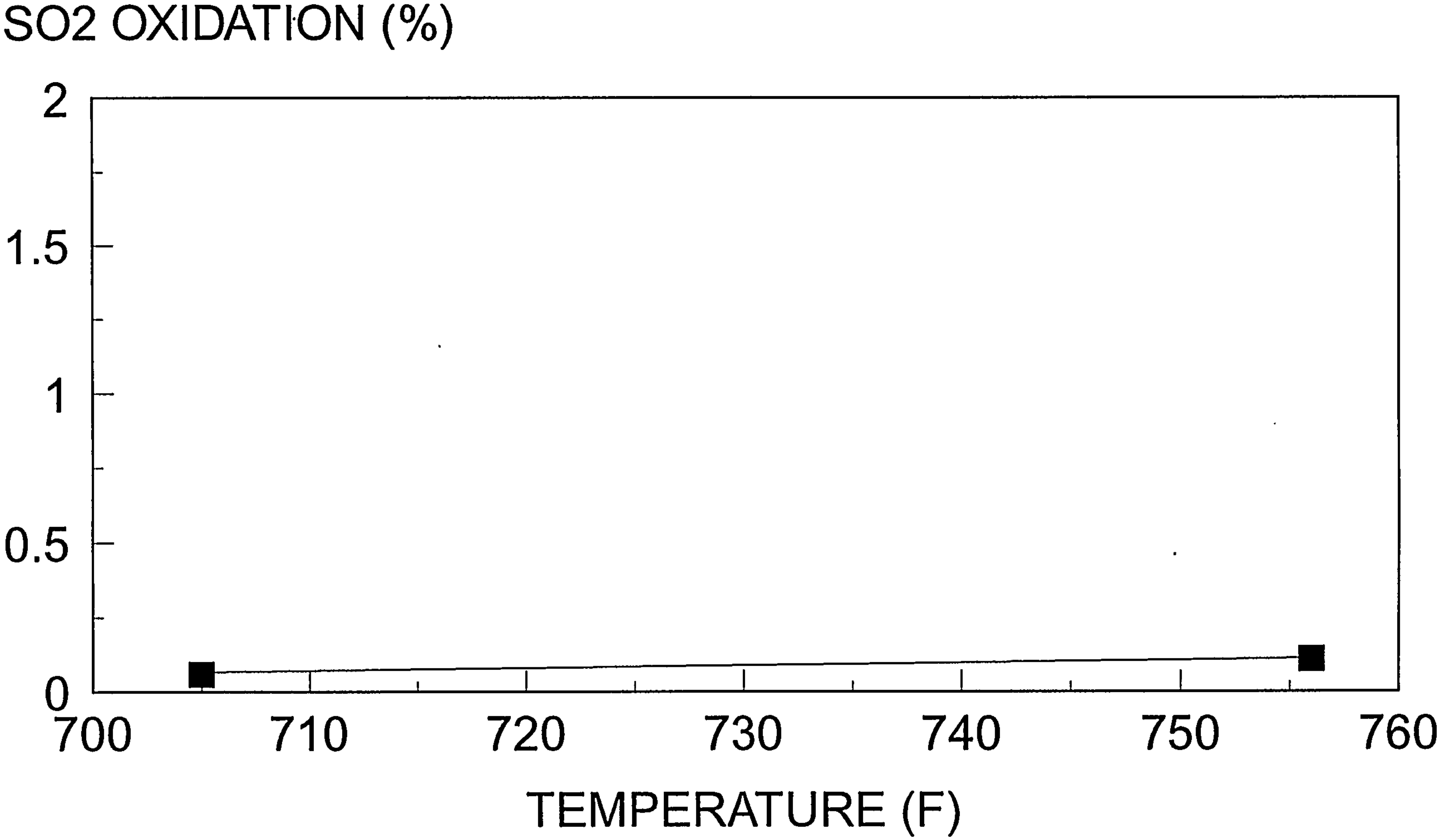
SO2 OXIDATION VS. FLOWRATE



HALDOR: NH3/NOx=0.80, 700 F

FIGURE 43a

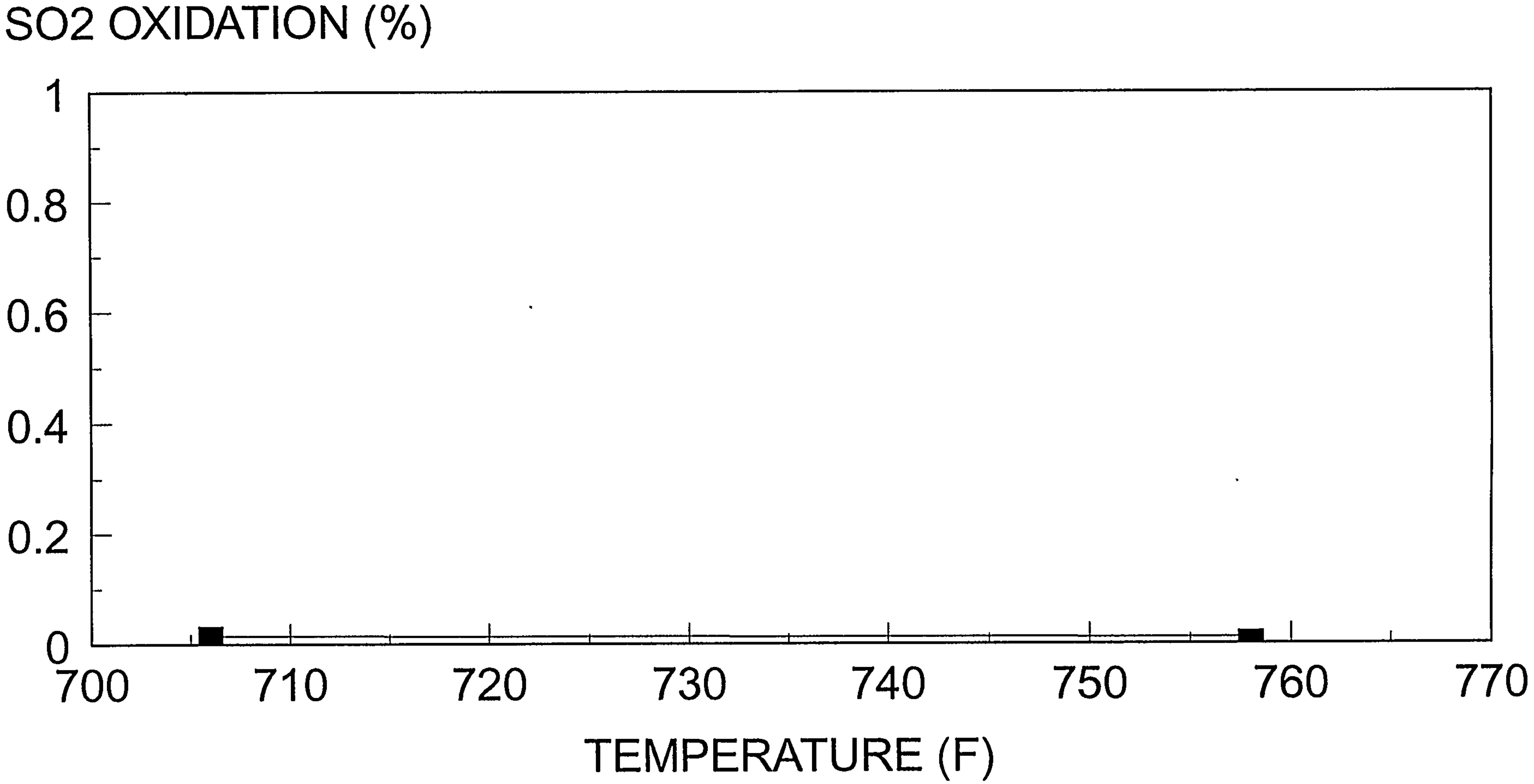
SO2 OXIDATION VS. TEMPERATURE



HALDOR: DESIGN FLOW, NH3/NOx=0.8

FIGURE 43b

SO2 OXIDATION VS. TEMPERATURE



HALDOR: Design Flow, NH3/NOX=0.80

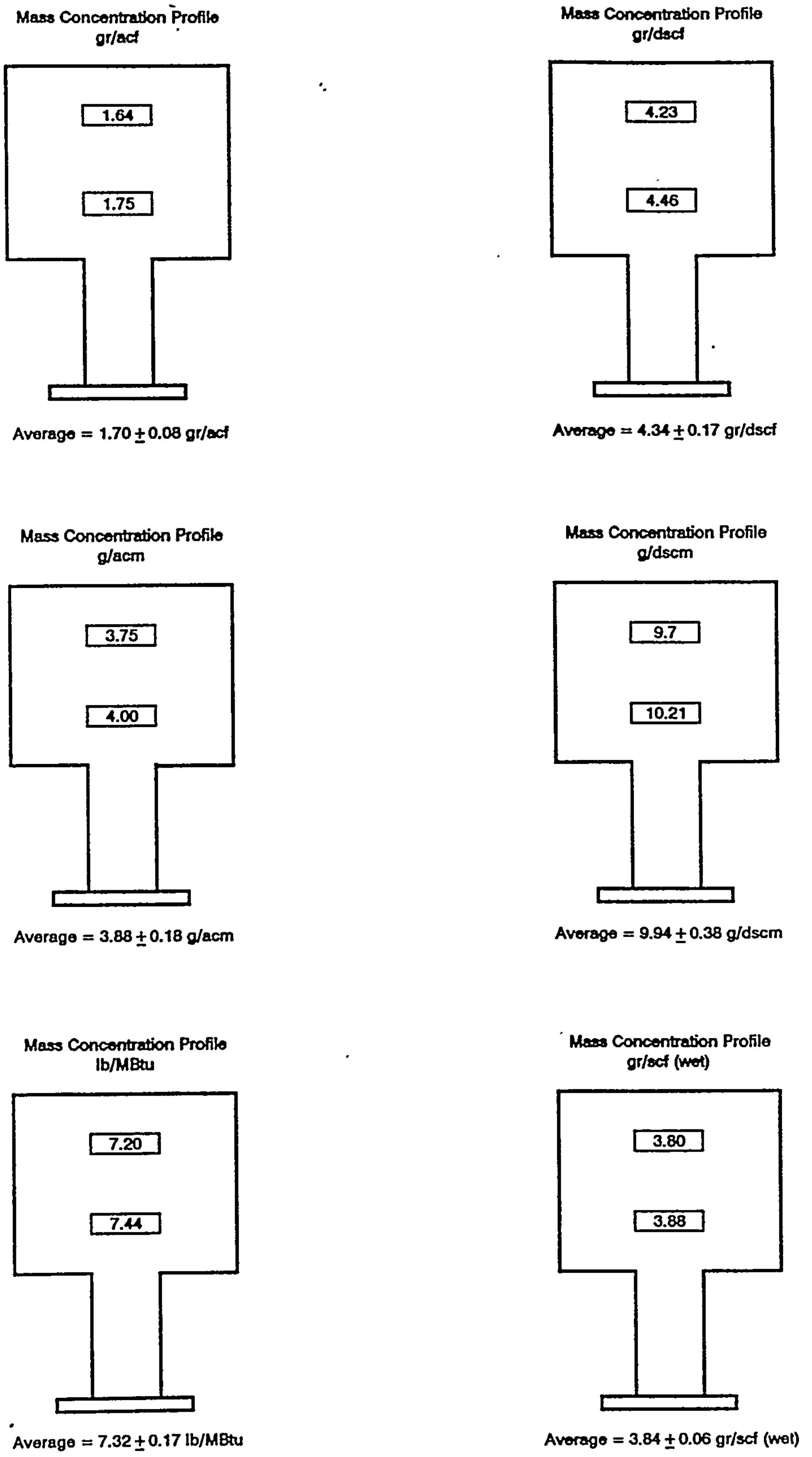
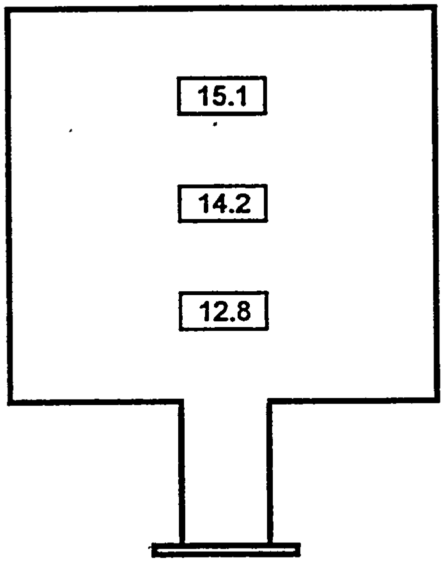


Figure 44. Six presentations of the Reactor F outlet mass concentration/mass emission profile.



REACTOR F
CATALYST LAYER 1 INLET

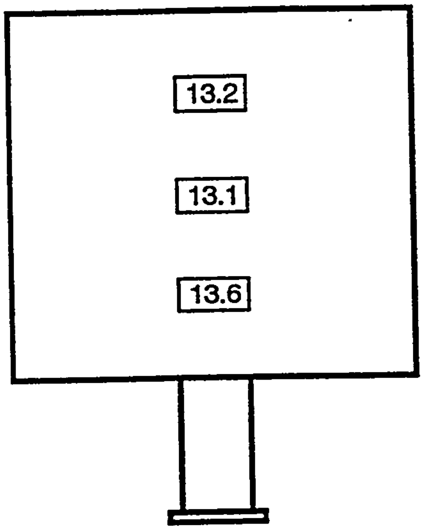
Velocity Profile
ft/s

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 SO_2 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 SO_2 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 SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 deposition occur in the test facility reactors. The general trend of increasing SO_2 oxidation is expected, however, and the plots provide a good basis for determining the potential for SO_3 formation across the SCR reactor at various operating temperatures.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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% O_2, dry) were 225 ± 5 ppmv and 256 ± 8 ppmv respectively. The N_2O 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% O_2).[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

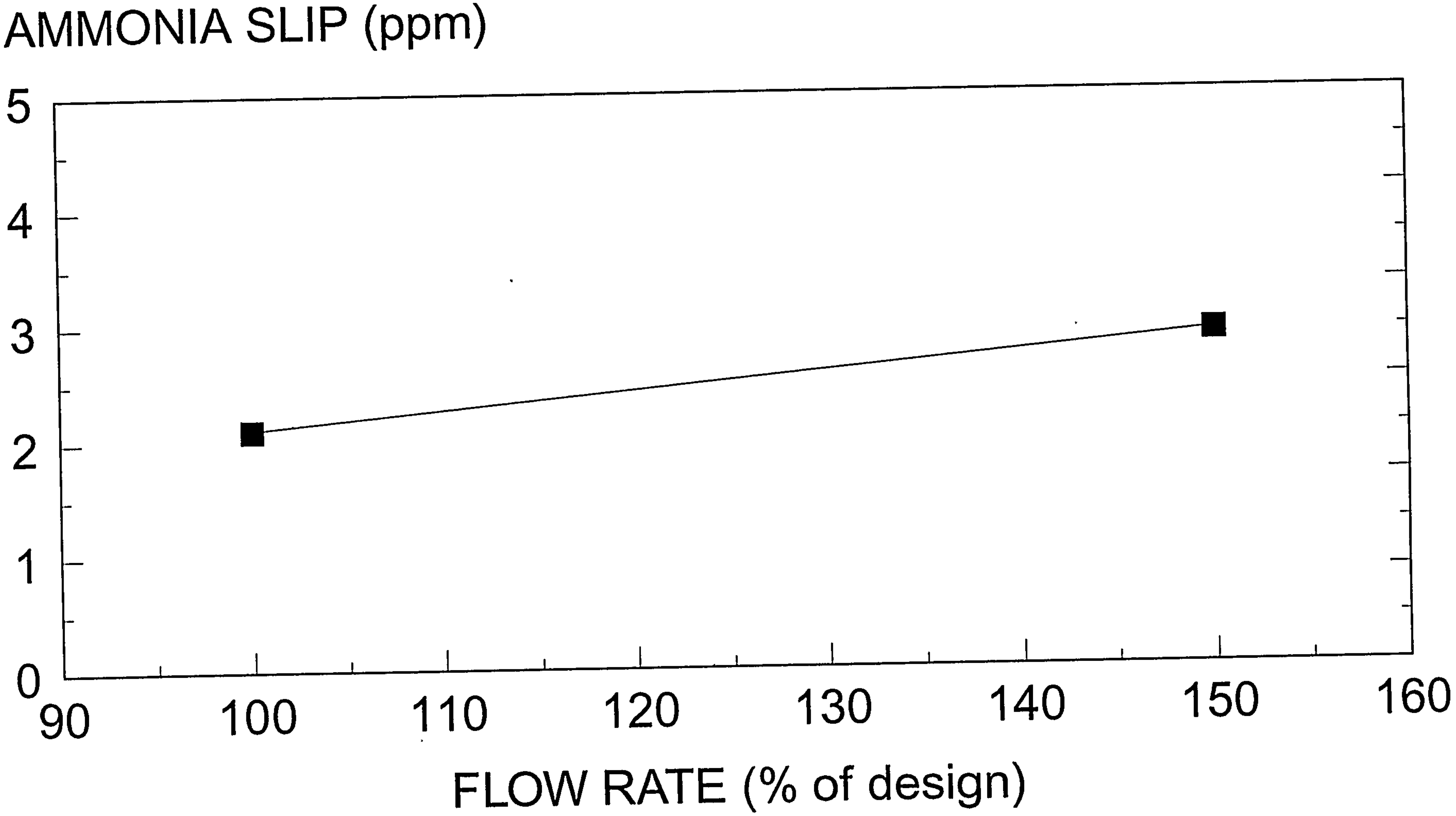
FLOW RATE (SCFM)	TEMP (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS. SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
467	705	5.646	1648	0.801	0.4	3.0	2.6	0.16
797	705	7.768	1642	0.800	2.0	2.9	0.9	0.05
493	757	6.722	1799	0.804	0.5	10.8	10.3	0.57

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

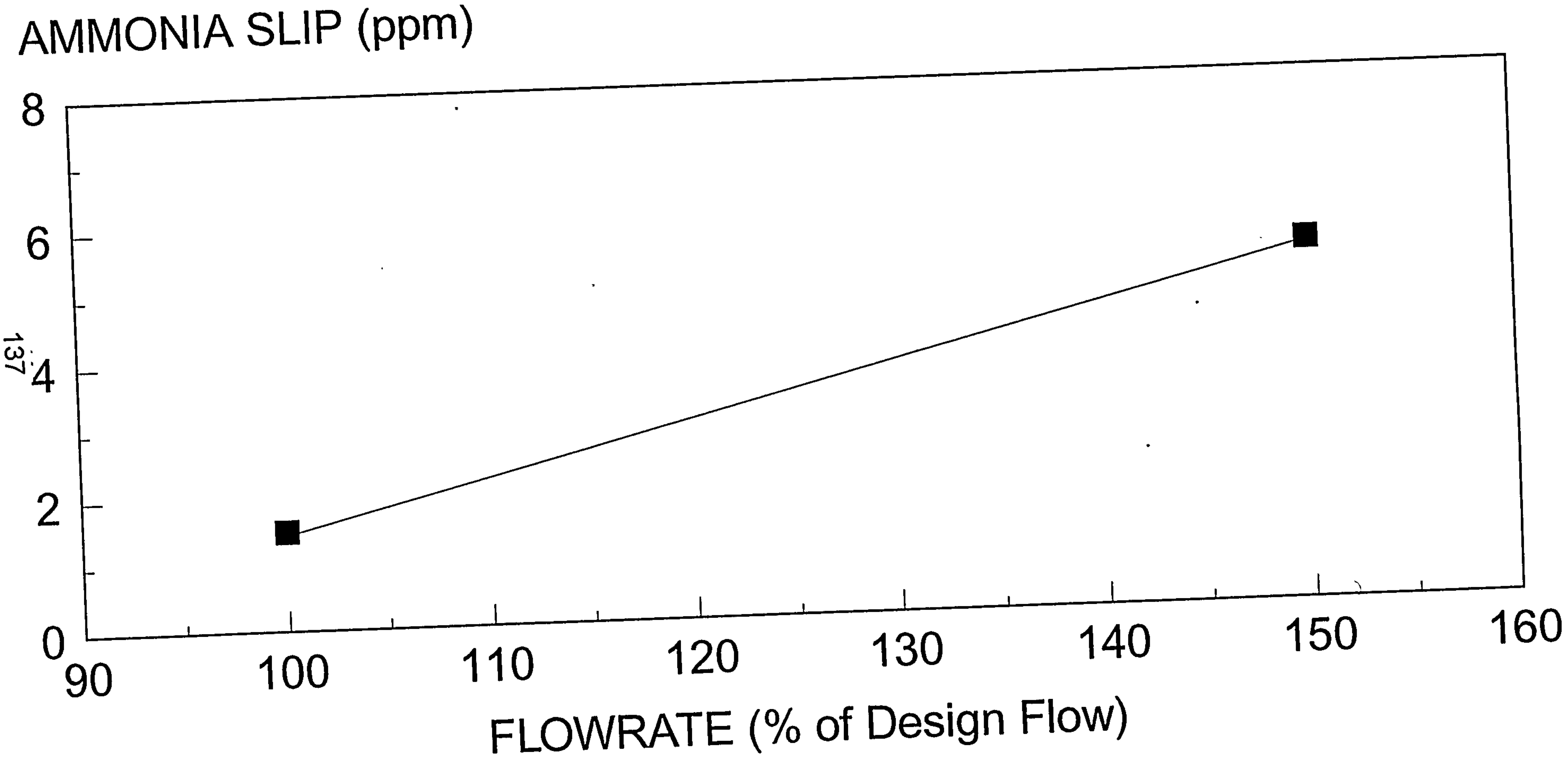
AMMONIA SLIP VS. FLOW RATE



HITACHI: 700 F, NH3/NOx=0.8

FIGURE 46b

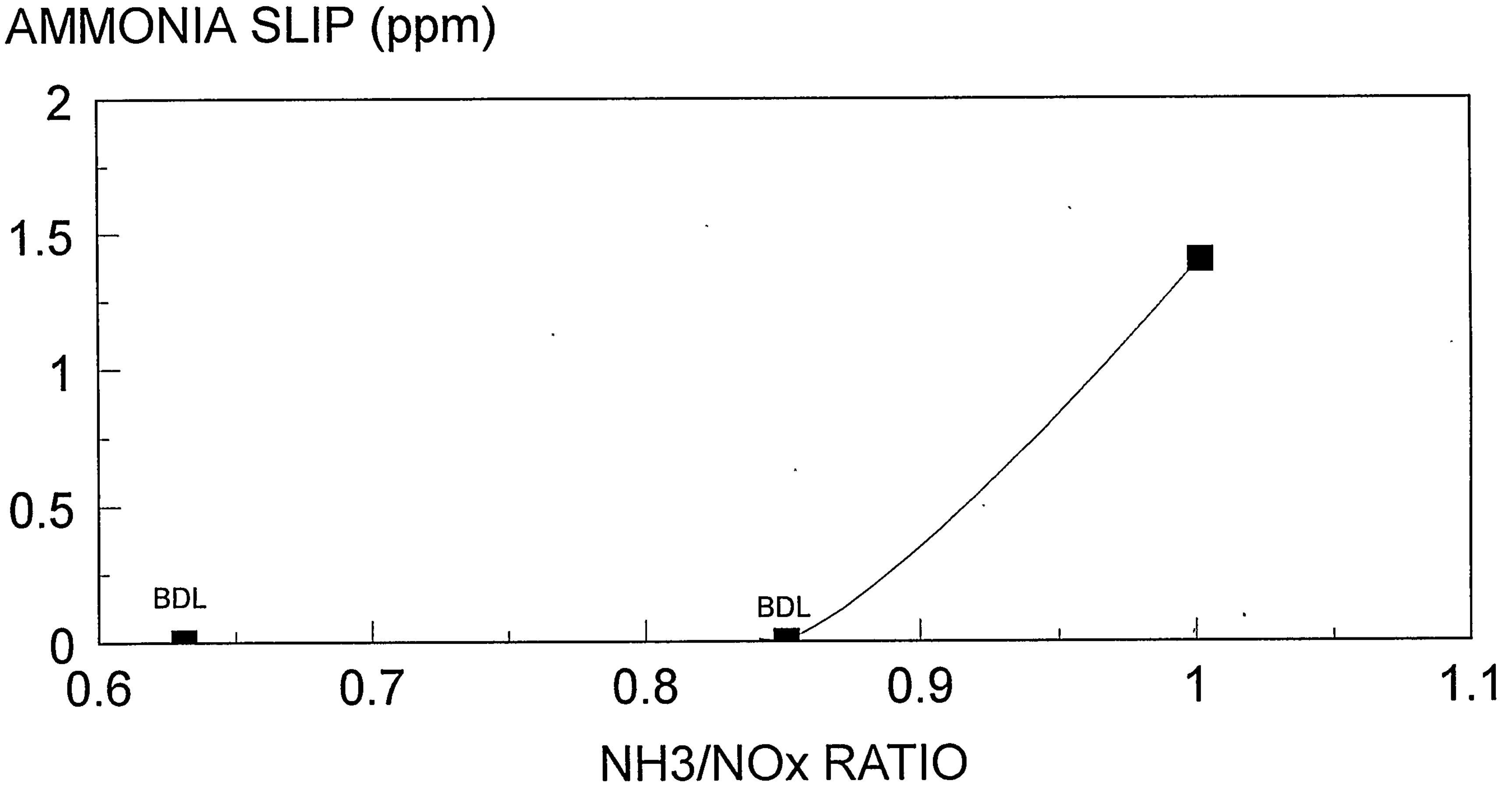
AMMONIA SLIP VS. FLOW RATE



HITACHI: NH3/NOx=0.80, 700 F

FIGURE 47a

AMMONIA SLIP VS. NH3/NOx RATIO

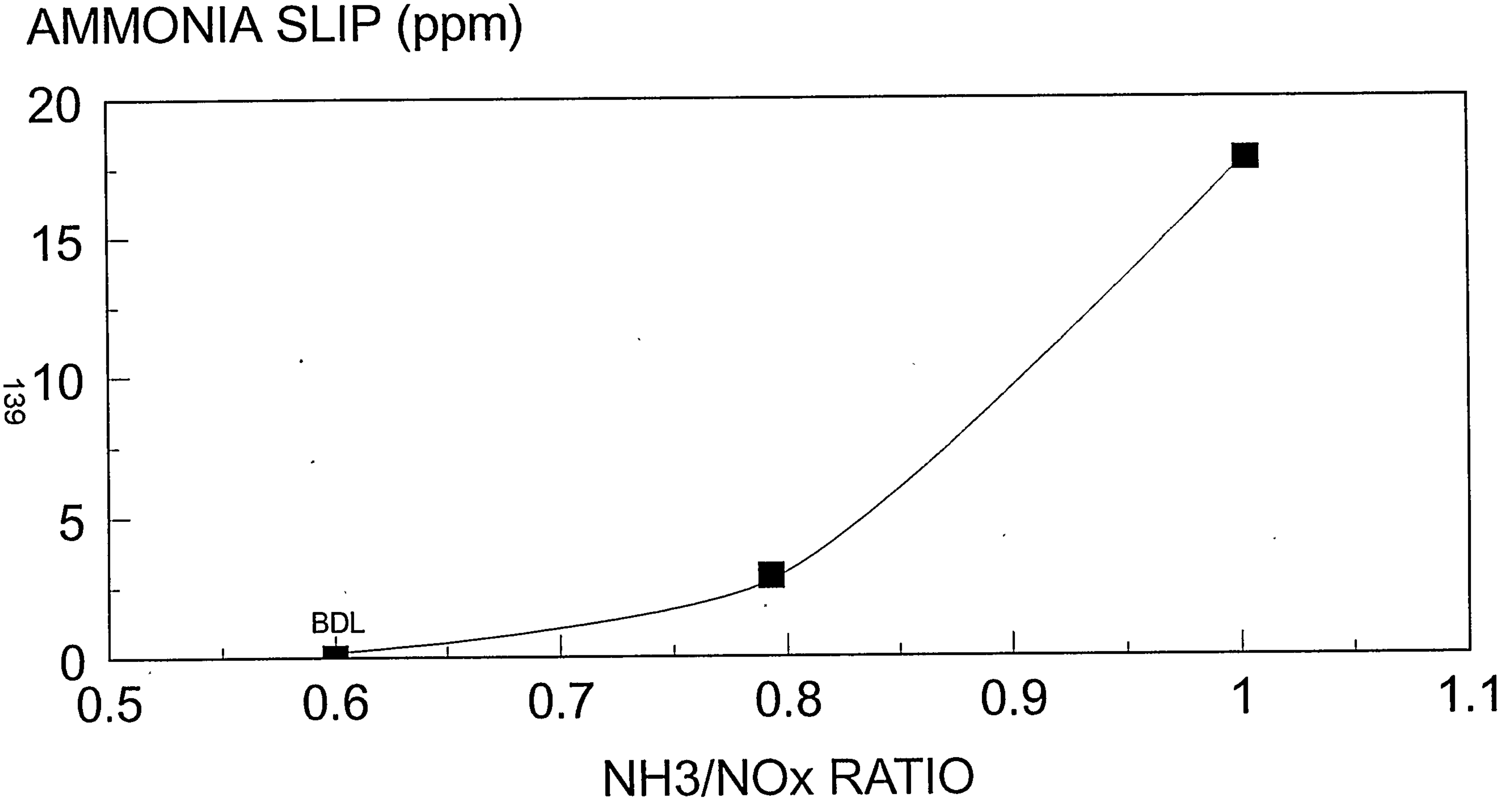


HITACHI: DESIGN FLOW, 620F

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

FIGURE 47b

AMMONIA SLIP VS. NH3/NOx RATIO

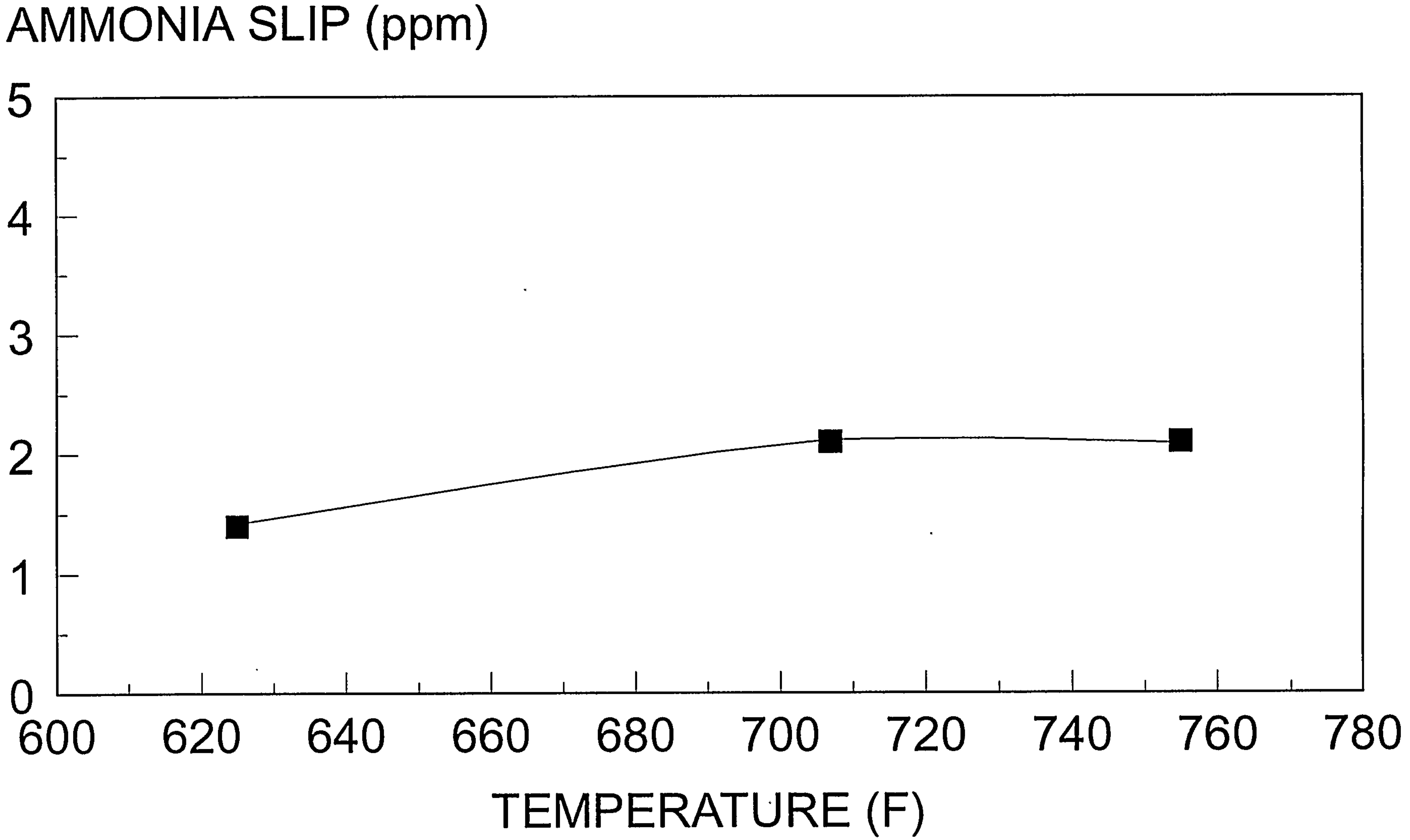


HITACHI: Design Flow, 620 F

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

FIGURE 48a

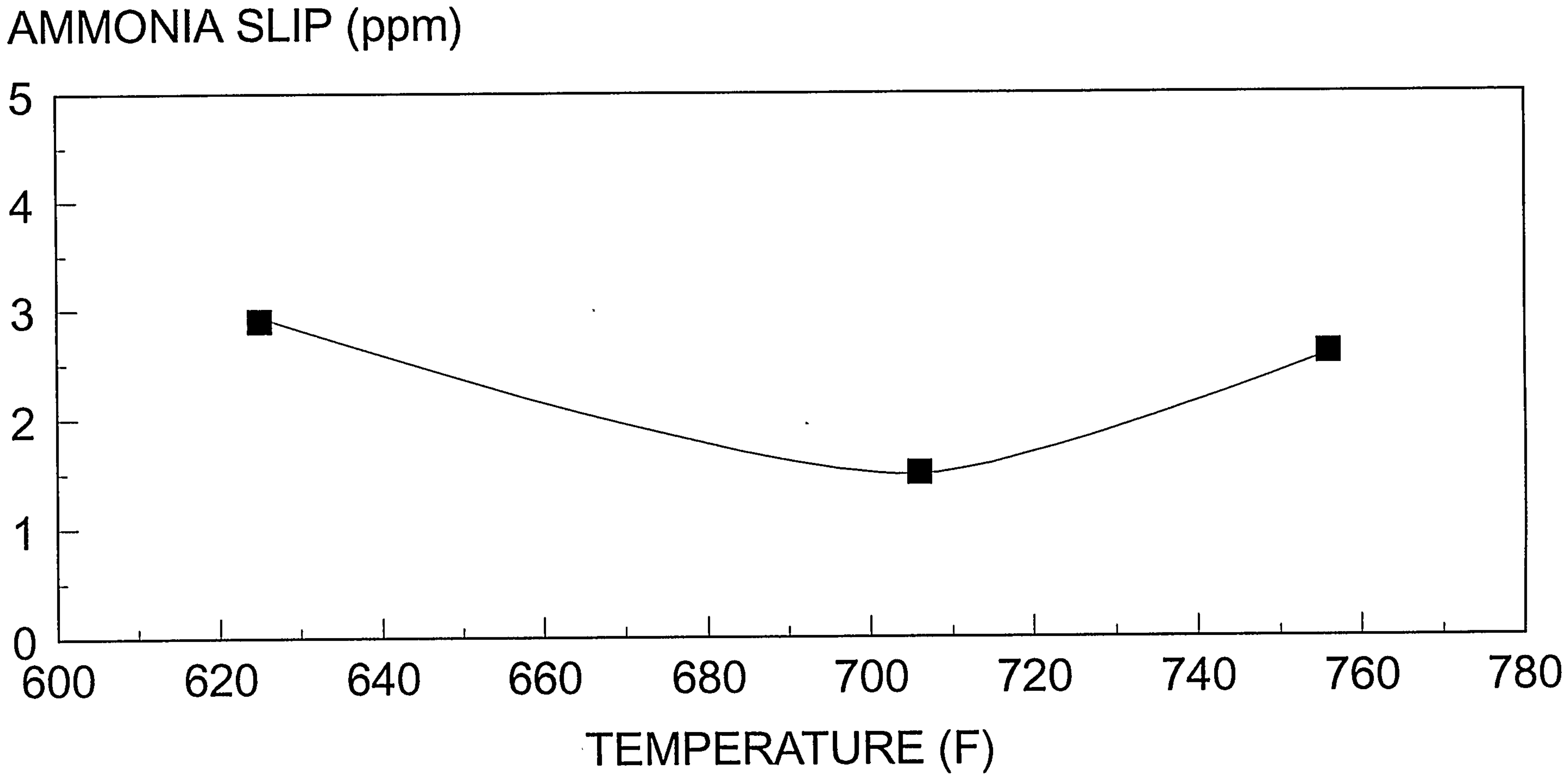
AMMONIA SLIP VS. TEMPERATURE



HITACHI: DESIGN FLOW, NH3/NOx=0.8

FIGURE 48b

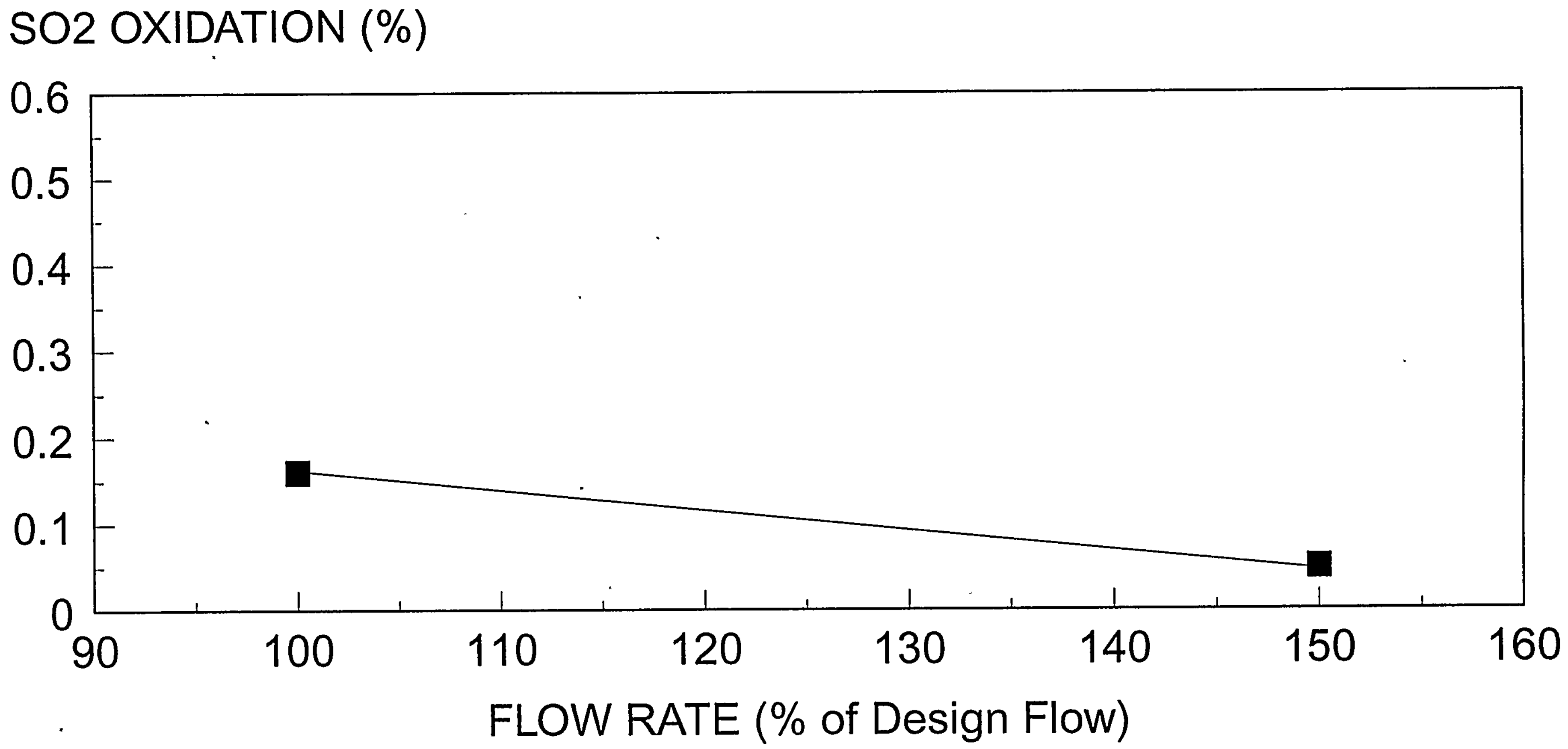
AMMONIA SLIP VS. TEMPERATURE



HITACHI: NH3/NOx=0.80, Design Flow

FIGURE 49

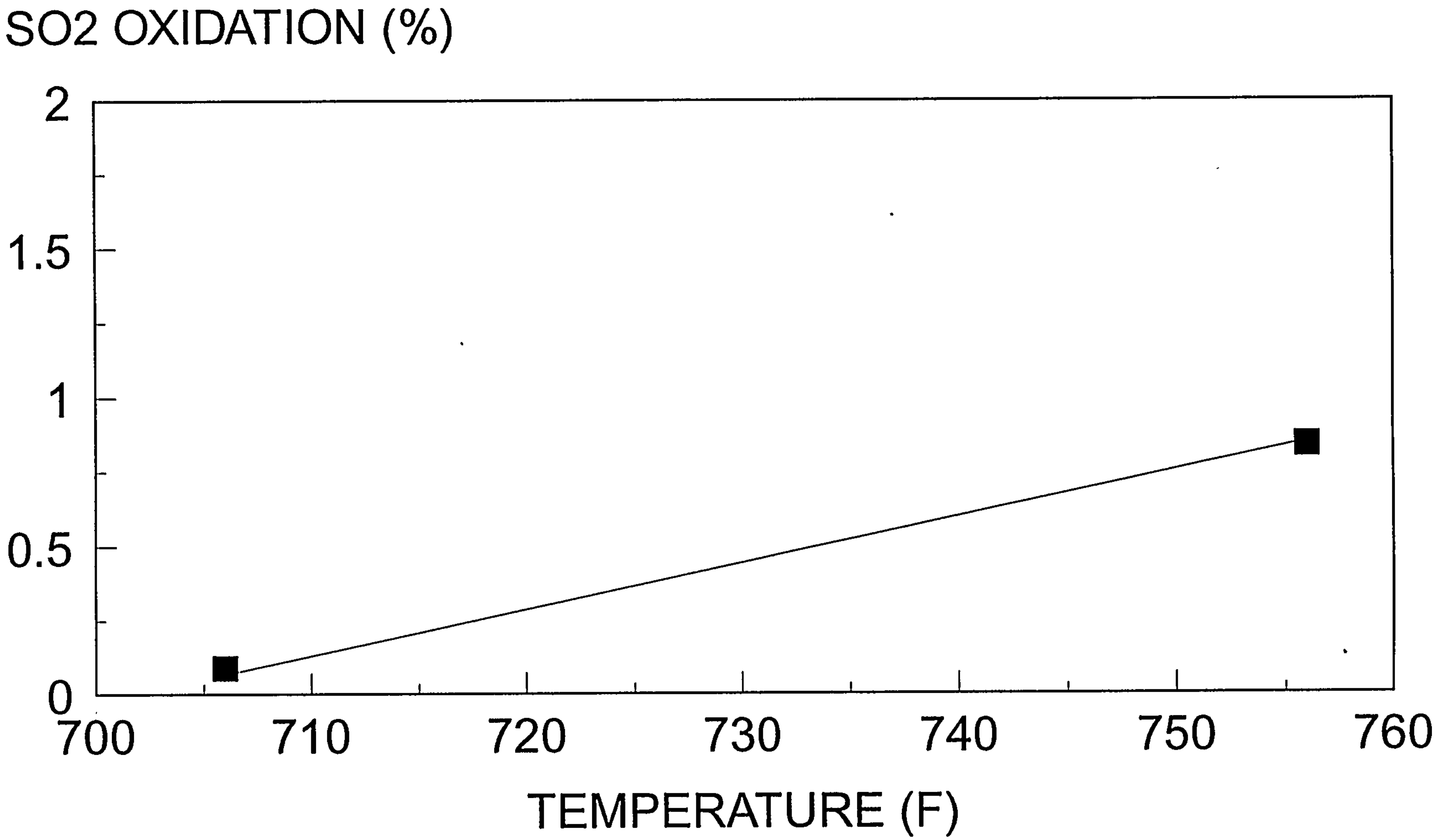
SO2 OXIDATION VS. FLOWRATE



HITACHI: NH3/NOx=0.80, 700 F

FIGURE 50a

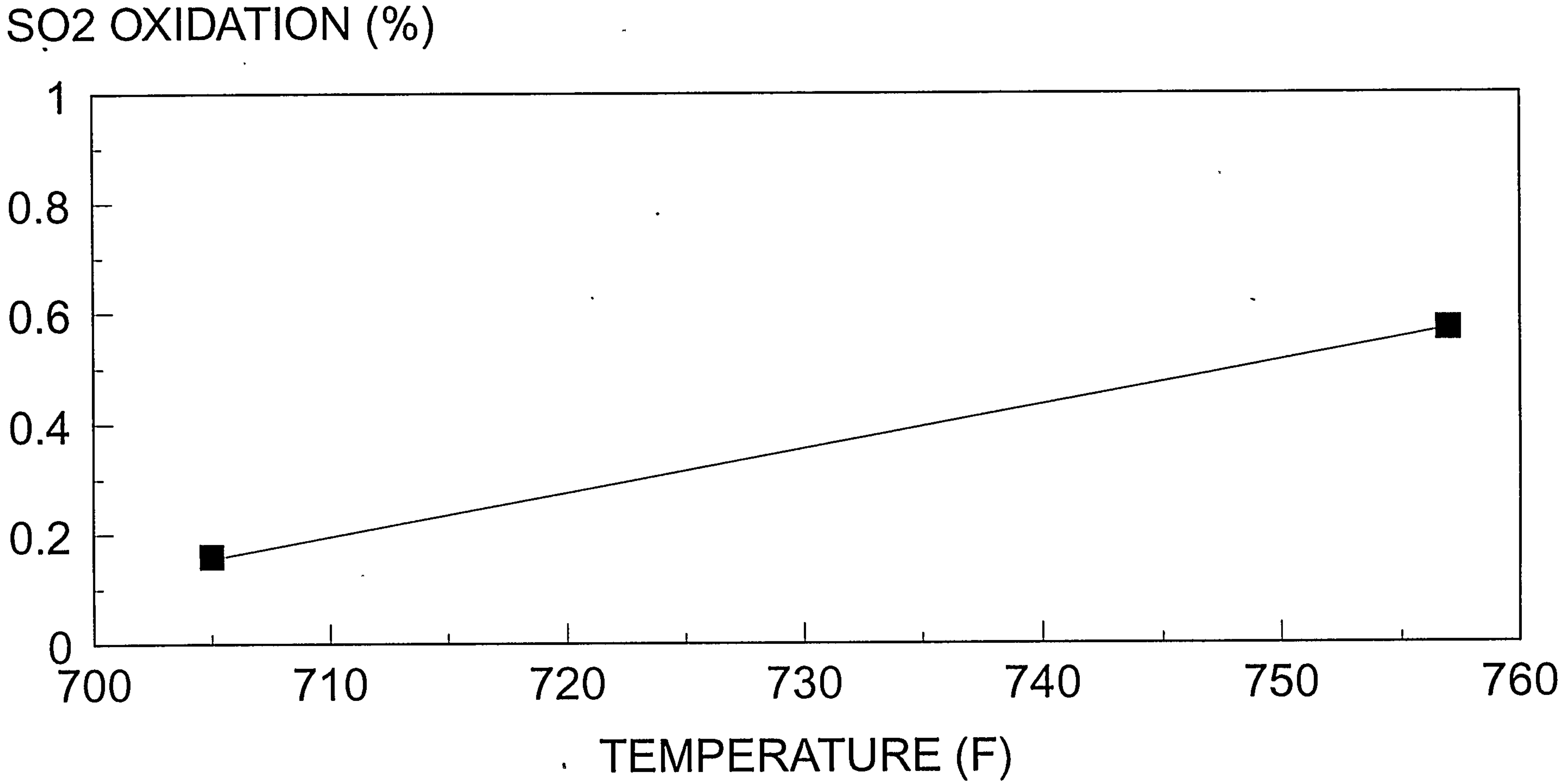
SO2 OXIDATION VS. TEMPERATURE



HITACHI: DESIGN FLOW, NH3/NOx=0.8

FIGURE 50b

SO2 OXIDATION VS. TEMPERATURE



HITACHI: Design Flow, NH3/NOX=0.80

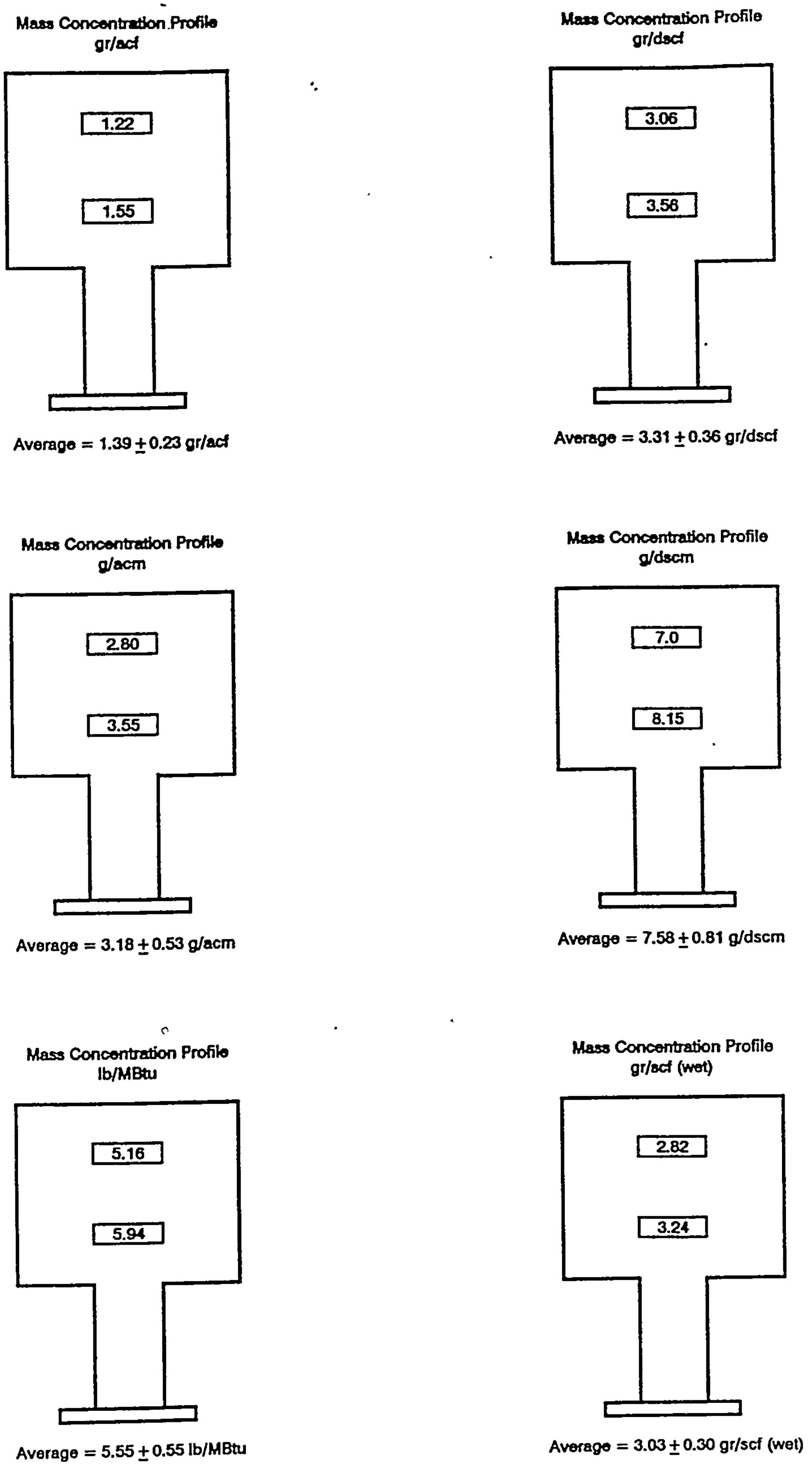
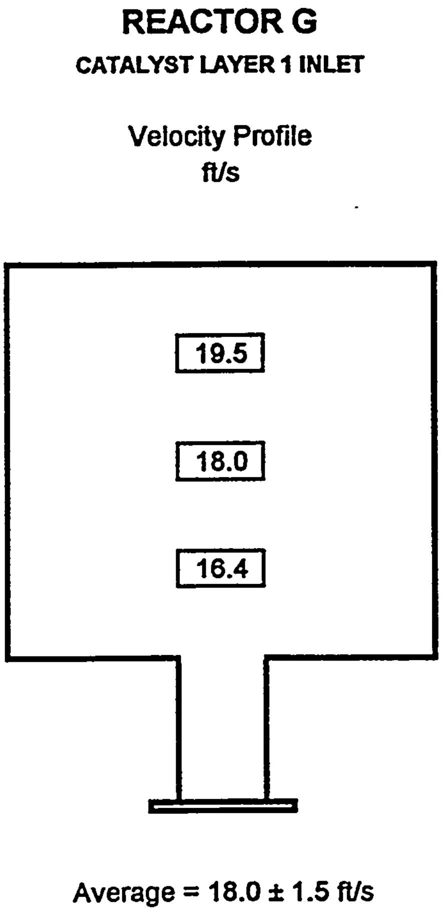


Figure 51. Six presentations of the Reactor G outlet mass concentration/mass emission profile.



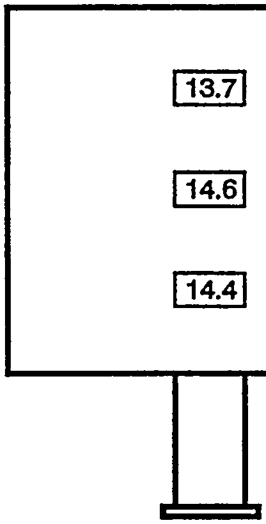
REACTOR G

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 SO_2 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 SO_2 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 SO_2 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 SO_2 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 SO_2 oxidation and information obtained from the catalyst suppliers indicate that increases in SO_2 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 SO_3 deposition occur in the test facility reactors. The general trend of increasing SO_2 oxidation is expected, however, and the plot provides a good basis for determining the potential for SO_3 formation across the SCR reactor at various operating temperatures.

The SO_2 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 SO_2 oxidation rates quote reactor flow rates as calculated for the reactor exit, since SO_3 is measured at this point. For consistency with other figures, the plots of SO_2 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% O_2, dry) were 234 ± 5 ppmv and 244 ± 2 ppmv respectively. The N_2O 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% O_2).[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

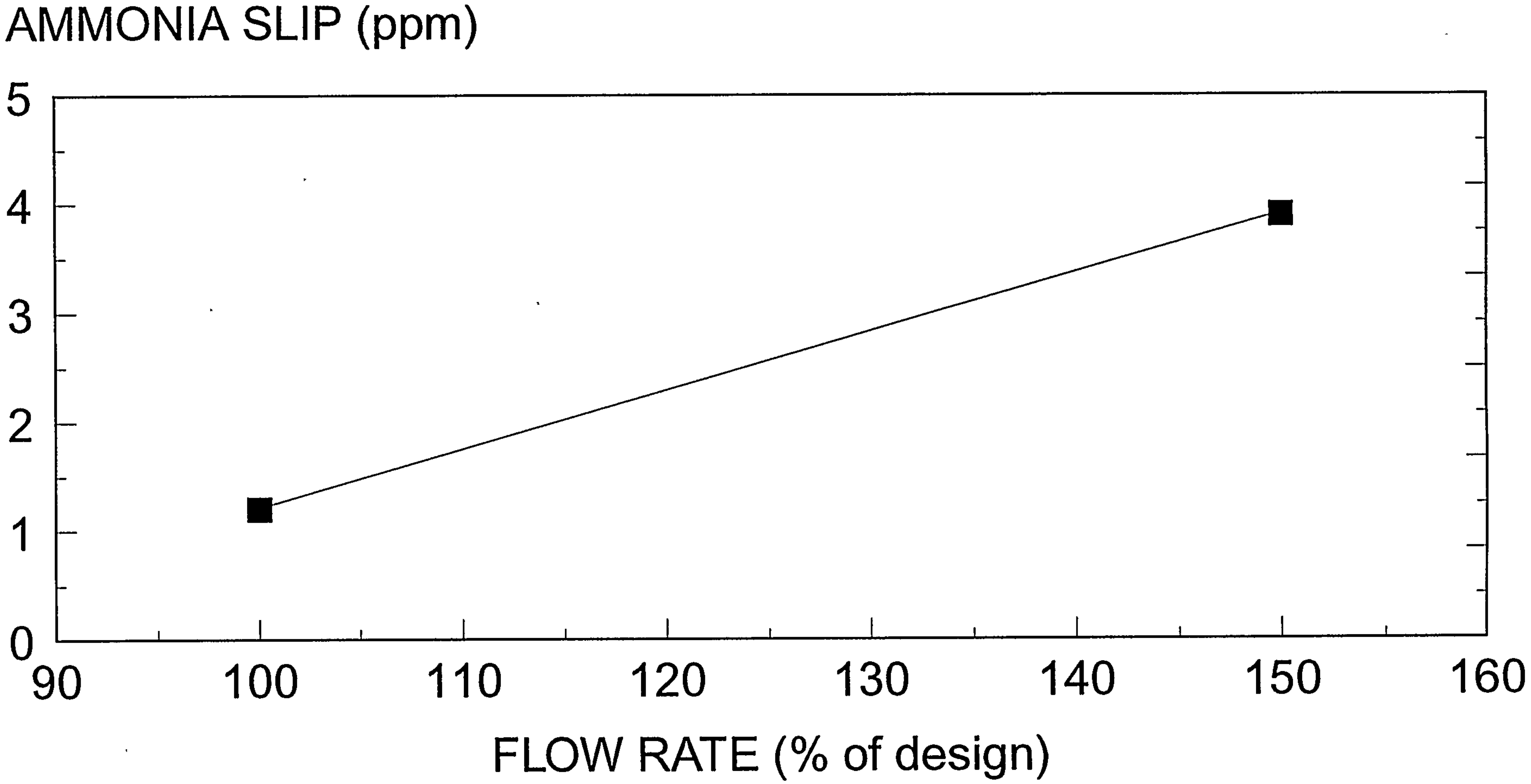
FLOW RATE (SCFM)	TEMP (°F)	OUTLET O_2 (%)	INLET SO_2 (ppmv)	NH_3/NO_x RATIO	MEAS SO_3 IN (ppmv)	SO_3 OUT (ppmv)	SO_3 formed (ppmv)	OXID. RATE (%)
498	704	7.678	1720	0.807	0.6	2.5	1.9	0.11
711	703	7.575	1666	0.783	1.3	5.2	3.9	0.23
494	756	7.751	1769	0.803	0.8	8.6	7.8	0.44

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

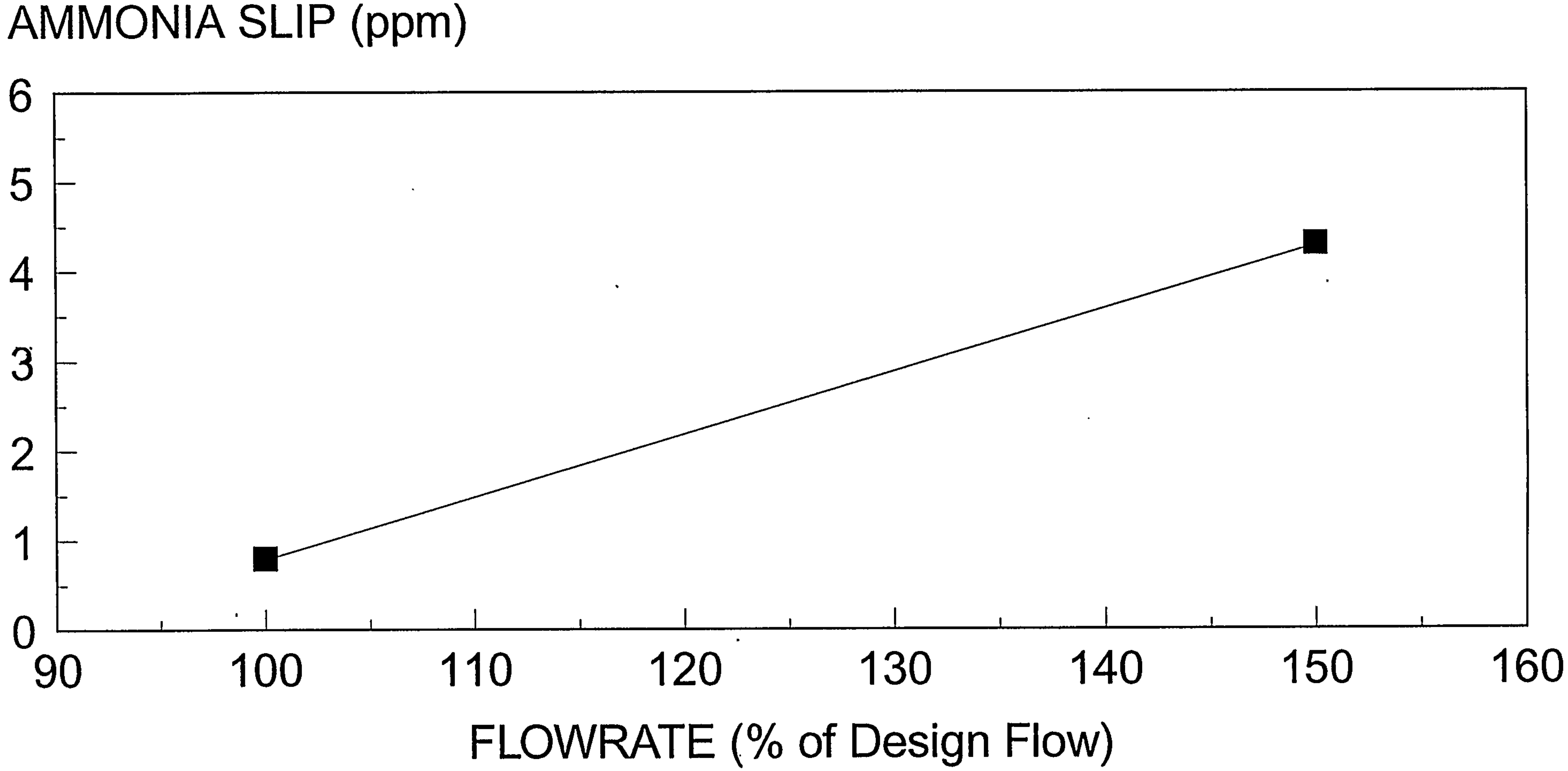
AMMONIA SLIP VS. FLOW RATE



CORM LD: 700 F, NH3/NOx=0.8

FIGURE 53b

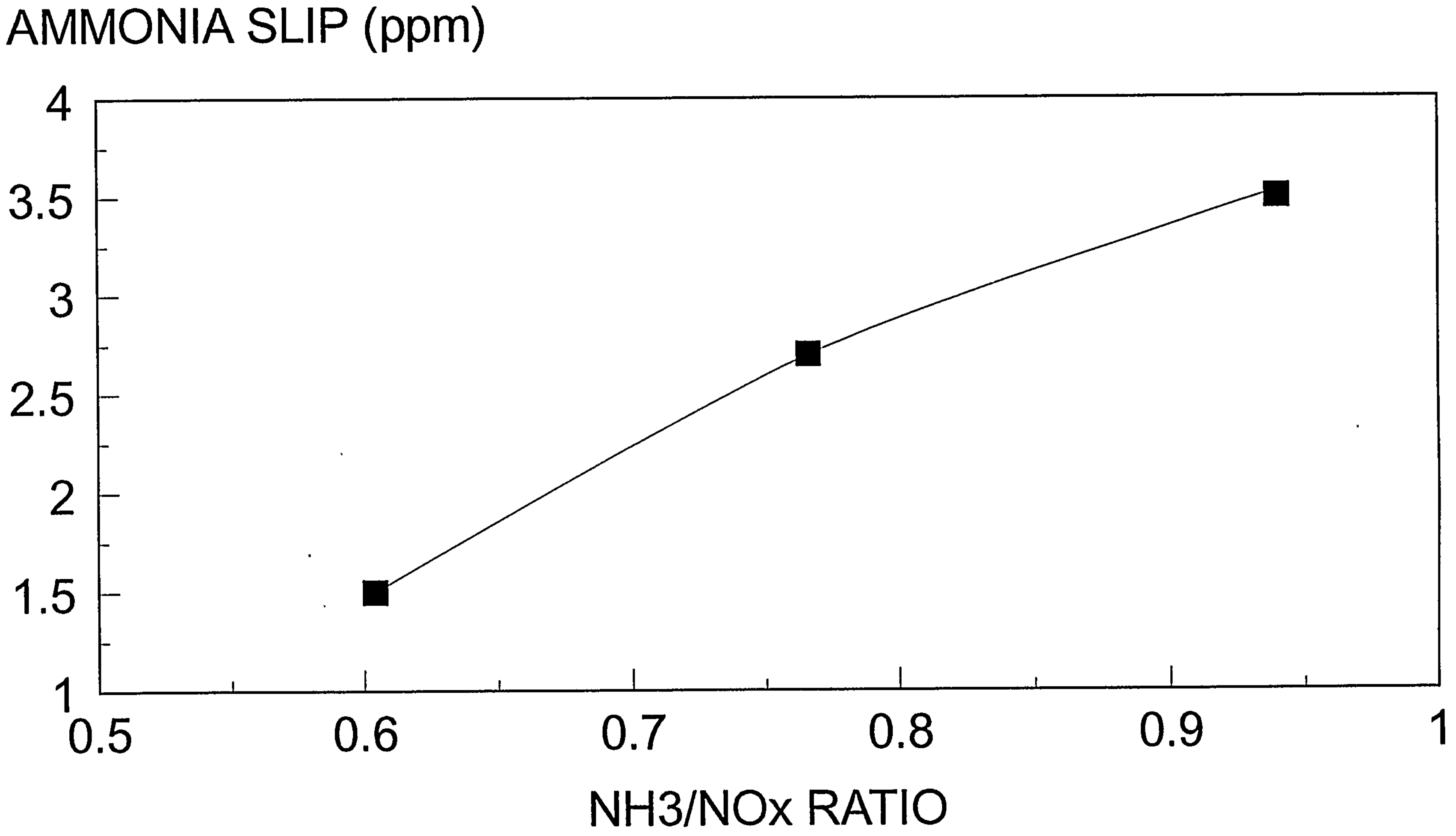
AMMONIA SLIP VS. FLOW RATE



CORM LD: NH3/NOx=0.80, 700 F

FIGURE 54a

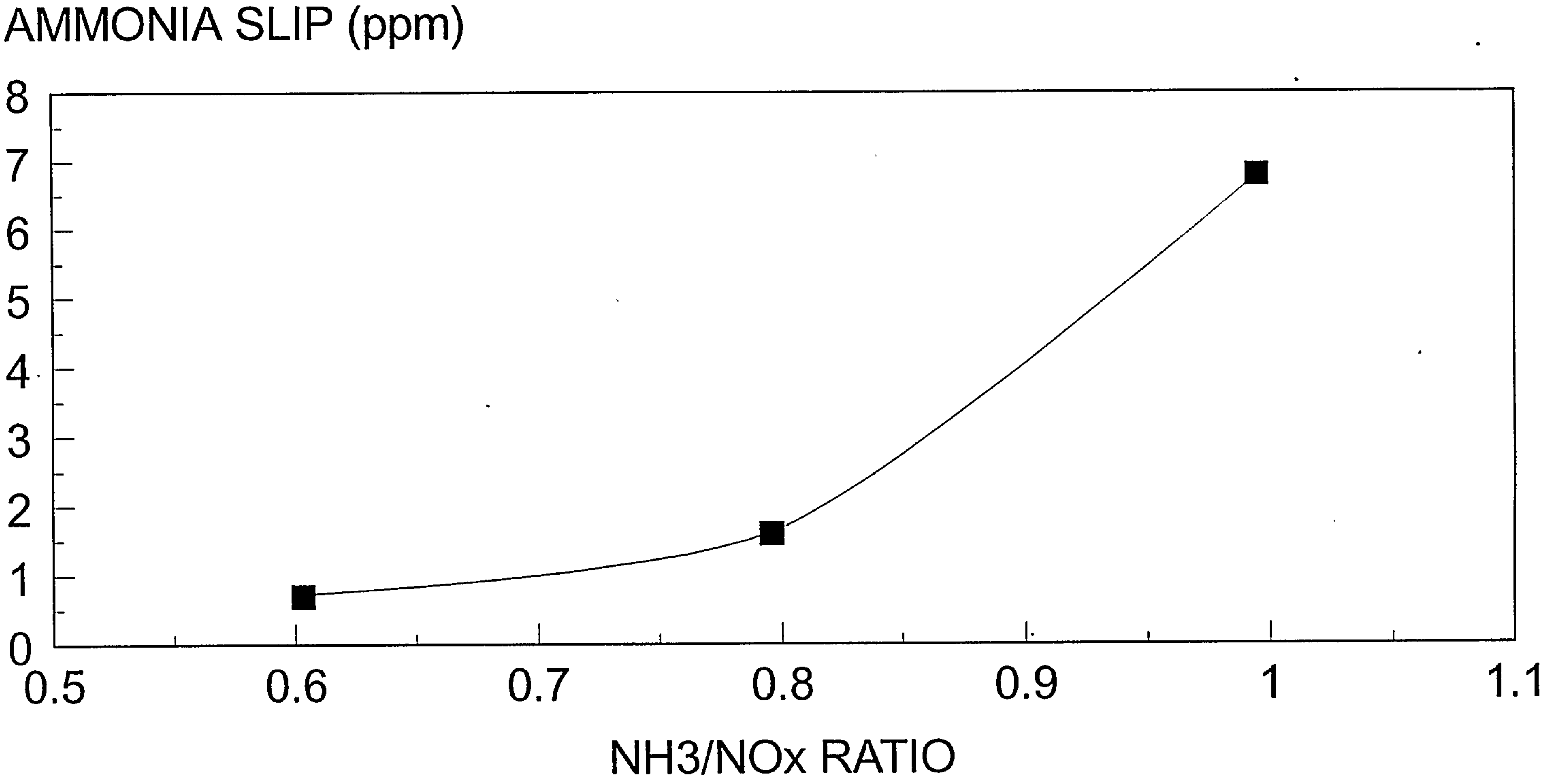
AMMONIA SLIP VS. NH3/NOx RATIO



CORM LD: DESIGN FLOW, 620F

FIGURE 54b

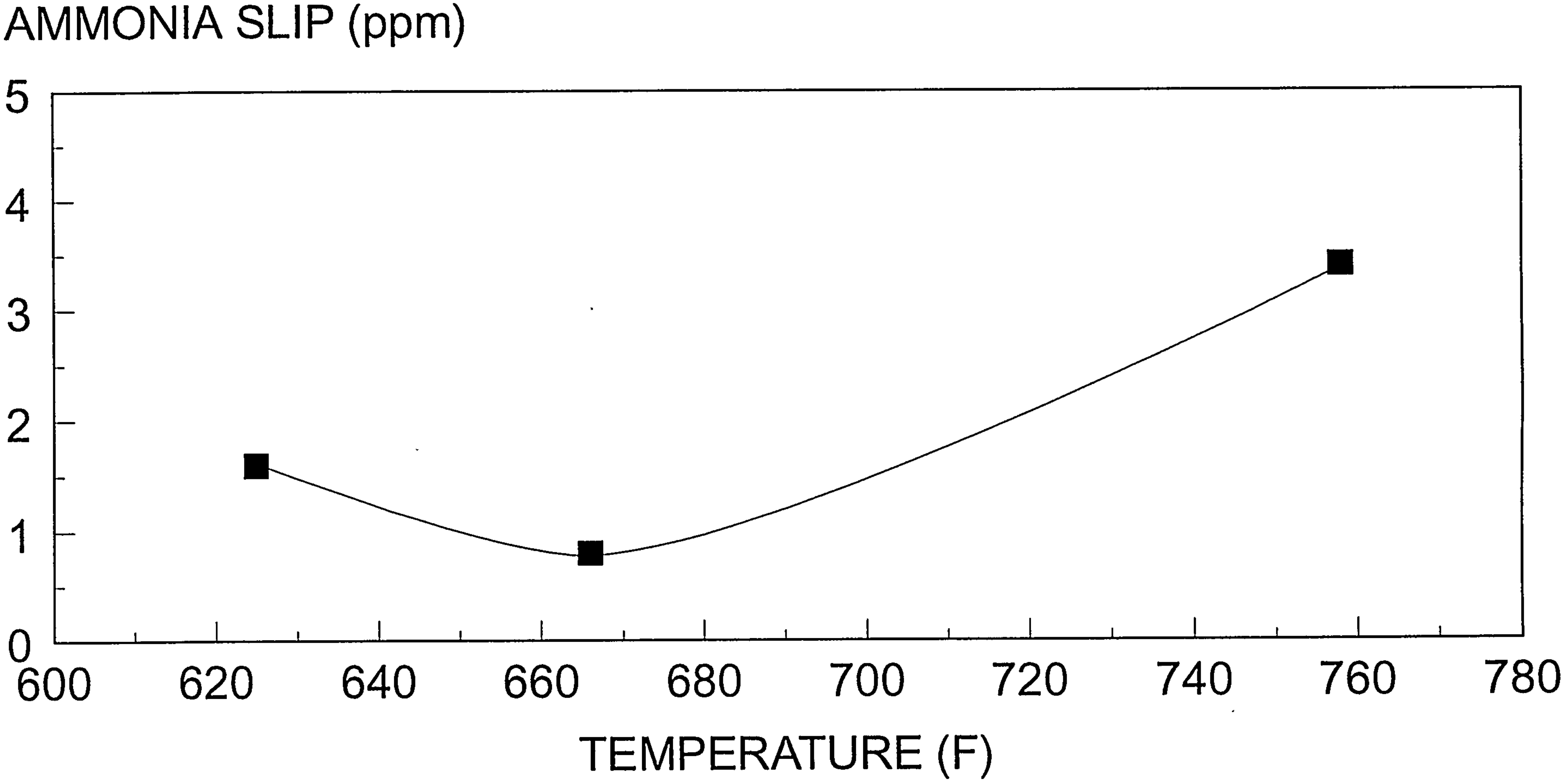
AMMONIA SLIP VS. NH3/NOx RATIO



CORM LD: Design Flow, 620 F

FIGURE 55

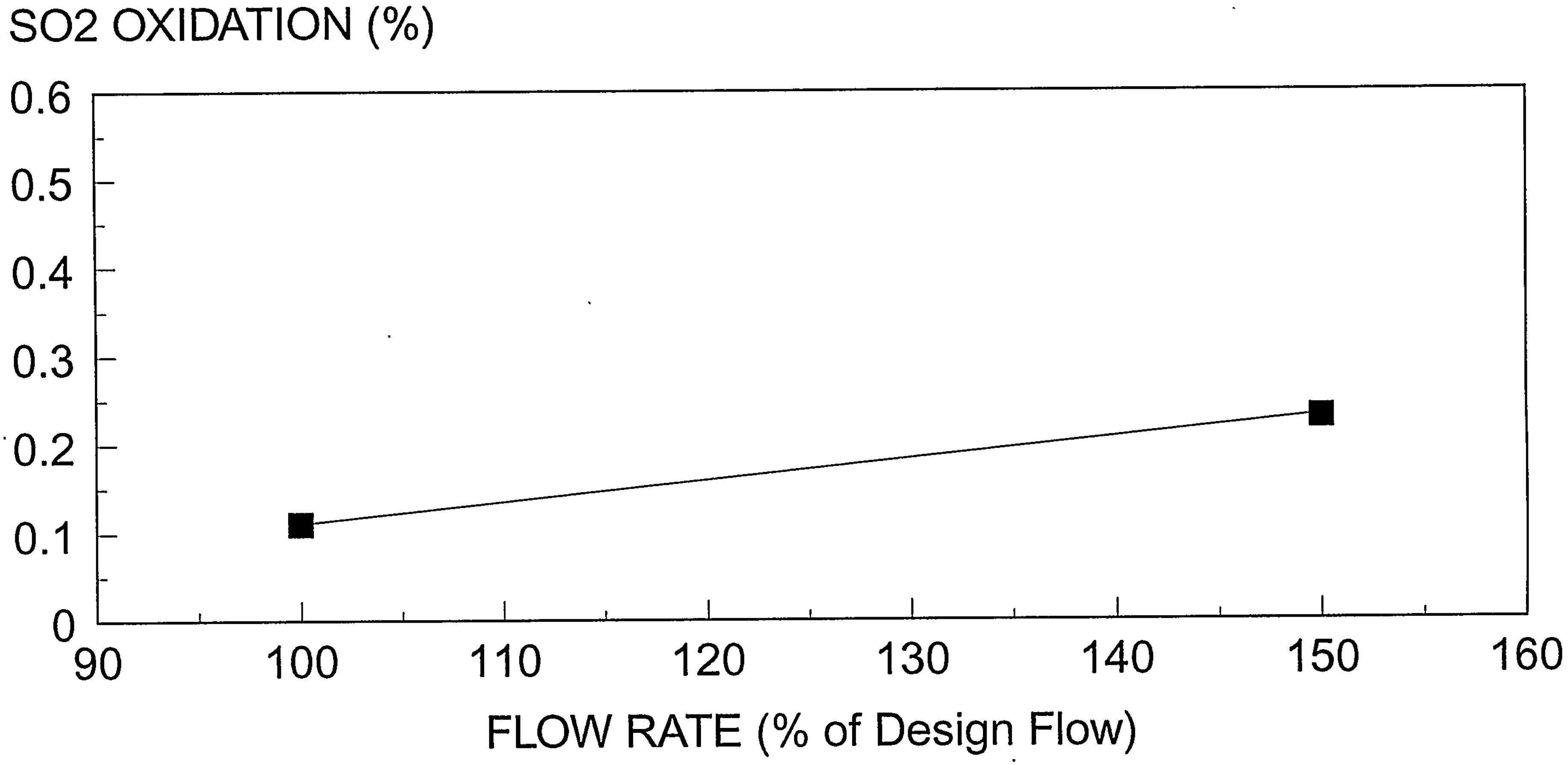
AMMONIA SLIP VS. TEMPERATURE



CORM LD: NH3/NOx=0.80, Design Flow

FIGURE 56

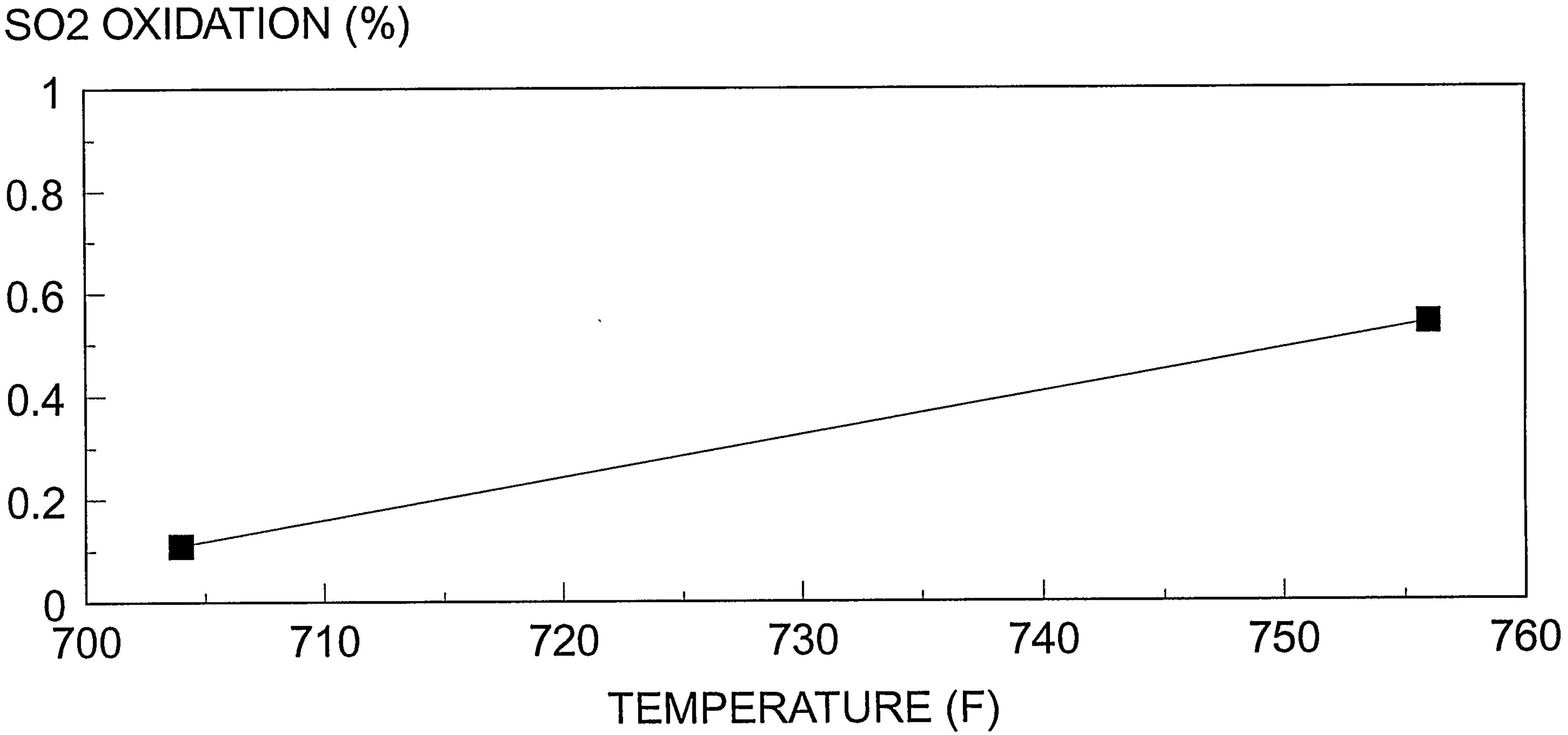
SO2 OXIDATION VS. FLOWRATE



CORM LD: NH3/NOx=0.80, 700 F

FIGURE 57

SO2 OXIDATION VS. TEMPERATURE



CORM LD: Design Flow, NH3/NOX=0.80

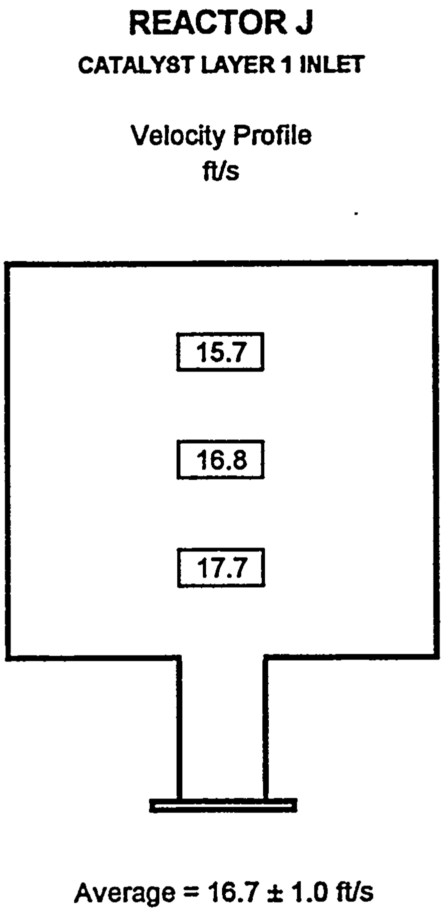


Figure 58a. Reactor J flue gas velocity profile.
Third Parametric Sequence

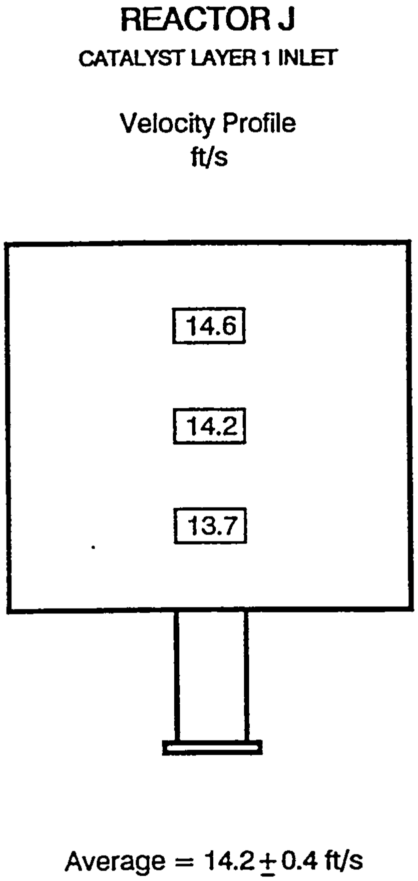


Figure 58b. Reactor J flue gas velocity profile.
Fourth Parametric Sequence

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

Prepared by

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SCS Contract Number C-92-000320
SRI Project Number 7613
SRI Report Number SRI-ENV-95-336-7613

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.

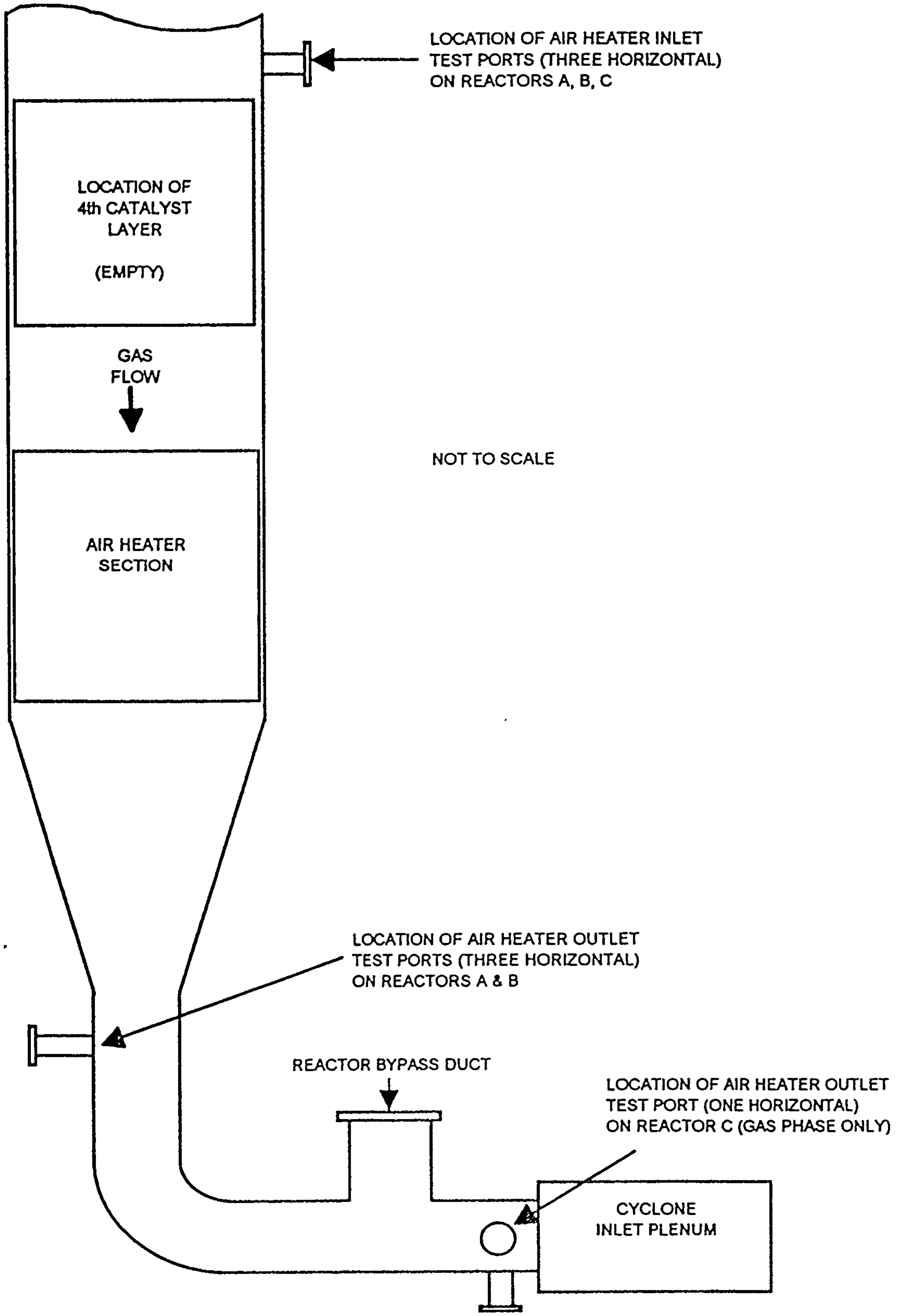

Figure 2-1. Schematic drawing of SCR reactor and air heater cross section (side view).

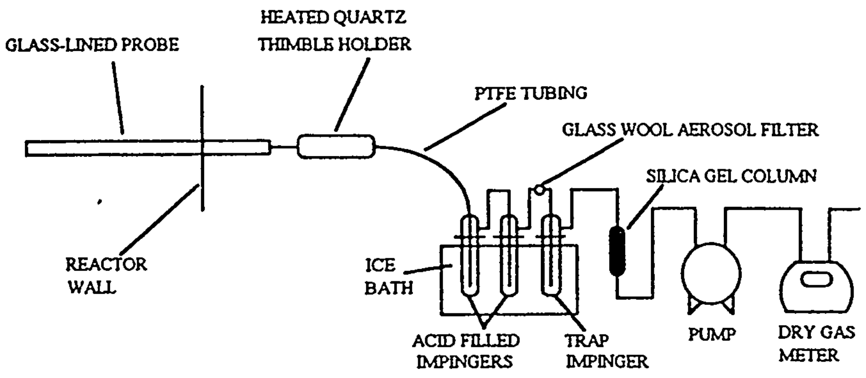

Figure 2-2. Schematic diagram of the ammonia sampling train.

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 ft^3 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 NH_3/NO_x ratio of 0.8.

The impinger solutions are made alkaline in the laboratory (converting the NH_4^+ ion to free NH_3 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, SO_2 and SO_3 concentrations were measured simultaneously at the reactor outlet downstream of the third catalyst layer (air heater inlet) and the air heater outlet. Sulfur dioxide (SO_2) and sulfur trioxide (SO_3) 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).

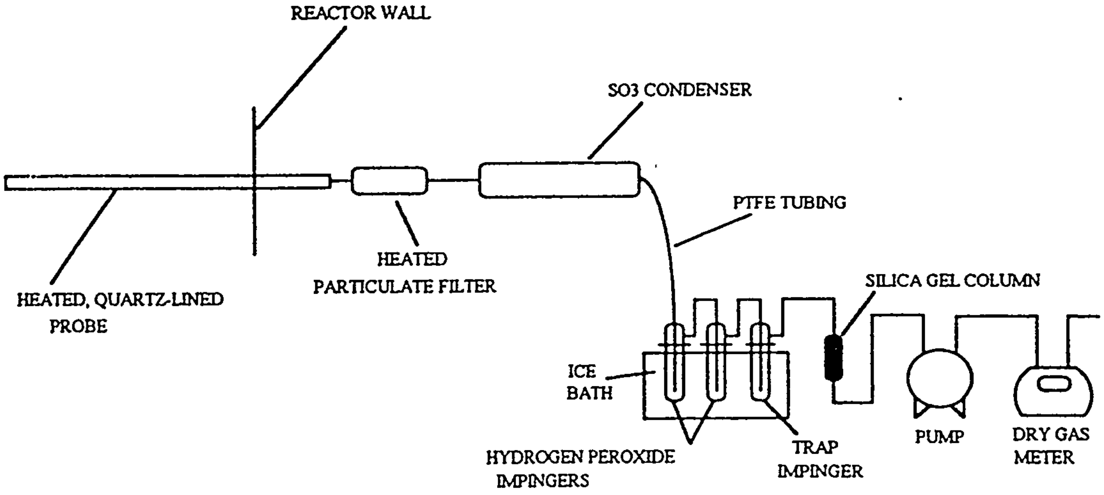

Figure 2-3. Schematic diagram of the controlled condensation sampling train for SO_2 and SO_3.

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

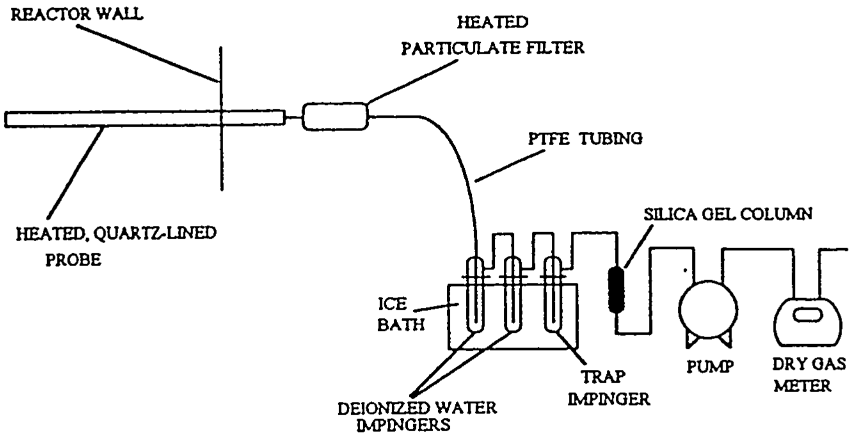

Figure 2-4. Schematic diagram of the chloride sampling train.

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.

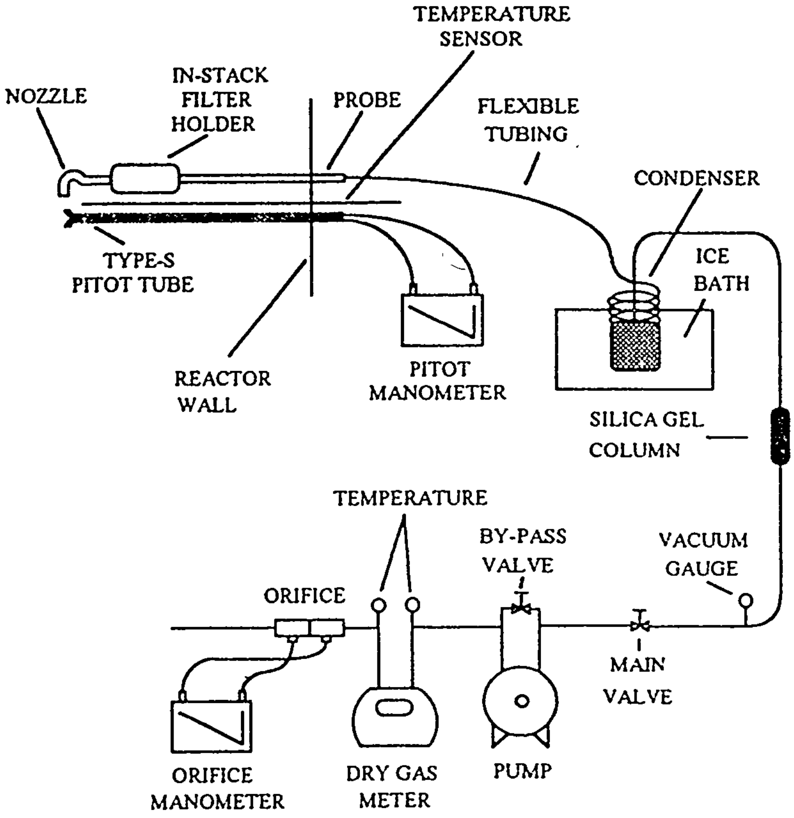

Figure 2-5. Schematic drawing of the mass concentration sampling train.

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 ($NH_3/NO_x = 0.8$), and at Test Condition 24 ($NH_3/NO_x = 1.0$). 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 µg/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 µg/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	$\frac{NH_3}{NO_x}$	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, µg/g	Estimated Upper Limit Solid-Phase NH_3, µg/g	Estimated Lower Limit Solid-Phase NH_3, µg/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 ± 71 ppm(v) dry @ 3% O_2, while the air heater outlet SO_2 concentrations averaged 1,539 ± 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: SO_2 and SO_3 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: SO_2 and SO_3 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 ^{O}F down to 300 ^{O}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.

SO_2 and SO_3 CONCENTRATIONS

In June 1994 (baseline preformance) SO_3 inlet concentrations ranged from 10 to 19 ppm(v) dry @ 3% O_2, while SO_3 concentrations at the reactor 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, 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.

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.

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 the average SO_2 concentrations, 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 ± 71 ppm(v) dry @ 3% O_2, while the air heater outlet SO_2 concentrations averaged 1,539 ± 165 ppm(v) dry @ 3% O_2.

HCl CONCENTRATIONS

Air heater inlet HCl concentrations, measured in October 1994, 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.

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

Week	Site	Gas	Number	Time, Begin	Time, End	Date	NH₃ Concentration ppm (v), dry			Analytical					Dry Gas Meter								
								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 l, dry	°K	in. Hg	°F	°F	ft³	ft³		
093	AAI	NHx	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	NHx	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	NHX	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	NHx	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	NHx	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	NHx	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	NHX	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	NHx	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	Site	Gas	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 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	µg/ml		ml	µM	ppm(v), dry, 3% O_2		scfm	°F		MW	%	STD L, dry	°K	in. Hg	°F	°F	ft³	ft³		
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% O2							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% O2							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		372	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% O2							< 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% O2							1.4	± 0.15						Testing Interval Averages				78	8.9									
																	σ	1.7	0.3									

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

Week	Site	O	Number				NH₃ Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
							ppm (v), dry, @ 3% O₂			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 I.D.	Corr. Factor
				Time, Begin	Time, End	Date	Average		σ	µg/ml		ml	µM	ppm(v), dry, 3% O_2		ecfm	°F		MW	%	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
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
										0.577			10.8	1.5															
093	AAI	NHG	06	1534	1613	13-Oct-94	1.1	±	0.01	0.439		244	7.7	1.1	24	400	705	1	77	2.8	154.66	300	29.98	80	81	660.000	666.000	Stack 1	0.998
										0.436			7.6	1.1															
093	AAI	NHG	07	1626	1704	13-Oct-94	1.0	±	0.80	0.129		346	3.2	0.5	24	400	705	1	78	2.6	154.51	300	29.98	81	81	666.200	672.200	Stack 1	0.998
										0.450			11.1	1.6															
Average NH₃ Concentration, ppm(v), dry @ 3% O2							1.2	±	0.28						Testing Interval Averages				77	2.8									
																		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
										0.441			8.7	1.2															
093	AAI	NHS	06	1534	1613	13-Oct-94	1.3	±	0.03	0.584		217	9.1	1.3	24	400	705	1	77	2.8	154.66	300	29.98	80	81	660.000	666.000	Stack 1	0.998
										0.605			9.4	1.3															
093	AAI	NHS	07	1626	1704	13-Oct-94	1.6	±	0.00	0.717		226	11.6	1.6	24	400	705	1	78	2.6	154.51	300	29.98	81	81	666.200	672.200	Stack 1	0.998
										0.719			11.6	1.6															
Average NH₃ Concentration, ppm(v), dry @ 3% O3							1.4	±	0.21						Testing Interval Averages				77	2.8									
																		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
										0.000			2.8	0.7															
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
										0.000			2.9	0.6															
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
										0.000			2.3	0.5															
Average NH₃ Concentration, ppm(v), dry @ 3% O4							< 0.6								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
										0.543			7.5	1.8															
093	AAO	NHS	06	1535	1605	13-Oct-94	1.7	±	0.02	0.455		228	7.4	1.7	24	400	705	1	77	9.3	153.70	299	29.98	78	80	560.000	566.000	SRI 3	0.9891
										0.464			7.6	1.7															
093	AAO	NHS	07	1625	1652	13-Oct-94	1.7	±	0.01	0.534		210	8.0	1.8	24	400	705	1	78	9.0	153.70	299	29.98	78	80	566.300	572.300	SRI 3	0.9891
										0.528			7.9	1.7															
Average NH₃ Concentration, ppm(v), dry @ 3% O5							1.7	±	0.06						Testing Interval Averages				77	9.5									
																		σ	0.6	0.6									

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

Week	Site	Gas	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 8 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(v), dry, 3% O_2		acfm	°F		MW	%	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
093	BAJ	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
				Possible leak^						0.200			4.0	0.6															
093	BAJ	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	BAJ	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% O2							0.6	±	0.06						Testing Interval Averages				84	4.1									
																		σ	1.5	0.1									
093	BAJ	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
				Possible leak^						0.147			1.9	0.3															
093	BAJ	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	BAJ	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% O2							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% O2							< 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% O2							0.8	±	0.10						Testing Interval Averages				84	7.6									
																		σ	1.5	0.4									

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

Week	Site	Oee	Number	Time, Begin	Time, End	Date	NH$_3$ Concentration ppm (v), dry, @ 3% O$_2$ Average		σ	Analytical NH$_3$	Dil	Vol.	NH$_3$	NH$_3$	Reactor Conditions Condition Number	Flow	Temp.	NH$_3$/NO$_x$	Unit 5 Boiler Load,	Sample O$_2$	Dry Gas Meter Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter I.D.	Corr. Factor
										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		
093	BAJ	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
										0 673			14 4	2 2															
093	BAJ	NHG	06	1554	1633	12-Oct	5 5	±	0 05	1 540		316	34 8	5 4	24	400	705	1	80	4 4	155.95	297	29.95	76	75	617.900	623 900	Stack 1	0 998
										1 560			35.2	5 5															
093	BAJ	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% O2							7.3	±	6.28						Testing Interval Averages				81	4									
																		σ	1 2	0 1									
093	BAJ	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
										0 763			11 1	1 7															
093	BAJ	NHS	06	1554	1633	12-Oct	3 9	±	0 00	1.770		200	25.3	3.9	24	400	705	1	80	4 4	155.95	297	29.95	76	75	617.900	623.900	Stack 1	0.998
										1.770			25 3	3 9															
093	BAJ	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% O3							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
										0 008			2 5	0 5															
093	BAO	NHG	06	1556	1624	12-Oct	< 0 5			0 009		351	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			2 5	0.5															
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% O4							< 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
										0 879			12 0	2 3															
093	BAO	NHS	06	1556	1624	12-Oct	4 5	±	0 03	2 820		117	23 6	4 5	24	400	705	1	80	7 3	153 84	299	29 95	76	80	516 000	522 000	SRI 1	0 9891
										2 790			23 3	4 5															
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% O5							6.5	±	5.61						Testing Interval Averages				81	7 3									
																		σ	1.2	0 3									

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

Week	Site	Oes	Number				NH_3 Concentration ppm (v), dry, @ 3% O_2				Analytical					Reactor Conditions						Dry Gas Meter								
				Time, Begin	Time, End	Date		Average		σ	NH_3	Dil	Vol.	NH_3	NH_3	Condition Number	Flow	Temp.	NH_3/ NO_x	Unit 8 Boiler Load,	Sample O_2	Volume, Total	Temp. Avg.	Barometric Pressure	Temp. Begin	Temp. End	Volume, Begin	Volume, End	Meter I.D.	Corr. Factor
											mg/ml		ml	µM	ppm(v), dry, 3% O_2		scfm	°F		MW	%	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
091	CAI	NHG	02	1028	1104	29-Sep		1.7	±	0.03	0.311	1	368	8.2	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
											0.318			8.4	1.7															
091	CAI	NHG	03	1259	1335	29-Sep		1.4	±	0.00	0.516		255	9.4	1.4	22	5000	705	0.8	85	2.6	152.47	306	30.04	90	92	445.600	451.600	Stack 1	1.001
											0.518			9.4	1.4															
091	CAI	NHG	04	1354	1432	29-Sep		0.8	±	0.01	0.280		288	5.8	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
											0.285			5.9	0.8															
Average NH_3 Concentration, ppm(v), dry @ 3% O2								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	1	218	10.1	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
											0.671			10.4	2.2															
091	CAI	NHS	03	1259	1335	29-Sep		1.7	±	0.00	0.781		209	11.7	1.7	22	5000	705	0.8	85	2.6	152.47	306	30.04	90	92	445.600	451.600	Stack 1	1.001
											0.781			11.7	1.7															
091	CAI	NHS	04	1354	1432	29-Sep		2.1	±	0.02	0.953		212	14.4	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
											0.969			14.7	2.1															
Average NH_3 Concentration, ppm(v), dry @ 3% O2								2.0	±	0.25						Testing Interval Averages				85	2									
																			σ	0	0									
091	CAO	NHG	02	1033	1104	29-Sep	<	0.5			0.033	1	388	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
											0.031			2.8	0.5															
091	CAO	NHG	03	1304	1335	29-Sep	<	0.5			0.027		420	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
											0.025			3.0	0.5															
091	CAO	NHG	04	1359	1429	29-Sep	<	0.4			0.014		338	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
											0.011			2.4	0.4															
Average NH_3 Concentration, ppm(v), dry @ 3% O2							<	0.5								Testing Interval Averages				85	5									
																			σ	0	0									
091	CAO	NHS	02	1033	1104	29-Sep		2.2	±	0.01	0.736	1	248	13.0	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
											0.742			13.1	2.2															
091	CAO	NHS	03	1304	1335	29-Sep		2.4	±	0.03	0.775		257	14.2	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
											0.788			14.5	2.5															
091	CAO	NHS	04	1359	1429	29-Sep		2.5	±	0.03	0.843		240	14.5	2.5	22	5000	705	0.8	85	5.2	150.24	307	30.04	92	93	404.000	410.000	SRI 3	0.989
											0.856			14.7	2.5															
Average NH_3 Concentration, ppm(v), dry @ 3% O2								2.4	±	0.17						Testing Interval Averages				85	5									
																			σ	0	0									

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

Week	Site	Gas	Number	Time, Begin	Time, End	Date	NH$_3$ Concentration ppm (v), dry, @ 3% O$_2$ Average		σ	Analytical NH$_3$ mg/ml	Dil	Vol. ml	NH$_3$ µM	NH$_3$ ppm(v), dry, 3% O$_2$	Reactor Conditions Condition Number	Flow acfm	Temp, °F	NH$_3$/NO$_x$	Unit 5 Boiler Load, MW	Sample O$_2$ %	Dry Gas Meter Volume, Total STD l, dry	Temp, Avg. °K	Barometric Pressure In. Hg	Temp, Begin °F	Temp, End °F	Volume, Begin ft^3	Volume, End ft^3	Meter I.D.	Corr. Factor
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
										1 25			22 9	3 2															
091	CAI	NHG	07	1020	1058	30-Sep	3 7	±	0 02	1 27		283	25 7	3 6	24	400	705	1	86	2 5	153.44	304	30.04	86	89	470 800	476 800	Stack 1	1.001
										1 28			25 9	3 7															
091	CAI	NHG	08	1239	1315	30-Sep	4 1	±	0 01	2 43		254	44 1	4 1	24	400	705	1	87	1 9	226 23	309	30.04	96	98	477 000	486 000	Stack 1	1.001
										2 42			43 9	4 1															
Average NH$_3$ Concentration, ppm(v), dry @ 3% O2							3.6	±	0.48						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
										3.12			46 4	6 5															
091	CAI	NHS	07	1020	1058	30-Sep	7 2	±	0 01	3 44		207	50 9	7 2	24	400	705	1	86	2 5	153 44	304	30.04	86	89	470 800	476 800	Stack 1	1.001
										3.45			51 0	7 2															
091	CAI	NHS	08	1239	1315	30-Sep	5 7	±	0.08	4 21		204	61 3	5 7	24	400	705	1	87	1 9	226 23	309	30.04	96	98	477 000	486.000	Stack 1	1.001
										4.13			60 2	5 6															
Average NH$_3$ Concentration, ppm(v), dry @ 3% O3							6.5	±	0.78						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
										0 008			2 7	0 5															
091	CAO	NHG	07	1025	1053	30-Sep	0 5	±	0.05	0 094		333	2 4	0 4	24	400	705	1	88	6 9	152.17	303	30.04	85	88	420.700	426.700	SRI 3	0.989
										0 116			2 8	0 5															
091	CAO	NHG	08	1244	1316	30-Sep	< 0 5			0 086		388	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
										0 080			2 8	0 5															
Average NH$_3$ Concentration, ppm(v), dry @ 3% O4							< 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	88	5 7	153 44	300	30 04	78	84	414 300	420 300	SRI 3	0 989
										1 54			25 5	4 4															
091	CAO	NHS	07	1025	1053	30-Sep	11 1	±	0 00	3 65		227	59 2	11 1	24	400	705	1	86	6 9	152 17	303	30 04	85	86	420 700	426.700	SRI 3	0 989
										3 65			59 2	11 1															
091	CAO	NHS	08	1244	1316	30-Sep	6 1	±	0 06	2 63		171	32 1	6 0	24	400	705	1	87	6 7	150 38	306	30.04	90	94	427 200	433.200	SRI 3	0.989
										2 67			32 6	6 1															
Average NH$_3$ Concentration, ppm(v), dry @ 3% O5							7.2	±	3.51						Testing Interval Averages				88	6									
																		σ	1	1									

Table A-3

							Concentration			Analytical								Dry Gas Meter								
Week	Site	Gas	Number				ppm (v), dry, @ 3% O_2			$SO_4^=$	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 I.D.	Corr. Factor
				Time, Begin	Time, End	Date	Average		σ	mg/ml		ml	µM	ppm, dry, @ 3% O2		MW	%	STD l, dry	°K	In. Hg	°F	°F	ft³	ft³		
092	SI	SO_3	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
										4 210			4	1 1												
092	SI	SO_3	02	1030	1043	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												
092	SI	SO_3	03	1054	1107	7-Oct-94	1 3	±	0.00	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_3 Concentration, ppm(v), dry @ 3% O2							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% O2							1880	±	11.2																	

Table A-4 (Reference Table 3-2)

							Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
Week	Site	Gas	Number				ppm (v), dry, @ 3% O_2			$SO_4^=$	Dil	Vol.	$SO_4^=$	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% O2		scfm	°F		MW	%	STD l, dry	°K	in. Hg	°F	°F	ft^3	ft^3		
076	AAI	SO3	01	1320	1335	15-Jun-94	14 3	±	0 10	1 648	25	100	47	14 3	22	5	700	0 8	84	3 4	75 06	312	30.17	101	102	614 300	617.300	Stack 1	1.0000
										1.664			47	14.4															
076	AAI	SO3	02	1349	1406	15-Jun-94	20 1	±	0 19	1.988		128	66	20.2	22	5	700	0 8	84	3 4	74 99	312	30.17	102	102	617.700	620.700	Stack 1	1.0000
										1.961			65	20.0															
076	AAI	SO3	03	1427	1441	15-Jun-94	20 5	±	0 23	2 438		108	69	20.4	22	5	700	0 8	84	2 9	74.99	312	30.17	103	101	321.300	324.300	Stack 1	1.0000
										2.477			70	20 7															
Average SO_3 Concentration, ppm(v), wet @ 3% O2							20.3	±	0.3						Testing Interval Averages				84	3 2									
																		σ	0	0.3									
076	AAI	SO2	01	1320	1335	15-Jun-94	2191 6	±	0 64	4 814	200	716	7181	2192.1															
										4 812			7178	2191 2															
076	AAI	SO2	02	1349	1406	15-Jun-94	2238 8	±	4 71	5 386		654	7338	2242 2															
										5 370			7317	2235 5															
076	AAI	SO2	03	1427	1441	15-Jun-94	2129 4	±	22 83	4 586		756	7223	2145 6															
										4 517			7114	2113 3															
Average SO_2 Concentration, ppm(v), wet @ 3% O2							2184	±	77																				
076	AAO	SO3	01	1325	1338	15-Jun-94	14 5	±	0 04	1 633	25	83 8	36	14 5	22	5	700	0 8	84	7 5	73 69	314	30.17	106	106	58.600	61.600	Stack 2	0.9897
										1 639			36	14 5															
076	AAO	SO3	02	1408	1420	15-Jun-94	17 1	±	0 04	2 152		74 8	42	17 1	22	5	700	0 8	84	7 6	73 89	313	30.17	105	104	61 900	64 900	Stack 2	0.9897
										2 144			42	17 0															
076	AAO	SO3	03	1434	1447	15-Jun-94	16 5	±	0 03	1 917		81 7	41	16 5	22	5	700	0 8	84	7 5	73 89	313	30 17	104	105	65 200	68.200	Stack 2	0.9897
										1 922			41	16 6															
Average SO_3 Concentration, ppm(v), wet @ 3% O2							16.8	±	0.4						Testing Interval Averages				84	7 5									
																		σ	0	0 1									
076	AAO	SO2	01	1325	1338	15-Jun-94	2269 5	±	26 65	4 479	200	594	5543	2250 6															
										4.554			5636	2288 3															
076	AAO	SO2	02	1408	1420	15-Jun-94	2294 3	±	2 89	4.487		601	5618	2292 3															
										4,495			5628	2296.4															
076	AAO	SO2	03	1434	1447	15-Jun-94	2317 4	±	2 68	4 275		642	5718	2315 6															
										4.282			5727	2319 3															
Average SO_2 Concentration, ppm(v), wet @ 3% O2							2306	±	16																				

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

Week Site Gas Number				Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
				ppm (v), dry, @ 3% O_2			$SO_4^=$	Dil	Vol.	$SO_4^=$	SO_2, or SO_3	Condition Number	Flow	Temp,	NH_3/NO_x	Unit 6 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% O2		scfm	°F		MW	%	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
076 BAI SO3 01	1307	1320	14-Jun-94	5 9	±	0 13	0 631	25	115	19	6 0	22	5	700	0 8	79	4 0	74 90	312	30.16	102	103	582.200	585.200	Stack 1	1.0000
							0 612			18	5 8															
076 BAI SO3 02	1335	1349	14-Jun-94	8 4	±	0 26	0 805		130	27	8 6	22	5	700	0 8	80	3 9	74 70	313	30.16	103	105	585.700	588.700	Stack 1	1 0000
							0 770			26	8 2															
076 BAI SO3 03	1403	1417	14-Jun-94	15 7	±	0 04	1 769		106	49	15 7	22	5	700	0 8	79	4 2	74 50	314	30 16	105	106	589 260	592.260	Stack 1	1 0000
							1 762			49	15 7															
Average SO_3 Concentration, ppm(v), wet @ 3% O2				12.1	±	5.2						Testing Interval Averages				79	4 0									
															σ	1	0 2									
076 BAI SO2 01	1307	1320	14-Jun-94	2007	±	38	4 384	200	703	6421	2033 9															
							4 268			6251	1980 1															
076 BAI SO2 02	1335	1349	14-Jun-94	2654	±	32	4 861		837	8476	2676 4															
							4 780			8335	2631 8															
076 BAI SO2 03	1403	1417	14-Jun-94	1651	±	4	3.692		665	5115	1648 4															
							3 705			5133	1654 2															
Average SO_2 Concentration, ppm(v), wet @ 3% O2				2104	±	508																				
076 BAO SO3 01	1312	1325	14-Jun-94	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	46.600	49.600	Stack 2	0.9897
							0.824			20	8.6															
076 BAO SO3 02	1341	1355	14-Jun-94	9 8	±	0.12	1.220		74.3	24	9 9	22	5	700	0 8	80	8 1	74 46	311	30.16	100	100	50.100	53.100	Stack 2	0.9897
							1 200			23	9 8															
076 BAO SO3 03	1408	1423	14-Jun-94	11 4	±	0 06	1 037		101	27	11 4	22	5	700	0 8	80	8 0	74 39	311	30.16	100	101	53.400	56.400	Stack 2	0.9897
							1 045			27	11 5															
Average SO_3 Concentration, ppm(v), wet @ 3% O2				10.6	±	1.1						Testing Interval Averages				80	8.1									
															σ	1	0 1									
076 BAO SO2 01	1312	1325	14-Jun-94	2171	±	2	4 011	200	613	5122	2172 0															
							4 006			5116	2169 3															
076 BAO SO2 02	1341	1355	14-Jun-94	2209	±	4	3 936		641	5256	2211 3															
							3 927			5244	2206 3															
076 BAO SO2 03	1408	1423	14-Jun-94	2190	±	11	3 887		645	5223	2182 4															
							3.915			5261	2198 1															
Average SO_2 Concentration, ppm(v), wet @ 3% O2				2190	±	19																				

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

				Concentration		Analytical					Reactor Conditions						Dry Gas Meter								
Week Site Gas Number				ppm (v), dry, @ 3% O_2		$SO_4^=$	Dil	Vol.	$SO_4^=$	SO_3, or SO_2	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% O2		scfm	°F		MW	%	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
076 CAI SO3 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
						2 182			51	15 3															
076 CAI SO3 02	1403	1416	13-Jun-94	21 2	± 0 07	2 628		104	71	21 1	22	5	700	0 8	80	3 3	76 80	304	30 13	87	89	574 000	577.000	Stack 1	1 0000
						2 640			72	21 2															
076 CAI SO3 03	1427	1442	13-Jun-94	20 1	± 0 13	2 452		105	67	20 1	22	5	700	0 8	80	3 4	76 25	306	30 13	91	93	577 400	580 400	Stack 1	1.0000
						2 429			66	20 0															
Average SO_3 Concentration, ppm(v), wet @ 3% O2				20.6	± 0.8						Testing Interval Averages				80	3 4									
													σ		0	0.1									
076 CAI SO2 01	1338	1350	13-Jun-94	1860	± 17	5 457	200	553	6287	1872 1															
						5 386			6205	1847 7															
076 CAI SO2 02	1403	1416	13-Jun-94	1805	± 0	4 901		596	6085	1805 0															
						4 902			6087	1805 4															
076 CAI SO2 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% O2				1822	± 33																				
076 CAO SO3 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 SO3 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	306	30.13	92	92	39.300	42.300	Stack 2	0.9897
						1.951			38	13 2															
076 CAO SO3 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	306	30 13	92	92	42.600	45.600	Stack 2	0.9897
						1 365			37	12 7															
Average SO_3 Concentration, ppm(v), wet @ 3% O2				13.0	± 0.3						Testing Interval Averages				80	5 5									
													σ		0	0.1									
076 CAO SO2 01	1342	1356	13-Jun-94	1963 4	± 3 7	4 474	200	612	5704	1960 8															
						4 486			5720	1966 0															
076 CAO SO2 02	1408	1421	13-Jun-94	1953 4	± 9 1	4 286		632	5643	1959 8															
						4 258			5606	1947 0															
076 CAO SO2 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% O2				1946	± 24																				

Table A-5 (Reference Table 3-3)

Week	Site	Gas	Number				Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
							ppm (v), dry, @ 3% O_2			$SO_4^=$	Dil	Vol.	$SO_4^=$	SO_3, or SO_2	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% O2		scfm	°F		MW	%	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
004	AAI	SO3	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	SO3	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	679.960	Stack 1	0.9980
										4 637			79	24 3															
004	AAI	SO3	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% O2							21.0	±	2.7						Testing Interval Averages				80	4 4									
																		σ	0	0 1									
004	AAI	SO2	01	0956	1010	17-Oct-94	1954	±	0 7	3 812	200	792	6290	1953 4															
										3 814			6293	1954 5															
004	AAI	SO2	02	1026	1040	17-Oct-94	1896	±	2 2	3.679		806	6178	1897 6															
										3 673			6168	1894 6															
004	AAI	SO2	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% O2							1890	±	67																				
004	AAO	SO3	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	SO3	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	SO3	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% O2							16.6	±	3.1						Testing Interval Averages				80	7									
																		σ	0	0 2									
004	AAO	SO2	01	0949	1001	17-Oct-94	1358	±	5 9	2 783	200	626	3829	1362 6															
										2 766			3607	1354.2															
004	AAO	SO2	02	1020	1037	17-Oct-94	1429	±	4 8	2 935		637	3895	1432 0															
										2.921			3876	1425 2															
004	AAO	SO2	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% O2							1413	±	48																				

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

							Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
Week	Site	Gas	Number				ppm (v), dry, @ 3% O_2			$SO_4^=$	Dil	Vol.	$SO_4^=$	SO_3, or SO_2	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% O2		scfm	°F		MW	%	STD l, dry	°K	In. Hg	°F	°F	ft³	ft³		
093	BAI	SO3	01	1307	1322	11-Oct-94	4.8	±	0.01	1.285	12.5	98.3	16	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
										1.283			16	4.8															
093	BAI	SO3	02	1347	1400	11-Oct-94	4.6	±	0.01	1.169		103	16	4.6	22	5000	700	0.8	88	3.6	78.47	296	30.00	73	73	582.600	585.600	Stack 1	0.998
										1.167			16	4.6															
093	BAI	SO3	03	1415	1429	11-Oct-94	3.0	±	0.05	0.738		106	10	3.0	22	5000	700	0.8	89	3.7	78.40	296	30.00	73	74	585.600	588.600	Stack 1	0.998
										0.722			10	3.0															
Average SO_3 Concentration, ppm(v), wet @ 3% O2							3.8	±	1.2						Testing Interval Averages				88	3.6									
																		σ	1	0.2									
093	BAI	SO2	01	1307	1322	11-Oct-94	2002	±	0.0	4.264	200	772	6858	2002.4															
										4.264			6858	2002.4															
093	BAI	SO2	02	1347	1400	11-Oct-94	2028	±	5.8	4.201		783	6853	2024.0															
										4.218			6881	2032.2															
093	BAI	SO2	03	1415	1429	11-Oct-94	2064	±	7.6	4.425		755	6960	2069.6															
										4.402			6924	2058.9															
Average SO_3 Concentration, ppm(v), wet @ 3% O2							2032	±	31																				
093	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
										2.913			28	11.7															
093	BAO	SO3	01	1340	1354	11-Oct-94	8.4	±	0.03	1.641		100	21	8.3	22	5000	700	0.8	88	7.8	78.36	294	30.00	67	71	476.000	479.000	SRI 3	0.9891
										1.648			21	8.4															
093	BAO	SO3	01	1408	1425	11-Oct-94	8.8	±	0.02	1.497		118	23	8.8	22	5000	700	0.8	89	7.6	78.51	293	30.00	68	68	479.600	482.600	SRI 3	0.9891
										1.492			23	8.8															
Average SO_3 Concentration, ppm(v), wet @ 3% O2							9.6	±	- 1.8						Testing Interval Averages				88	8									
																		σ	1	1									
093	BAO	SO2	01	1300	1315	11-Oct-94	1729	±	2.1	3.515	200	566	4145	1730.2															
										3.509			4138	1727.2															
093	BAO	SO2	01	1340	1354	11-Oct-94	1817	±	4.5	2.856		783	4659	1819.8															
										2.846			4643	1813.4															
093	BAO	SO2	01	1408	1425	11-Oct-94	1633	±	6.8	2.883		710	4264	1637.6															
										2.866			4239	1627.9															
Average SO_2 Concentration, ppm(v), wet @ 3% O2							1726	±	92																				

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

Week	Site	Gas	Number				Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
							ppm (v), dry, @ 3% O$_2$			SO$_4^=$	Dil	Vol.	SO$_4^=$	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% O2		scfm	°F		MW	%	STD l, 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	296	29.94	74	74	549.700	552.700	Stack 1	0.998
										1.094			16.8	4.7															
093	CAI	SO3	03	1041	1056	10-Oct-94	3.5	±	0.04	0.860		111	12.4	3.5	22	5000	700	0.8	89	2.7	78.31	296	29.94	73	73	553.000	556.000	Stack 1	0.998
										0.874			12.6	3.6															
Average SO$_3$ Concentration, ppm(v), wet @ 3% O2							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	1982.5															
										4.184			6912	1986.3															
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	1056	10-Oct-94	1944	±	0.3	4.441		747	6911	1944.2															
										4.440			6910	1943.8															
Average SO$_3$ Concentration, ppm(v), wet @ 3% O2							1949	±	14																				
093	CAO	SO3	01	0926	0641	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	296	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	1036	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$_3$ Concentration, ppm(v), wet @ 3% O2							7.3	±	0.5						Testing Interval Averages				89	4									
																		σ	1	0									
093	CAO	SO2	01	0926	0641	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	1036	1050	10-Oct-94	1495	±	6.0	3.346		727	5066	1490.5															
										3.365			5097	1498.9															
Average SO$_3$ Concentration, ppm(v), wet @ 3% O2							1479	±	46																				

Table A-6 (Reference Table 3-4)

				Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
Week Site Gas Number				ppm (v), dry, @ 3% O_2			Cl^-	Dil	Vol.	Cl^-	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 I.D	Corr. Factor
	Time, Begin	Time, End	Date	Average		σ	mg/ml		ml	µM	ppm, dry, @ 3% O2		scfm	°F		MW	%	STD l, dry	°K	In. Hg	°F	°F	ft³	ft³		
094 AAI HCl 01	1309	1323	17-Oct	92 4	±	0 32	1 428 1 421	25	783	291 290	92 6 92 2	22	5000	700	0 8	80	4 5	76 85	304	30 18	88	87	683.500	686.500	Stack 1	0 998
094 AAI HCl 02	1334	1347	17-Oct	94 2	±	0 45	1 335 1 344		853	297 299	93 9 94 5	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	1 610 1 600		680	285 283	91 8 91 2	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% O2				93	±	1.9						Testing Interval Averages				80	4 5									
															σ	0	0 1									
093 AAO HCl 01	1304	1319	17-Oct	82 1	±	6 40	0 986 1 101	25	790	203 227	77 6 86 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	1 160 1 146		697	211 208	81 4 80 4	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	1 098 1 088		735	210 208	80 6 79 9	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% O2				81	±	1.0						Testing Interval Averages				80	7									
															σ	0	0									

Table A-6, continued (Reference Table 3-4)

Week	Site	Gas	Number	Time, Begin	Time, End	Date	Concentration ppm (v), dry, @ 3% O_2 Average		σ	Analytical Cl^-	Dil	Vol.	Cl^-	HCl	Reactor Conditions Condition Number	Flow	Temp.	NH_3/NO,	Unit 5 Boiler Load,	Sample O_2	Dry Gas Meter 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, @ 3% O2		scfm	°F		MW	%	STD l, dry	°K	In. Hg	°F	°F	ft³	ft³		
093	BAJ	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
										1 626			341	100 3															
093	BAJ	HCl	02	1018	1031	11-Oct	97 6	±	0 15	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															
093	BAJ	HCl	03	1046	1059	11-Oct	104 8	±	0 61	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% O2							101	±	5.0						Testing Interval Averages				89	3 4									
																		σ	1	0 1									
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
										1.214			234	88 7															
093	BAO	HCl	02	1012	1028	11-Oct	95 0	±	6 92	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															
093	BAO	HCl	03	1041	1055	11-Oct	96 0	±	1 77	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% O2							93	±	4.1						Testing Interval Averages				88	8									
																		σ	1	1									

Table A-6, continued (Reference Table 3-4)

Week Site Gas Number				Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
				ppm (v), dry, @ 3% O_2			Cl$^-$	Dil	Vol.	Cl$^-$	HCl	Condition Number	Flow	Temp.	NH_3/NO,	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% O2		scfm	°F		MW	%	STD l, dry	°K	In. Hg	°F	°F	ft³	ft³		
093 CAI HCl 01	1329	1343	10-Oct	106.5	±	11.72	2.009	25	777	407	114.8	22	5000	700	0.8	89	2.6	77.58	299	29.94	79	77	556.200	559.200	Stack 1	0.998
							1.719			348	98.2															
093 CAI HCl 02	1359	1412	10-Oct	96.9	±	2.42	1.612		807	339	95.2	22	5000	700	0.8	89	2.6	77.95	297	29.94	76	75	559.700	562.700	Stack 1	0.998
							1.670			351	98.7															
093 CAI HCl 03	1424	1436	10-Oct	102.6	±	0.31	1.644		848	362	102.8	22	5000	700	0.8	88	2.8	78.02	297	29.94	75	75	563.100	566.100	Stack 1	0.998
							1.637			361	102.4															
Average HCl Concentration, ppm(v), wet @ 3% O2				100	±	4.0						Testing Interval Averages				89	2.7									
															σ	1	0.1									
093 CAO HCl 01	1324	1339	10-Oct	85.2	±	0.95	1.540	25	720	289	85.9	22	5000	700	0.8	89	3.5	77.47	296	29.94	74	74	449.200	452.200	SRI 3	0.9891
							1.516			284	84.6															
093 CAO HCl 02	1353	1408	10-Oct	85.5	±	1.15	1.516		725	286	84.7	22	5000	700	0.8	89	3.4	77.40	297	29.94	74	75	453.500	456.500	SRI 3	0.9891
							1.545			292	86.4															
093 CAO HCl 03	1418	1434	10-Oct	83.9	±	0.73	1.554		701	284	84.5	22	5000	700	0.8	89	3.5	77.40	297	29.94	74	75	457.400	460.400	SRI 3	0.9891
							1.535			280	83.4															
Average HCl Concentration, ppm(v), wet @ 3% O2				86	±	0.8						Testing Interval Averages				89	3									
															σ	0	0									

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_2O	7.98 % wet	Duct Area	3.36 ft^2
Ambient Pressure	30.04 in. Hg		
Stack Pressure	-21.0 in. H_2O		
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_2O
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.

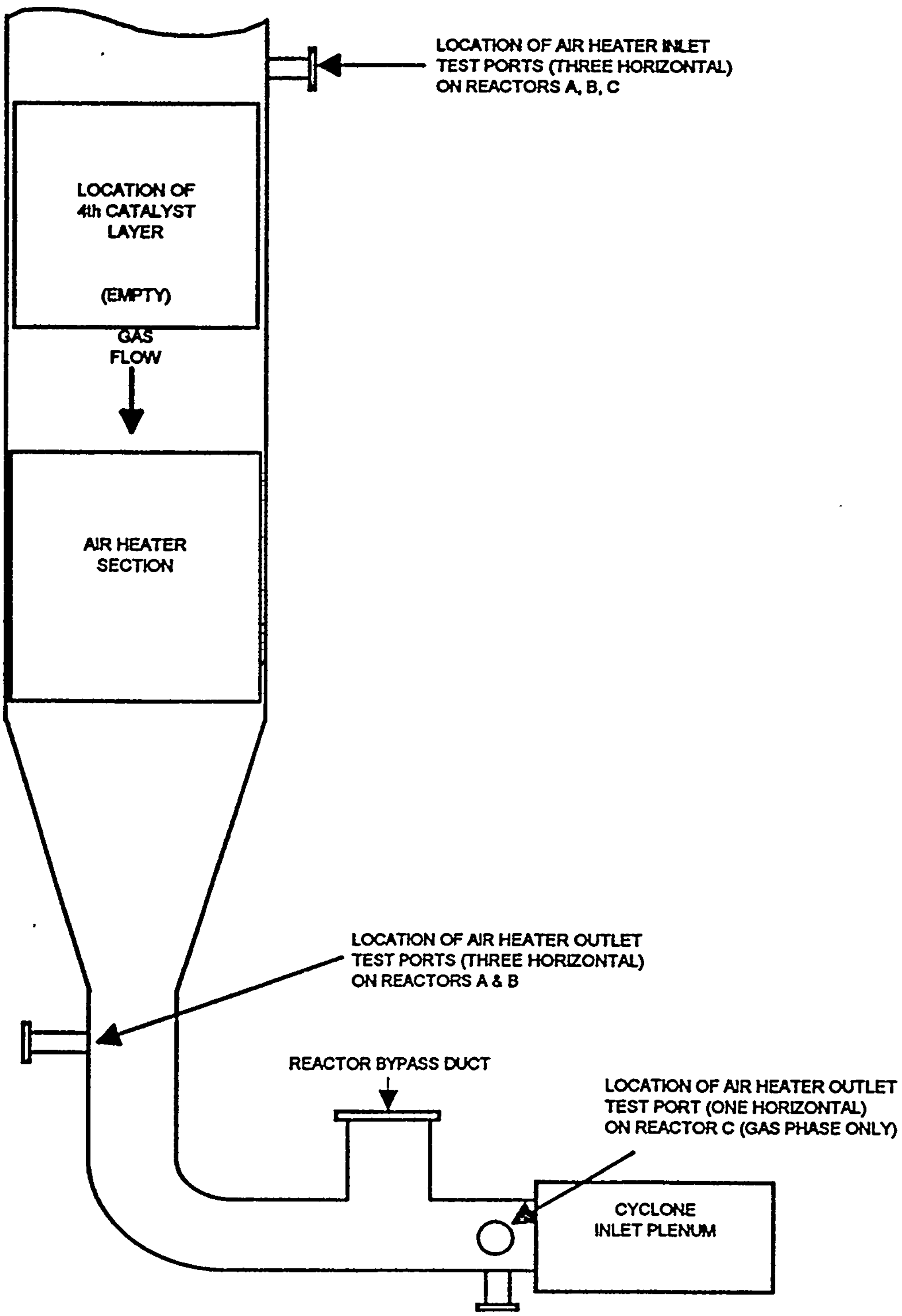

Figure 2-1. Schematic drawing of SCR air heater cross section (side view).

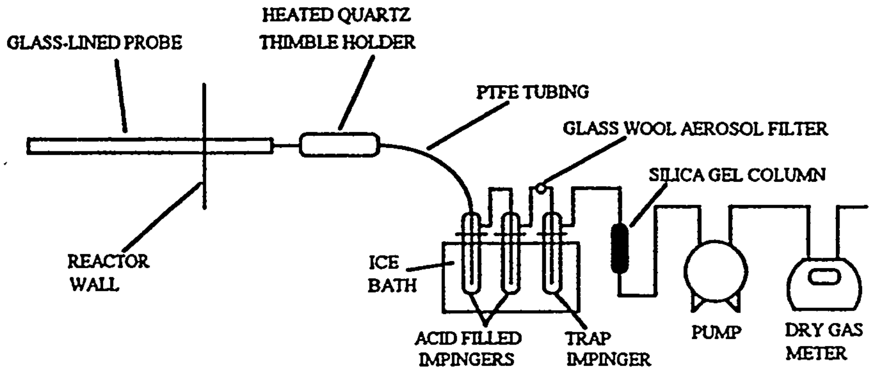

Figure 2-2. Schematic diagram of the ammonia sampling train.

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 ft^3 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 NH_3/NO_x ratio of 0.8.

The impinger solutions are made alkaline in the laboratory (converting the NH_4^+ ion to free NH_3 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, SO_2 and SO_3 concentrations were measured simultaneously at the reactor outlet downstream of the third catalyst layer (air heater inlet) and the air heater outlet. Sulfur dioxide (SO_2) and sulfur trioxide (SO_3) 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).

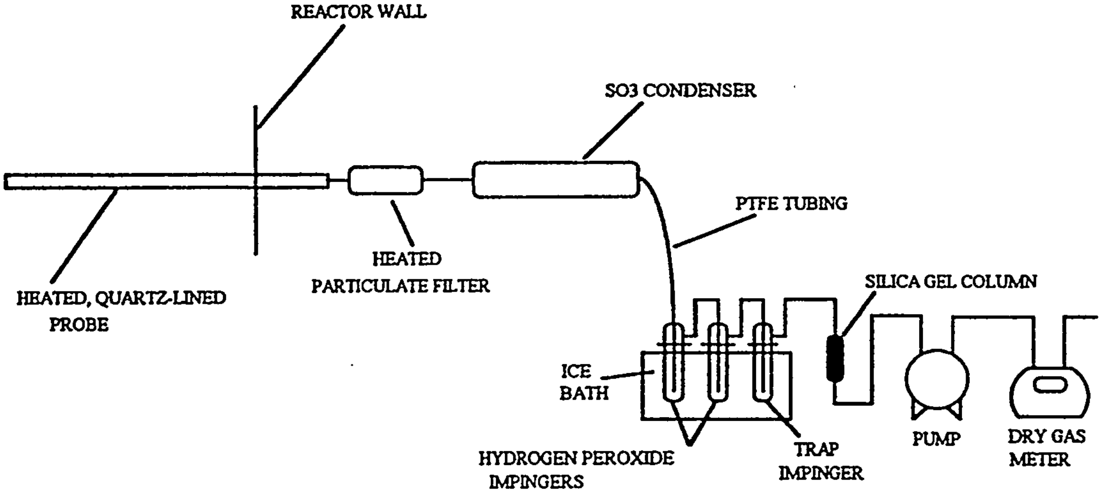

Figure 2-3. Schematic diagram of the controlled condensation sampling train for SO_2 and SO_3.

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 ^{o}F. The sample then passes through a quartz filter housed in a heated quartz filter holder, also maintained at 550 ^{o}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 ^{o}F and 130 ^{o}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

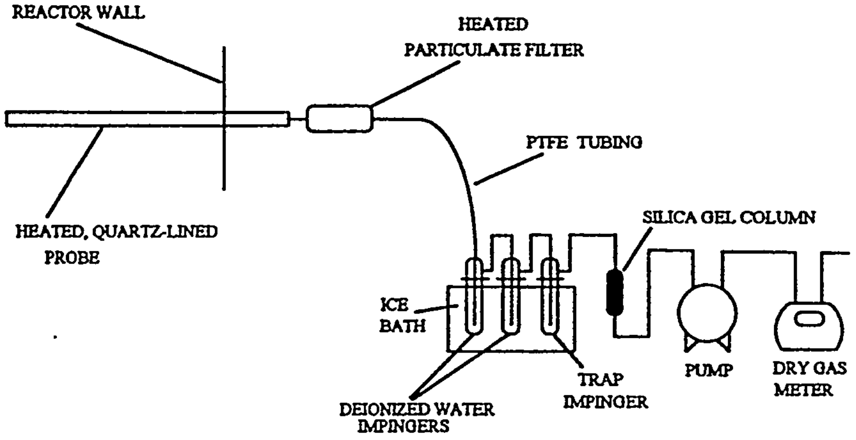

Figure 2-4. Schematic diagram of the chloride sampling train.

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.

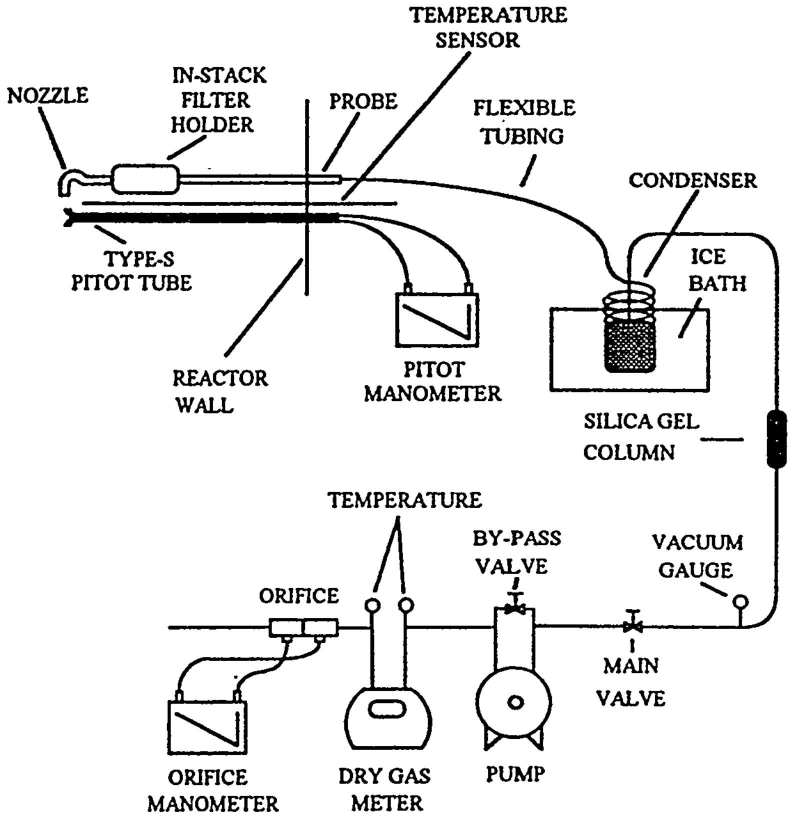

Figure 2-5. Schematic drawing of the mass concentration sampling train.

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 (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 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 µg/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	$\frac{NH_3}{NO_x}$	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, µg/g	Estimated Upper Limit Solid-Phase NH_3, µg/g	Estimated Lower Limit Solid-Phase NH_3, µg/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			
			Outlet	<0.3	Contaminated			
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, µg/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 ± 58 ppm(v) dry @ 3% O_2, while the air heater outlet SO_2 concentrations averaged 1,852 ± 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: SO_2 and SO_3 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% O_2. Air heater outlet HCl concentrations fell within the range of 237 ± 12 to 258 ± 8 ppm(v) dry @ 3% O_2. 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

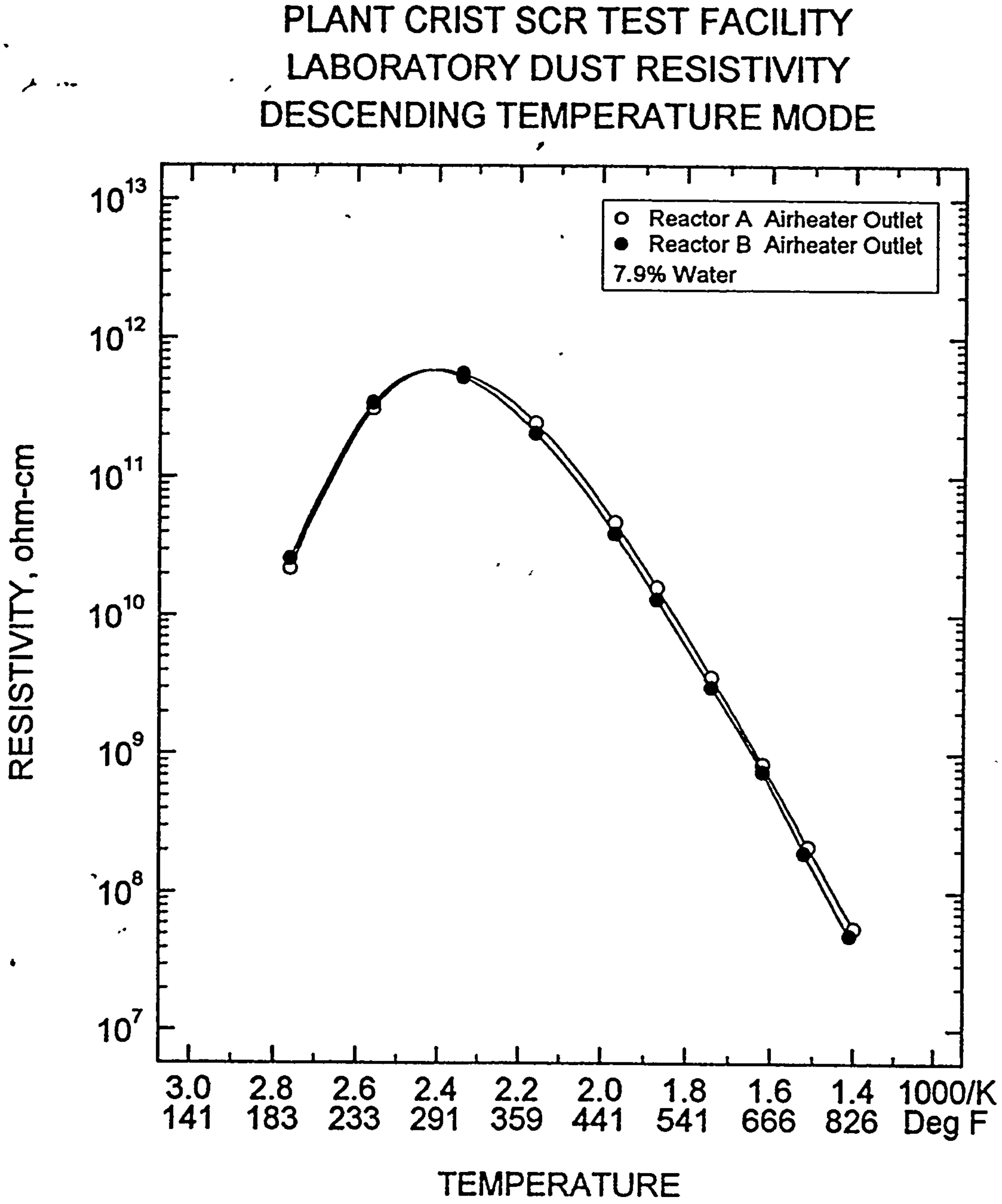

Figure 3-1. Resistivity/temperature relationship for air heater inlet and outlet fly ashes.

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_2O_3	23.73	24.03	24.77	25.04
TiO_2	1.15	1.15	1.2	1.24
Fe_2O_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_2O	2.76	2.81	2.92	2.96
Na_2O	0.94	0.96	0.98	1.04
SO_3	0.79	0.88	0.69	0.95
P_2O_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.

	Reactor A 11/8/94		Reactor B 11/9/94		
	Air Heater Inlet	Air Heater Outlet	Air Heater Inlet	Air Heater Outlet	
Element	Concentration (ppm)				Element
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.

SO_2 AND SO_3 CONCENTRATIONS

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 ± 58 ppm(v) dry @ 3% O_2, while the air heater outlet SO_2 concentrations averaged 1,852 ± 66 ppm(v) dry @ 3% O_2. Within the tolerance of the standard deviations given for average SO_2 concentrations in Table 3-2, there was no statistical difference in the concentrations of SO_2 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% O_2. Air heater outlet HCl concentrations fell within the range of 237 ± 12 to 258 ± 8 ppm(v) dry @ 3% O_2. 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

NH_3 Concentrations
SO_2 Concentrations
SO_3 Concentrations
HCl Concentrations
Particulate Mass Concentrations

Table A-1 (Reference Table 3-1)

							NH₃ Concentration			Reactor Conditions											Analytical					Dry Gas Meter			
Week	Site	Gas	Number				ppm (v), dry, @ 3% O₂			Condition Number	Flow	Temp,	NH₃/NOₓ	Unit 6 Boiler Load,	Sample O₂	NH₃, as N	Dil	Vol.	NH₃	NH₃	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	%	µg/ml		ml	µM	ppm, dry, 3% O₂	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
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
																0.266			6.6	1.1									
102	AAI	NHG	06	1026	1059	15-Dec-94	1.3	±	0.03	22	5000	700	0.8	86	4.5	0.389		286	7.9	1.3	150.33	304	30.25	84	90	699.500	705.500	Stack 3	0.973
																0.400			8.2	1.3									
102	AAI	NHG	07	1124	1155	15-Dec-94	1.3	±	0.01	22	5000	700	0.8	84	4.8	0 325		346	8.0	1.3	149.51	305	30.25	88	92	705.700	711.700	Stack 3	0.973
																0.329			8.1	1.4									
Average NH₃ Concentration, ppm(v), dry @ 3% O₂							1.2	±	0.16	Testing Interval Averages				85	4.6														
													σ	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
																0.465			7.5	1.2									
102	AAI	NHS	06	1026	1059	15-Dec-94	1.4	±	0.02	22	5000	700	0.8	86	4.5	0.510		232	8.5	1.4	150.33	304	30.25	84	90	699.500	705.500	Stack 3	0.973
																0.522			8.7	1.4									
102	AAI	NHS	07	1124	1155	15-Dec-94	1.1	±	0.02	22	5000	700	0.8	84	4.8	0.447		199	6.4	1.1	149.51	305	30.25	88	92	705.700	711.700	Stack 3	0.973
																0.456			6.5	1.1									
Average NH₃ Concentration, ppm(v), dry @ 3% O₂							1.2	±	0.16	Testing Interval Averages				85	4.6														
													σ	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
																0.025			1.7	0.3									
102	AAO	NHG	06	1036	1104	15-Dec-94	< 0.3			22	5000	700	0.8	86	7.8	0.032		236	1.7	0.3	161.92	290	30.25	61	64	163.500	169.500	Stack 1	1.001
																0.033			1.7	0.3									
102	AAO	NHG	07	1133	1201	15-Dec-94	< 0.3			22	5000	700	0.8	84	7.4	0.029		227	1.6	0.3	160.99	292	30.25	63	68	169.900	175.900	Stack 1	1.001
																0.029			1.6	0.3									
Average NH₃ Concentration, ppm(v), dry @ 3% O₂							< 0.3			Testing Interval Averages				85	7.5														
													σ	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
																1.770			22.1	4.0									
102	AAO	NHS	06	1036	1104	15-Dec-94	4.0	±	0.04	22	5000	700	0.8	86	7.8	2.130		139	21.1	4.0	161.92	290	30.25	61	64	163.500	169.500	Stack 1	1.001
																2.160			21.4	4.1									
102	AAO	NHS	07	1133	1201	15-Dec-94	3.6	±	0.01	22	5000	700	0.8	84	7.4	1.860		145	19.3	3.6	160.99	292	30.25	63	68	169.900	175.900	Stack 1	1.001
																1.870			19.4	3.6									
Average NH₃ Concentration, ppm(v), dry @ 3% O₂							3.9	±	0.25	Testing Interval Averages				85	7.5														
													σ	1	0.2														

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

W e e k	S i t e	C a s e	N u m b e r				NH_3 Concentration				Reactor Conditions											Analytical					Dry Gas Meter			
				Time, Begin	Time, End	Date	ppm (v), dry, @ 3% O_2	Average		σ	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 I.D.	Corr. Factor
												acfm	°F		MW	%	µg/ml		ml	µM	ppm, dry, 3% O_2	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
102	AAI	NHG	01	1354	1432	14-Dec-94		2.2	±	0.00	24	5000	700	1.0	83	4.2	0.556	1	364	14.5	2.2	154.90	294	30.20	64	76	668.500	674.500	Stack 3	0.973
																	0.556			14.5	2.2									
102	AAI	NHG	02	1458	1533	14-Dec-94		2.9	±	0.04	24	5000	700	1.0	83	4.2	0.722		348	17.9	2.8	152.17	299	30.20	76	83	674.800	680.800	Stack 3	0.973
																	0.737			18.3	2.9									
102	AAI	NHG	03	1618	1655	14-Dec-94		3.7	±	0.07	24	5000	700	1.0	84	4.3	0.845		380	22.9	3.7	151.33	301	30.20	82	83	681.000	687.000	Stack 3	0.973
																	0.869			23.6	3.8									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2								2.9	±	0.74	Testing Interval Averages				83	4.2														
														σ	1	0.1														
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
																	1.320			21.6	3.3									
102	AAI	NHS	02	1458	1533	14-Dec-94		3.7	±	0.03	24	5000	700	1.0	83	4.2	1.510		215	23.2	3.7	152.17	299	30.20	76	83	674.800	680.800	Stack 3	0.973
																	1.530			23.5	3.7									
102	AAI	NHS	03	1618	1655	14-Dec-94		5.4	±	0.10	24	5000	700	1.0	84	4.3	2.220		209	33.1	5.3	151.33	301	30.20	82	83	681.000	687.000	Stack 3	0.973
																	2.280			34.0	5.4									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2								4.1	±	1.08	Testing Interval Averages				83	4.2														
														σ	1	0.1														
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
																	0.062			1.9	0.4									
102	AAO	NHG	02	1508	1537	14-Dec-94	<	0.4			24	5000	700	1.0	83	7.5	0.039		284	2.0	0.4	161.34	291	30.20	64	63	140.200	146.200	Stack 1	1.001
																	0.035			2.0	0.4									
102	AAO	NHG	03	1626	1655	14-Dec-94	<	0.4			24	5000	700	1.0	84	7.3	0.033		286	2.0	0.4	161.96	289	30.20	61	62	146.500	152.500	Stack 1	1.001
																	0.021			2.0	0.4									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2							<	0.4			Testing Interval Averages				83	7.5														
														σ	1	0.3														
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
																	2.390			29.2	5.5									
102	AAO	NHS	02	1506	1537	14-Dec-94		5.7	±	0.05	24	5000	700	1.0	83	7.5	2.330		184	30.6	5.7	161.34	291	30.20	64	63	140.200	146.200	Stack 1	1.001
																	2.360			31.0	5.8									
102	AAO	NHS	03	1626	1655	14-Dec-94		6.9	±	0.10	24	5000	700	1.0	84	7.3	2.360		224	37.8	6.9	161.96	289	30.20	61	62	146.500	152.500	Stack 1	1.001
																	2.410			38.6	7.0									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2								6.8	±	0.80	Testing Interval Averages				83	7.5														
														σ	1	0.3														

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

Week	Site	Gas	Number				NH_3 Concentration ppm (v), dry, @ 3% O_2			Reactor Conditions											Analytical					Dry Gas Meter			
				Time, Begin	Time, End	Date	Average		σ	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 I.D.	Corr. Factor
											scfm	°F		MW	%	µg/ml		ml	µM	ppm, dry, 3% O_2	STD l, dry	°K	in. Hg	°F	°F	ft³	ft³		
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	Gas	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 I.D.	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
																3.270			78.7	13.0									
102	BAI	NHG	06	1436	1520	16-Dec-94	17.5	±	0.14	24	400	705	1.0	83	4.9	4.320		337	104	17.4	150.04	304	30.22	85	90	763.500	769.500	Stack 3	0.973
																4.370			105	17.6									
102	BAI	NHG	07	1545	1620	16-Dec-94	21.8	±	0.33	24	400	705	1.0	83	4.9	5.600		322	129	21.6	149.50	305	30.22	87	92	770.200	776.200	Stack 3	0.973
																5.720			132	22.1									
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
																2.830			41.4	6.8									
102	BAI	NHS	06	1436	1520	16-Dec-94	13.2	±	0.16	24	400	705	1.0	83	4.9	3.440		318	78.1	13.1	150.04	304	30.22	85	90	763.500	769.500	Stack 3	0.973
																3.500			79.5	13.3									
102	BAI	NHS	07	1545	1620	16-Dec-94	16.8	±	0.24	24	400	705	1.0	83	4.9	6.380		218	99.3	16.7	149.50	305	30.22	87	92	770.200	776.200	Stack 3	0.973
																6.510			101	17.0									
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
																0.035			2.2	0.4									
102	BAO	NHG	06	1445	1515	16-Dec-94	0.9	±	0.02	24	400	705	1.0	83	7.8	0.230		268	4.4	0.8	158.57	296	30.22	73	73	226.300	232.300	Stack 1	1.001
																0.236			4.5	0.9									
102	BAO	NHG	07	1549	1619	16-Dec-94	1.9	±	0.05	24	400	705	1.0	83	7.8	0.446		328	10.4	2.0	161.14	291	30.22	67	62	232.700	238.700	Stack 1	1.001
																0.430			10.1	1.9									
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	3.090	1	175	38.6	7.5	158.12	297	30.22	77	72	219.800	225.800	Stack 1	1.001
																3.170			39.6	7.7									
102	BAO	NHS	06	1445	1515	16-Dec-94	10.8	±	0.17	24	400	705	1.0	83	7.8	4.890		158	55.2	10.7	158.57	296	30.22	73	73	226.300	232.300	Stack 1	1.001
																5.000			56.4	10.9									
102	BAO	NHS	07	1549	1619	16-Dec-94	20.2	±	0.00	24	400	705	1.0	83	7.8	8.380		178	107	20.2	161.14	291	30.22	67	62	232.700	238.700	Stack 1	1.001
																8.380			107	20.2									
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)

Week	Site	Gas	Number				NH_3 Concentration			Reactor Conditions											Analytical					Dry Gas Meter			
				Time, Begin	Time, End	Date	ppm (v), dry, @ 3% O_2 Average		σ	Condition Number	Flow	Temp.	NH_3/ NO_x	Unit 5 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 I.D.	Corr. Factor
											acfm	°F		MW	%	µg/ml		ml	µM	ppm, dry, 3% O_2	STD l, dry	°K	in. Hg	°F	°F	ft^3	ft^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
																7.130			144	22.6									
103	CAI	NHG	06	1451	1523	20-Dec-94	19.1	±	0.23	24	400	705	1.0	82	4.4	5.140		318	117	18.9	150.18	304	30.22	82	92	859.600	865.600	Stack 3	0.973
																5.230			119	19.2									
103	CAI	NHG	07	1541	1614	20-Dec-94	20.1	±	0.00	24	400	705	1.0	83	4.1	4.670		377	126	20.1	149.50	305	30.22	88	91	866.000	872.000	Stack 3	0.973
																4.670			126	20.1									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2							20.5	±	1.76	Testing Interval Averages				83	4.2														
													σ	1	0.2														
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
																6.770			96.2	15.1									
103	CAI	NHS	06	1451	1523	20-Dec-94	14.3	±	0.05	24	400	705	1.0	82	4.4	5.920		209	88.4	14.3	150.18	304	30.22	82	92	859.600	865.600	Stack 3	0.973
																5.950			88.8	14.4									
103	CAI	NHS	07	1541	1614	20-Dec-94	14.6	±	0.00	24	400	705	1.0	83	4.1	6.020		212	91.2	14.6	149.50	305	30.22	88	91	866.000	872.000	Stack 3	0.973
																6.020			91.2	14.6									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2							14.6	±	0.36	Testing Interval Averages				83	4.2														
													σ	1	0.2														
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
																0.033			2.1	0.3									
103	CAO	NHG	06	1507	1537	20-Dec-94	0.5	±	0.03	24	400	705	1.0	82	4.3	0.156		295	3.3	0.5	161.14	291	30.22	64	65	312.600	318.600	Stack 1	1.001
																0.168			3.5	0.5									
103	CAO	NHG	07	1557	1627	20-Dec-94	1.3	±	0.06	24	400	705	1.0	83	4.0	0.400		308	8.8	1.3	160.83	292	30.22	65	66	309.000	315.000	Stack 1	1.001
																0.424			9.3	1.4									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2							0.7	±	0.54	Testing Interval Averages				83	4.3														
													σ	1	0.3														
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
																8.830			120	18.1									
103	CAO	NHS	06	1507	1537	20-Dec-94	17.6	±	0.11	24	400	705	1.0	82	4.3	4.610	2	178	117	17.6	161.14	291	30.22	64	65	312.600	318.600	Stack 1	1.001
																4.650			118	17.7									
103	CAO	NHS	07	1557	1627	20-Dec-94	18.0	±	0.06	24	400	705	1.0	83	4.0	5.950	2	144	122	18.1	160.83	292	30.22	65	66	309.000	315.000	Stack 1	1.001
																5.920			122	18.0									
Average NH_3 Concentration, ppm(v), dry @ 3% O_2							18.0	±	0.30	Testing Interval Averages				83	4.3														
													σ	1	0.3														

Table A-2 (Reference Table 3-2)

Week	Site	Gas	Number				Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
							ppm (v), dry, @ 3% O_2			$SO_4^=$	Dil	Vol.	$SO_4^=$	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	Average		σ	µg/ml		ml	µM	ppm(v), dry, @ 3% O2		acfm	°F		MW	%	STD L, dry	°K	in. Hg	°F	°F	ft³	ft³		
102	AAI	SO3	01	1402	1416	15-Dec-94	17.7	±	0.12	2.519	25	82.9	54	17.8	22	5	700	0.8	84	4.6	75.30	303	30.25	82	90	712.100	715.100	Stack 3	0.9730
										2.494			54	17.6															
102	AAI	SO3	02	1429	1443	15-Dec-94	22.4	±	0.06	3.211		83.3	70	22.4	22	5	700	0.8	85	4.1	74.15	308	30.25	91	98	715.800	718.800	Stack 3	0.9730
										3.198			69	22.3															
102	AAI	SO3	03	1458	1511	15-Dec-94	22.1	±	0.02	2.979		88.0	68	22.1	22	5	700	0.8	85	4.1	73.75	309	30.25	94	101	719.200	722.200	Stack 3	0.9730
										2.976			68	22.1															
Average SO_3 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	200	666	5501	1797.1															
										3.903			5415	1769.0															
102	AAI	SO2	02	1429	1443	15-Dec-94	1788	±	1	4.079		654	5558	1788.9															
										4.077			5555	1788.0															
102	AAI	SO2	03	1458	1511	15-Dec-94	1775	±	1	3.850		682	5483	1774.4															
										3.863			5489	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	25	80.1	40	14.8	22	5	700	0.8	84	7.5	80.34	292	30.25	66	67	176.300	179.300	Stack 1	1.0010
										1.900			40	14.8															
102	AAO	SO3	02	1433	1448	15-Dec-94	18.2	±	0.05	2.333		82.4	50	18.3	22	5	700	0.8	85	7.2	80.27	292	30.25	67	67	179.700	182.700	Stack 1	1.0010
										2.324			50	18.2															
102	AAO	SO3	03	1500	1515	15-Dec-94	15.0	±	0.11	2.036		77.3	41	14.9	22	5	700	0.8	85	7.2	80.42	292	30.25	66	66	183.100	186.100	Stack 1	1.0010
										2.057			41	15.1															
Average SO_3 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	200	689	5017	1868.4															
										3.461			4968	1850.2															
102	AAO	SO2	02	1433	1448	15-Dec-94	1795	±	0	3.069		770	4923	1795.1															
										3.068			4922	1794.5															
102	AAO	SO2	03	1500	1515	15-Dec-94	1786	±	2	2.882		818	4911	1787.4															
										2.877			4903	1784.3															
Average SO_2 Concentration, ppm(v), wet @ 3% O_2							1813.3	±	40.1																				

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

Week Site Gas Number				Concentration			Analytical					Reactor Conditions						Dry Gas Meter								
				ppm (v), dry, @ 3% O_2			$SO_4^=$	Dil	Vol.	$SO_4^=$	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	Average		σ	µg/ml		ml	µM	ppm(v), dry, @ 3% O2		scfm	°F		MW	%	STD L, dry	°K	in. Hg	°F	°F	ft^3	ft^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	298	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	78	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_3 Concentration,				6.0	±	1.7						Testing Interval Averages				83	4.7									
ppm(v), wet @ 3% O2															σ	1	0.2									
102 BAI SO2 01	0907	0921	17-Dec-94	1847	±	6	4.381	200	633	5777	1851.2															
							4.360			5750	1842.4															
102 BAI SO2 02	0934	0947	17-Dec-94	1865	±	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,				1858.7	±	10.3																				
ppm(v), wet @ 3% O2																										
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	80.18	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	246.800	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_3 Concentration,				9.1	±	0.4						Testing Interval Averages				83	7.5									
ppm(v), wet @ 3% O2															σ	1	0.1									
102 BAO SO2 01	0911	0927	17-Dec-94	1805	±	9	3.484	200	664	4820	1798.6															
							3.506			4853	1811.0															
102 BAO SO2 02	0937	0952	17-Dec-94	1805	±	16	3.248		758	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,				1812.3	±	12.8																				
ppm(v), wet @ 3% O2																										

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

Week Site Gas Number				Concentration ppm (v), dry, @ 3% O_2			Analytical					Reactor Conditions						Dry Gas Meter								
	Time, Begin	Time, End	Date	Average		σ	$SO_4^{=}$	Dil	Vol.	$SO_4^{=}$	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
							µg/ml		ml	µM	ppm(v), dry, @ 3% O2		scfm	°F		MW	%	STD L, dry	°K	In. Hg	°F	°F	ft³	ft³		
103 CAI SO3 01	1100	1114	19-Dec-94	1.7	±	0.02	0.260	25	91.5	6	1.7	22	5	700	0.8	88	2.3	78.25	292	30.28	60	72	805.500	808.500	Stack 3	0.9730
							0.264			6	1.7															
103 CAI SO3 02	1133	1147	19-Dec-94	3.3	±	0.00	0.486		94.6	12	3.3	22	5	700	0.8	89	2.1	76.79	297	30.28	70	82	808.600	811.800	Stack 3	0.9730
							0.486			12	3.3															
103 CAI SO3 03	1208	1221	19-Dec-94	1.8	±	0.05	0.339		74.8	7	1.9	22	5	700	0.8	87	2.1	75.93	301	30.28	78	86	812.000	815.000	Stack 3	0.9730
							0.327			6	1.8															
Average SO_3 Concentration, ppm(v), wet @ 3% O2				2.3	±	0.9						Testing Interval Averages				88	2.2									
															σ	1	0.1									
103 CAI SO2 01	1100	1114	19-Dec-94	1919	±	4	4.990	200	671	6976	1921.7															
							4.975			6955	1916.0															
103 CAI SO2 02	1133	1147	19-Dec-94	1886	±	10	4.824		673	6764	1878.6															
							4.860			6814	1892.6															
103 CAI SO2 03	1208	1221	19-Dec-94	1884	±	7	4.305		746	6691	1879.2															
							4.327			6725	1888.8															
Average SO_2 Concentration, ppm(v), wet @ 3% O2				1896.2	±	19.7																				
103 CAO SO3 01	1110	1123	19-Dec-94	5.3	±	0.03	1.434	25	50.3	19	5.2	22	5	700	0.8	88	3.4	82.06	286	30.28	55	57	261.530	264.530	Stack 1	1.0010
							1.445			19	5.3															
103 CAO SO3 02	1143	1158	19-Dec-94	6.3	±	0.01	1.372		61.1	22	6.3	22	5	700	0.8	88	3.8	81.59	288	30.28	58	60	264.930	267.930	Stack 1	1.0010
							1.368			22	6.3															
103 CAO SO3 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	289	30.28	60	63	268.250	271.260	Stack 1	1.0010
							1.264			21	6.0															
Average SO_3 Concentration, ppm(v), wet @ 3% O2				5.9	±	0.5						Testing Interval Averages				88	3.7									
															σ	1	0.2									
103 CAO SO2 01	1110	1123	19-Dec-94	1896	±	14	4.624	200	702	6763	1888.1															
							4.673			6834	1908.2															
103 CAO SO2 02	1143	1158	19-Dec-94	1964	±	2	5.28		621	6831	1963.2															
							5.286			6839	1965.5															
103 CAO SO2 03	1218	1232	19-Dec-94	1927	±	1	4.63		694	6694	1926.8															
							4.633			6699	1928.0															
Average SO_2 Concentration, ppm(v), wet @ 3% O2				1930.0	±	33.2																				

Table A-3 (Reference Table 3-3)

							HCl Concentration			Reactor Conditions						Analytical					Dry Gas Meter								
Week	Site	Gas	Number				ppm (v), dry, @ 3% O_2			Condition Number	Flow	Temp,	$\frac{NH_3}{NO_x}$	Unit 5 Boiler Load,	Sample O_2	Cl^-	Dil	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		σ		scfm	°F		MW	%	µg/ml		ml	µM	ppm, dry, @ 3% O_2	STD L, dry	°K	In. Hg	°F	°F	ft³	ft³		
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	308	30.25	96	94	722.500	725.500	Stack 3	0.973
																1.380			706	222.0									
102	AAI	HCl	02	1611	1628	15-Dec-94	239.8	±	1.64	22	5000	700	0.8	85	4.1	1.347		791	751	241.0	74.42	307	30.25	91	94	726.000	729.000	Stack 3	0.973
																1.334			744	238.7									
102	AAI	HCl	03	1634	1648	15-Dec-94	216.4	±	0.00	22	5000	700	0.8	85	4.2	1.237		766	668	216.4	74.15	308	30.25	92	97	729.300	732.300	Stack 3	0.973
																1.237			668	216.4									
Average HCl Concentration, ppm(v), wet @ 3% O2							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
																1.105			616	223.2									
102	AAO	HCl	02	1614	1628	15-Dec-94	242.7	±	5.30	22	5000	700	0.8	85	7.2	1.348		835	794	246.4	94.27	291	30.25	63	64	189.900	193.400	Stack 1	1.0010
																1.307			770	238.9									
102	AAO	HCl	03	1638	1652	15-Dec-94	245.7	±	3.74	22	5000	700	0.8	85	7.2	1.057		852	635	243.0	76.49	307	30.25	93	93	193.800	196.800	Stack 1	1.0010
																1.060			649	248.3									
Average HCl Concentration, ppm(v), wet @ 3% O2							237.4	±	11.7	Testing Interval Averages				85	7														
													σ	0	0														

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

Week	Site	Gas	Number				HCl Concentration			Reactor Conditions						Analytical					Dry Gas Meter								
							ppm (v), dry, @ 3% O_2			Condition Number	Flow	Temp,	NH_3/NO_x	Unit 8 Boiler Load,	Sample O_2	Cl^-	Dil	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		σ		scfm	°F		MW	%	µg/ml		ml	µM	ppm, dry, @ 3% O_2	STD L, dry	°K	in. Hg	°F	°F	ft³	ft³		
102	BAI	HCl	01	1027	1043	17-Dec-94	257.7	±	2.38	22	5000	700	0.8	82	5.1	1.448	25	733	749	256.0	74.19	307	30.16	92	93	792.800	795.800	Stack 3	0.973
																1.467			758	259.4									
102	BAI	HCl	02	1057	1111	17-Dec-94	248.7	±	0.78	22	5000	700	0.8	82	4.9	1.582		658	734	248.2	74.13	307	30.16	92	94	796.100	799.100	Stack 3	0.973
																1.569			737	249.3									
102	BAI	HCl	03	1117	1130	17-Dec-94	242.7	±	0.44	22	5000	700	0.8	82	4.6	1.545		671	731	243.0	73.99	307	30.16	92	96	799.500	802.500	Stack 3	0.973
																1.541			729	242.4									
Average HCl Concentration, ppm(v), wet @ 3% O2							245.7	±	4.2	Testing Interval Averages				82	4.9														
													σ	0	0.3														
102	BAO	HCl	01	1031	1045	17-Dec-94	246.6	±	0.88	22	5000	700	0.8	82	7.5	1.195	25	780	657	247.2	79.57	294	30.16	69	71	250.700	253.700	Stack 1	1.0010
																1.189			654	245.9									
102	BAO	HCl	02	1101	1115	17-Dec-94	244.2	±	0.58	22	5000	700	0.8	82	7.6	1.193		764	643	243.7	79.50	294	30.16	71	70	254.100	257.100	Stack 1	1.0010
																1.197			645	244.6									
102	BAO	HCl	03	1121	1135	17-Dec-94	242.6	±	4.09	22	5000	700	0.8	82	7.5	1.147		808	654	245.5	79.65	294	30.16	69	70	257.400	260.400	Stack 1	1.0010
																1.120			638	239.8									
Average HCl Concentration, ppm(v), wet @ 3% O2							244.5	±	2.0	Testing Interval Averages				82	8														
													σ	0	0														

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

							HCl Concentration			Reactor Conditions						Analytical					Dry Gas Meter								
Week	Site	Gas	Number				ppm (v), dry, @ 3% O_2			Condition Number	Flow	Temp.	NH_3/ NO_x	Unit 5 Boiler Load,	Sample O_2	Cl^-	Dil	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		σ		scfm	°F		MW	%	µg/ml		ml	µM	ppm, dry, @ 3% O_2	STD L, dry	°K	in. Hg	°F	°F	ft³	ft³		
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
																2.730			1042	296.2									
103	CAI	HCl	02	1404	1418	19-Dec-94	255.1	±	1.30	22	5000	700	0.8	87	2.3	2.513		506	897	256.0	75.52	302	30.28	82	88	818.700	821.700	Stack 3	0.973
																2.495			890	254.1									
103	CAI	HCl	03	1429	1441	19-Dec-94	268.8	±	8.76	22	5000	700	0.8	87	2.3	2.551		532	957	275.0	75.03	304	30.28	86	91	822.200	825.200	Stack 3	0.973
																2.436			914	262.6									
Average HCl Concentration, ppm(v), wet @ 3% O2							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
																1.665			877	253.8									
103	CAO	HCl	02	1359	1415	19-Dec-94	266.2	±	0.00	22	5000	700	0.8	87	3.7	1.618		808	922	266.2	80.73	291	30.28	64	65	275.000	278.000	Stack 1	1.0010
																1.618			922	266.2									
103	CAO	HCl	03	1423	1440	19-Dec-94	253.0	±	0.00	22	5000	700	0.8	87	3.8	1.501		822	870	253.0	80.65	291	30.28	65	65	278.300	281.300	Stack 1	1.0010
																1.501			870	253.0									
Average HCl Concentration, ppm(v), wet @ 3% O2							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_2O	7.9 % wet	Duct Area	15.5677 ft^2
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-13 in. H_2O		
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_2O
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_2O	9.1 % wet	Duct Area	15.5677 ft^2
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-13 in. H_2O		
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_2O
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_2O	8.8 % wet.	Duct Area	15.5677 ft^2
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-13 in. H_2O		
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_2O
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_2O	7.1	% wet	Duct Area	3.36	ft^2
Ambient Pressure	30.21	in. Hg			
Stack Pressure	-23	in. H_2O			
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_2O
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_2O	7.9 % wet	Duct Area	3.36 ft^2
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-23 in. H_2O		
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_2O
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_2O	8.4 % wet	Duct Area	3.36 ft^2
Ambient Pressure	30.21 in. Hg		
Stack Pressure	-23 in. H_2O		
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_2O
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_2O	10.5	% wet	Duct Area	15.5677	ft^2
Ambient Pressure	30.08	in. Hg			
Stack Pressure	-13.3	in. H_2O			
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_2O
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_2O	11.0 % wet	Duct Area	15.5677 ft^2
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-13.3 in. H_2O		
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_2O
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_2O	9.9 % wet	Duct Area	15.5677 ft^2
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-13.3 in. H_2O		
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_2O
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_2O	8.1	% wet	Duct Area	3.36	ft^2
Ambient Pressure	30.08	in. Hg			
Stack Pressure	-20	in. H_2O			
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_2O
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_2O	8.2 % wet	Duct Area	3.36 ft^2
Ambient Pressure	30.08 in. Hg		
Stack Pressure	-20 in. H_2O		
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_2O
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:
DESCENDING ✓ 455°C
ASCENDING
ACID
PROJECT NO. 7613.07.01
TEST NO.
PLANT/COMPANY PLANT CRIST MT COMPOSITES

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-AAO-M17-1,-2,-3			8.00	-60
3	—				
4	097-BAO-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 15DEC94 APPARATUS NO. 2 PAGE NO. 1
ROJECT 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					
5DEC/0838	435 / 439	1.40	−2000	$.29 \times 10^{-3}$	7.10	5.52×10^{7}	
	432 / 437	1.41		$.32 \times 10^{-3}$	7.34	4.90×10^{7}	
0900	377 / 391	1.51		$.75 \times 10^{-4}$		2.13×10^{8}	
	373 / 387	1.52		$.81 \times 10^{-4}$		1.94×10^{8}	
0920	329 / 346	1.62		$.19 \times 10^{-4}$		8.42×10^{8}	
	326 / 343	"		$.21 \times 10^{-4}$		7.47×10^{8}	
0942	285 / 303	1.74		$.45 \times 10^{-5}$		3.55×10^{9}	
	283 / 301	"		$.52 \times 10^{-5}$		3.03×10^{9}	
1005	245 / 263	1.87		$.10 \times 10^{-5}$		1.[illegible] x10 [illegible]	
	243 / 2[illegible]	"		$.12 \times 10^{-5}$		1.31×10^{10}	
1023	218 / 235	1.97		$.34 \times 10^{-6}$		4.71×10^{10}	
	216 / 233	1.98		$.40 \times 10^{-6}$		3.92×10^{10}	
1100	175 / 191	2.16		$.65 \times 10^{-7}$		2.46×10^{11}	
	173 / 189	"		$.75 \times 10^{-7}$		2.13×10^{11}	
1141	140 / 154	2.34		$.29 \times 10^{-7}$		5.52×10^{11}	
	139 / 153	2.35		$.30 \times 10^{-7}$		5.23×10^{11}	
1236	107 / 118	2.56		$.51 \times 10^{-7}$		3.14×10^{11}	
	107 / 118	"		$.46 \times 10^{-7}$		3.41×10^{11}	
1350	80 / 89	2.76		$.73 \times 10^{-6}$		2.19×10^{10}	
	80 / 89	"		$.61 \times 10^{-6}$		2.57×10^{10}	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	
				$\times 10^{-}$		x10	

FORM ENV022

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
INCE 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
Date sampled	------
Date received	December 20, 1994

P.O. Number: BH-52063

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
T_{250} Temperature = 2498 °F

Loss On Ignition = 12.38

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

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

John T. Burt
Manager, Birmingham Laboratory

AMERICAN COUNCIL OF INDEPENDENT LABORATORIES

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 708-953-9300 FAX: 708-953-9306
INCE 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. 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

ANALYSIS OF ASH	WEIGHT %, IGNITED BASIS
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 oxide	2.81
Sodium oxide	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
	100.00

Silica Value = 70.30
Base:Acid Ratio = 0.33
T_{250} Temperature = 2509 °F

Loss On Ignition = 12.60

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

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

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
INCE 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 = 69.97
Base:Acid Ratio = 0.33
T_{250} 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.
John T. Bust
Manager, Birmingham Laboratory

AMERICAN COUNCIL OF INDEPENDENT LABORATORIES INC.

COMMERCIAL TESTING & ENGINEERING CO.
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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
	100.00

Silica Value = 72.20
Base:Acid Ratio = 0.30
T_{250} Temperature = 2541 °F

Loss On Ignition = 11.91

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

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

John T. Burt

Manager, Birmingham Laboratory

AMERICAN COUNCIL OF INDEPENDENT LABORATORIES

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 M 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	4.3	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

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

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 $\bar{\bar{x}} + 3\sigma$

LB:dc