NASA-CR-203718

A PILOT-SCALE EVALUATION OF A NEW TECHNOLOGY TO CONTROL NOx EMISSIONS FROM BOILERS AT KSC:

HYDROGEN PEROXIDE INJECTION INTO BOILER FLUE GASES FOLLOWED BY WET SCRUBBING OF ACID GASES

Annual Progress Report

Submitted to

National Aeronautics and Space Administration
Kennedy Space Center

by

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STATEMENT OF THE PROBLEM

Emissions of nitrogen oxides (NOx) are a significant problem in the United States. NOx are formed in any combustion process, therefore it is not surprising that NOx are emitted from the boilers at KSC. Research at UCF has shown (in the laboratory) that injecting H_2O_2 into hot simulated flue gases can oxidize the NO and NO_2 to their acid gas forms, HNO_2 and HNO_3, respectively. These acid gases are much more water soluble than their counterparts, and theoretically can be removed easily by wet scrubbing. This technology was of interest to NASA, both for their boilers at KSC, and for their combustion sources elsewhere. However, it was necessary to field test the technology and to provide pilot-scale data to aid in design of full-scale facilities. Hence this project was initiated in May of 1996.

OVERVIEW OF PROGRESS

The project is making good progress, and is on schedule (see Table 1). The main objectives for the past year were to select a boiler on-site at KSC for the construction and operation of the pilot plant and for the conduct of the experimental program, to make appropriate contacts between UCF personnel and KSC personnel, to plan out the experimental methodology and procedures, and to design/select/purchase all the major equipment needed for the experimental phase. Highlights of progress made during this first year of the project are as follows:

* A boiler was selected and contact was made with operating and technical personnel at KSC regarding this project. A good working relationship has been established between UCF and KSC personnel.

* A significant amount of time was spent in the design of both the experimental plan and of the pilot scale equipment in order to ensure success of the pilot plant operation.

Table 1. Overall Project Schedule

YEAR	MONTH	PROJECT SCHEDULE
1996	MAY	Coordinate project requirements with Kennedy Space Center (KSC).
	JUNE	Form Working Group.
	JULY	Begin Literature Reviews.
	AUG	Select Boiler at KSC.
	SEPT	Produce preliminary process design.
	OCT	Meet with Hydrogen peroxide(H_2O_2) vendor.
	NOV	Finish system design.
	DEC	Complete equipment orders.
	JAN	Complete coordination with H_2O_2 vendor.
	FEB	Begin preparing equipment list.
	MAR	Order Materials.
	APR	Construct pilot plant.
1997	MAY	Begin Operation of pilot plant.
	JUNE	Determine test points.
	JULY	Operate pilot plant.
	AUG	Operate pilot plant.
	SEPT	Analyze data.
	OCT	Analyze data.
	NOV	Make presentations and briefings at KSC.
	DEC	Begin preparing draft final report. Disassemble pilot plant.
	JAN	Continue work on final report. Complete disassembly and clean-up.
	FEB	Submit draft final report. Discuss related follow-on work.
	MAR	Make revisions and submit final report/dissertation.
	APR	Write papers for technology transfer.

* An industrial partner was found who is participating in the project in a very meaningful way. EKA Nobel, Inc., of Marietta, Georgia, is supplying considerable engineering expertise, and will supply all the hydrogen peroxide and some equipment to this project free of charge.

DISCUSSION OF WORK PROGRESS

Several major tasks have been accomplished since the start of this project. First, the project team has made good contacts with NASA and contractor support personnel at KSC, mostly due to the efforts of Michelle Collins. The team has made several trips to KSC to meet the technical people who will be involved, and to meet the operating personnel who will be responsible for the boiler operation during the testing. Michelle's knowledge of the individuals at KSC has proved invaluable in establishing good contacts for the entire team. In addition, contact was established between Dr. Cooper and Mr. Joel Tenney of EKA Nobel, a world-wide supplier of hydrogen peroxide (among other chemicals), in regards to their supplying some of the materials to be used in this project. Mr. Tenney's response was gratifying in that EKA became enthusiastic about this project and have been contributing their time and expertise in a most helpful manner.

Much time and effort was expended on the process design of the pilot plant equipment. In addition to various UCF project team members devoting significant portions of their time, our industrial partner, EKA Nobel, made substantial contributions of engineering time and expertise to this phase of the project. The analytical needs of the project were assessed and a plan for measuring the various species of NOx in the gases was devised. The need for a research-grade ion chromatograph became obvious, and one was ordered. The team has developed a process flow diagram, a material balance table, detailed sketches of equipment for the pilot plant, a list of equipment, and a sketch of the analytical sampling setup. These items are all included in Appendix I as part of the documentation for this report.

Boiler number 2 has been selected as the boiler to which modifications will be made in order to test this new technology. The site is indoors, and has sufficient room for construction and operation of the pilot plant, and has a natural gas supply, and water and electricity for the pilot plant. Sketches of how the pilot plant will fit into the boilerhouse are also provided in Appendix I.

The purposes of the pilot plant are to confirm the laboratory results, to gather additional chemical reaction (kinetic) data, and to develop larger scale information suitable for design of full-scale facilities and a detailed economic analyses of the process. A draft experimental design plan was devised and is presented in Appendix II. The final "treatment levels" for all variables will be set after finding the actual NOx levels coming from Boiler 2.

MAJOR JOBS REMAINING AND WORK PLANNED FOR NEXT QUARTER

The major tasks planned for the coming year are as follows:

1. Finish ordering all equipment for the pilot plant
2. Construct the pilot plant
3. Write start-up and operating procedures for the pilot plant
4. Start up and operate the pilot plant to obtain all required data
5. Analyze the results obtained from the pilot plant
6. Document our work with a final report
7. Ensure technology transfer through publication of peer-reviewed papers, through presentations at conferences, and through meetings at KSC.

PERSONNEL STATUS

Dr. Cooper remains as Project Director and Principal Investigator. Dr. Clausen and Dr. Dietz are co-Principal Investigators. Michelle Collins is the PhD student in charge, and Quang Nguyen, Loubna Tazi, and John Collins (no relation to Michelle) are masters students involved in this project. Dr. Pwu-Sheng Liu (research associate) is doing computer modeling of the kinetic reactions.

FINANCIAL STATUS

The project is a cost-reimbursable federal demonstration project, but expenditures to date are somewhat behind the timeline of work accomplished as shown previously in Table 1. This is because it took a while to get the design to the state where equipment could be ordered. The purchase of materials and equipment for the construction and operation of the pilot plant will soon increase the expenditures, and we expect to fulfill our budget. In addition, a significant portion of the faculty release time will be charged during the summer semester. Table 2 shows the current status of expenditures vs budget by major category.

TABLE 2
Project Expenditures vs Project (Two-Year) Budget
(As of Jan 31, 1997)

In Thousands of Dollars, rounded

Category	Budgeted	Expended/Encumbered	Balance
Personnel	160	37	123
Capital Equipment	42	22	20
Supplies/Materials	32	0	32
Travel	4	1	3
Total Direct Costs	244	60	184
Indirect Costs	53	9	44
Total Project	297	69	228

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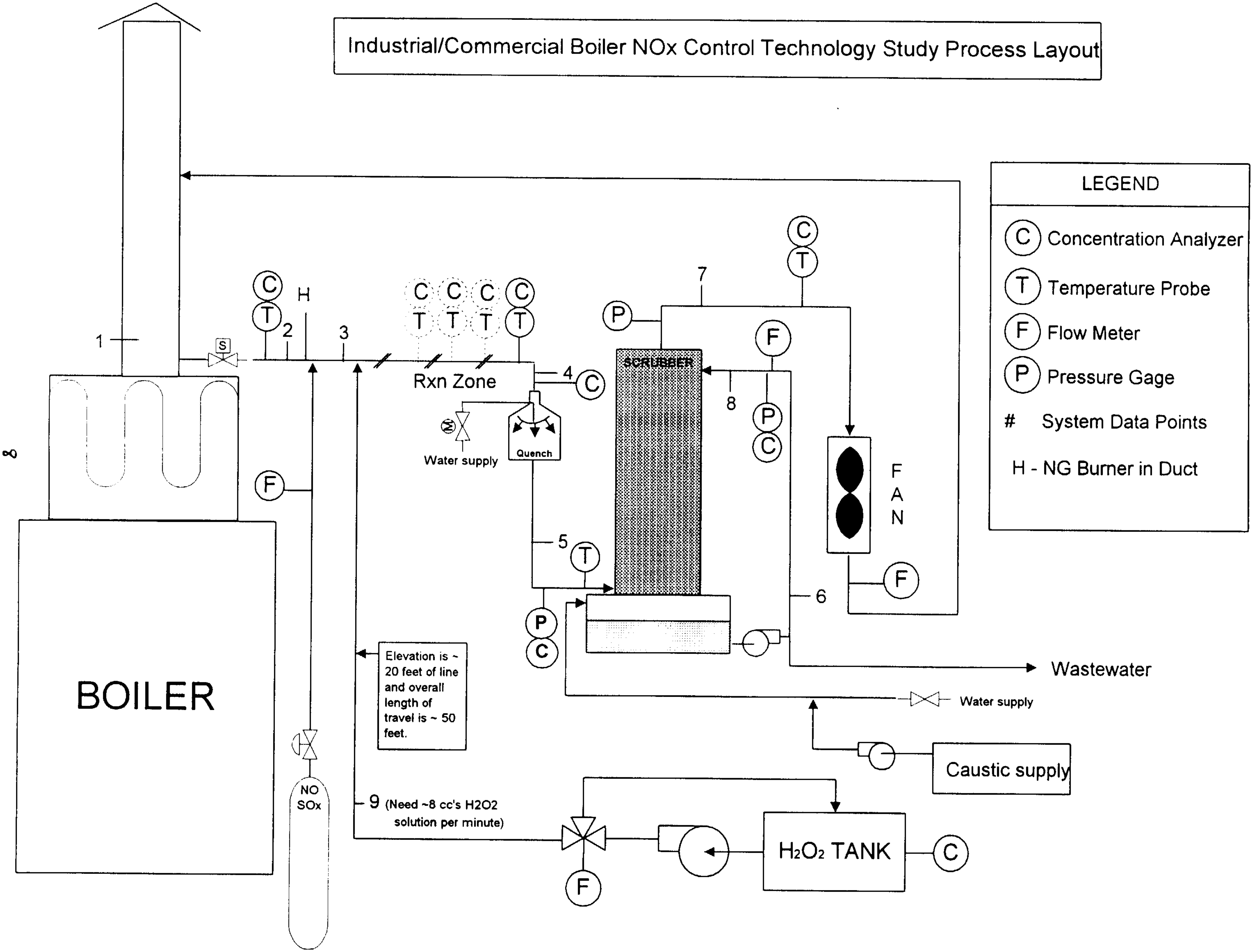
APPENDIX I

MATERIAL BALANCES, DRAWINGS AND OTHER DOCUMENTS RELATED TO PILOT PLANT EQUIPMENT DESIGN AND SELECTION

Industrial/Commercial Boiler NOx Control Technology Study Process Layout



Summary Design Tables

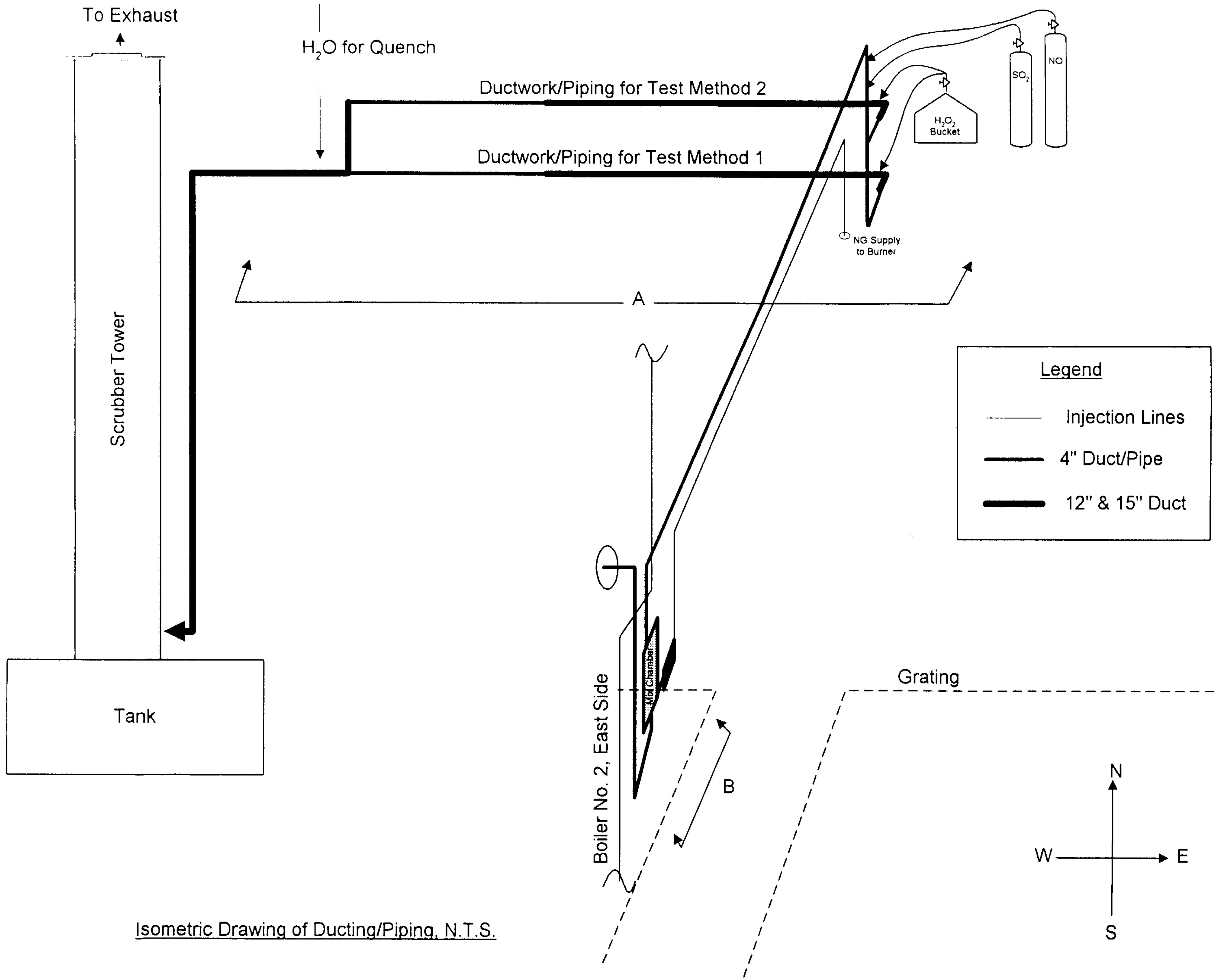
System Point 1, Figure 1 - Boiler Stack Gas						
Constituent	lb-moles/hr	%wet basis	% dry basis	Mole Fraction		ppm
O2	5.82	2.00	2.41	2.00E-02		
N2	210.52	72.20	87.20	7.22E-01		
CO2	25.07	8.60	10.38	8.60E-02		
H2O	50.13	17.19	N.A.	1.72E-01		
NO	0.021135	0.007249	0.008754	7.25E-05		72
NO2	0.002348	0.000805	0.000973	8.05E-06		8
Totals	291.56	100.00	100.00	1.00E+00		
Gas flow rate (cfm) = 3406						
Temperature (deg. F) = 500			Pressure (atm) = 1			

System Point 2, Figure 1 - Slip Stream Gas Before Heater Coils (Note: NO injection is included in this summary)						
Constituent	lb-moles/hr	%wet basis	% dry basis	Mole Fraction		ppm
O2	0.85	1.99	2.40	1.99E-02		
N2	30.92	72.21	87.20	7.22E-01		
CO2	3.68	8.59	10.38	8.59E-02		
H2O	7.36	17.19	N.A.	1.72E-01		
NO	0.008565	0.020004	0.024156	2.00E-04		200
NO2	0.000345	0.000805	0.000972	8.05E-06		8
Totals	42.82	100.00	100.00	1.00E+00		
Gas flow rate (cfm) = 500						
Temperature (deg. F) = 500			Pressure (atm) = 1			

System Point 3, Figure 1 - Slip Stream Gas After Heater Coils						
Constituent	lb-moles/hr	%wet basis	% dry basis	Mole Fraction		ppm
O2	0.85	1.99	2.40	1.99E-02		
N2	30.92	72.21	87.20	7.22E-01		
CO2	3.68	8.59	10.38	8.59E-02		
H2O	7.36	17.19	N.A.	1.72E-01		
NO	0.008565	0.020004	0.024156	2.00E-04		200
NO2	0.000345	0.000805	0.000972	8.05E-06		8
Totals	42.82	100.00	100.00	1.00E+00		
Gas flow rate (cfm) = 725						
Temperature (deg. F) = 932			Pressure (atm) = 1			

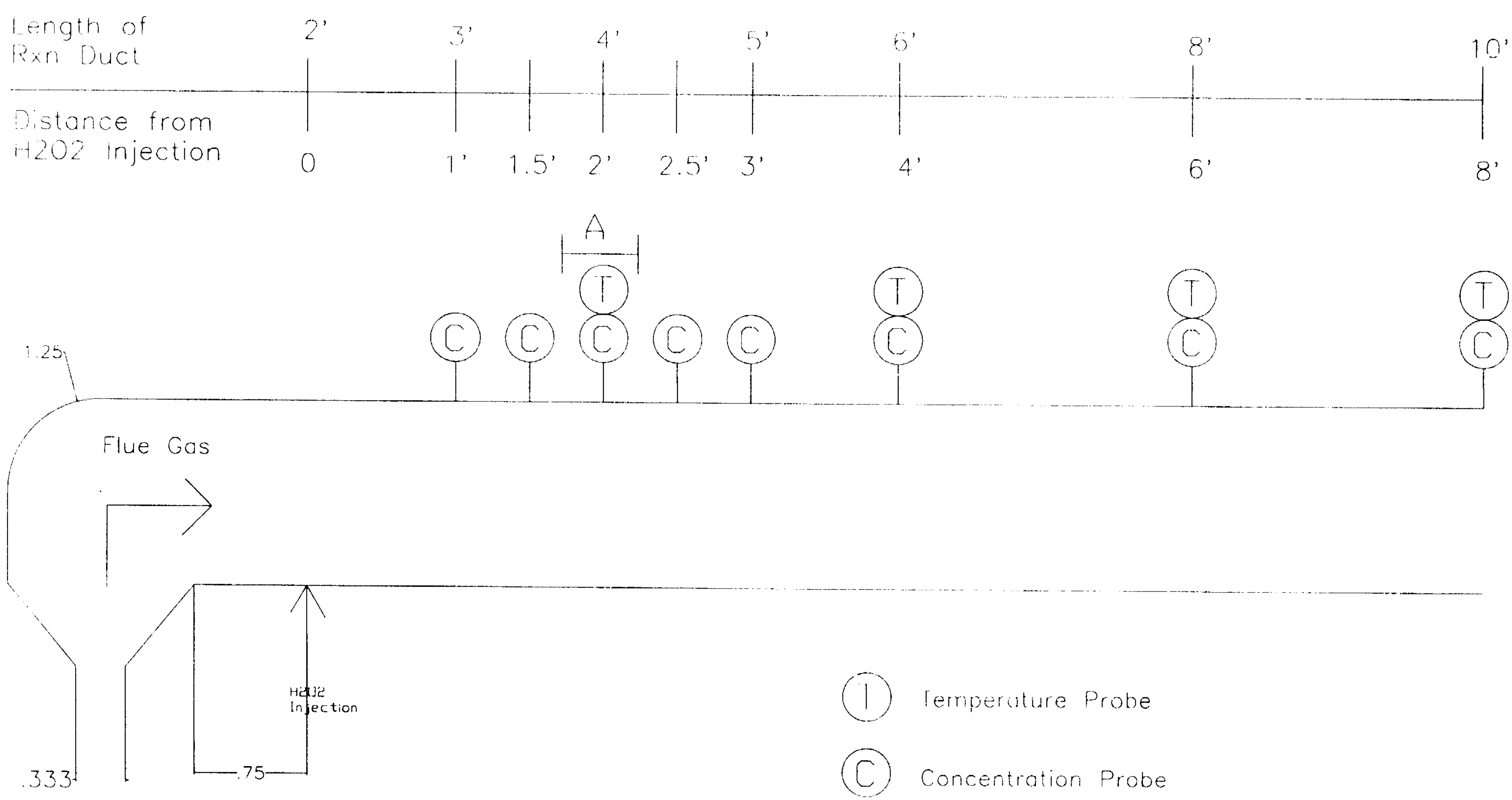
System Point 4, Figure 1 - Slip Stream Gas After Reaction Zone (Note: H2O2 injection & resultant rxns are included in this table. Injection = 0.02 lb-moles H2O2/hr.)						
Constituent	lb-moles/hr	%wet basis	% dry basis	Mole Fraction		ppm
O2	0.86	2.00	2.42	2.00E-02		
N2	30.92	72.12	87.18	7.21E-01		
CO2	3.68	8.58	10.37	8.58E-02		
H2O	7.40	17.27	N.A.	1.73E-01		
NO	0.000857	0.001998	0.002415	2.00E-05		20
NO2	0.002914	0.006797	0.008216	6.80E-05		68
HNO2	0.002570	0.005993	0.007244	5.99E-05		60
HNO3	0.002570	0.005993	0.007244	5.99E-05		60
Totals	42.87	100.00	100.00	1.00E+00		
Gas flow rate (cfm) = 710						
Temperature (deg. F) = 900			Pressure (atm) = 1			

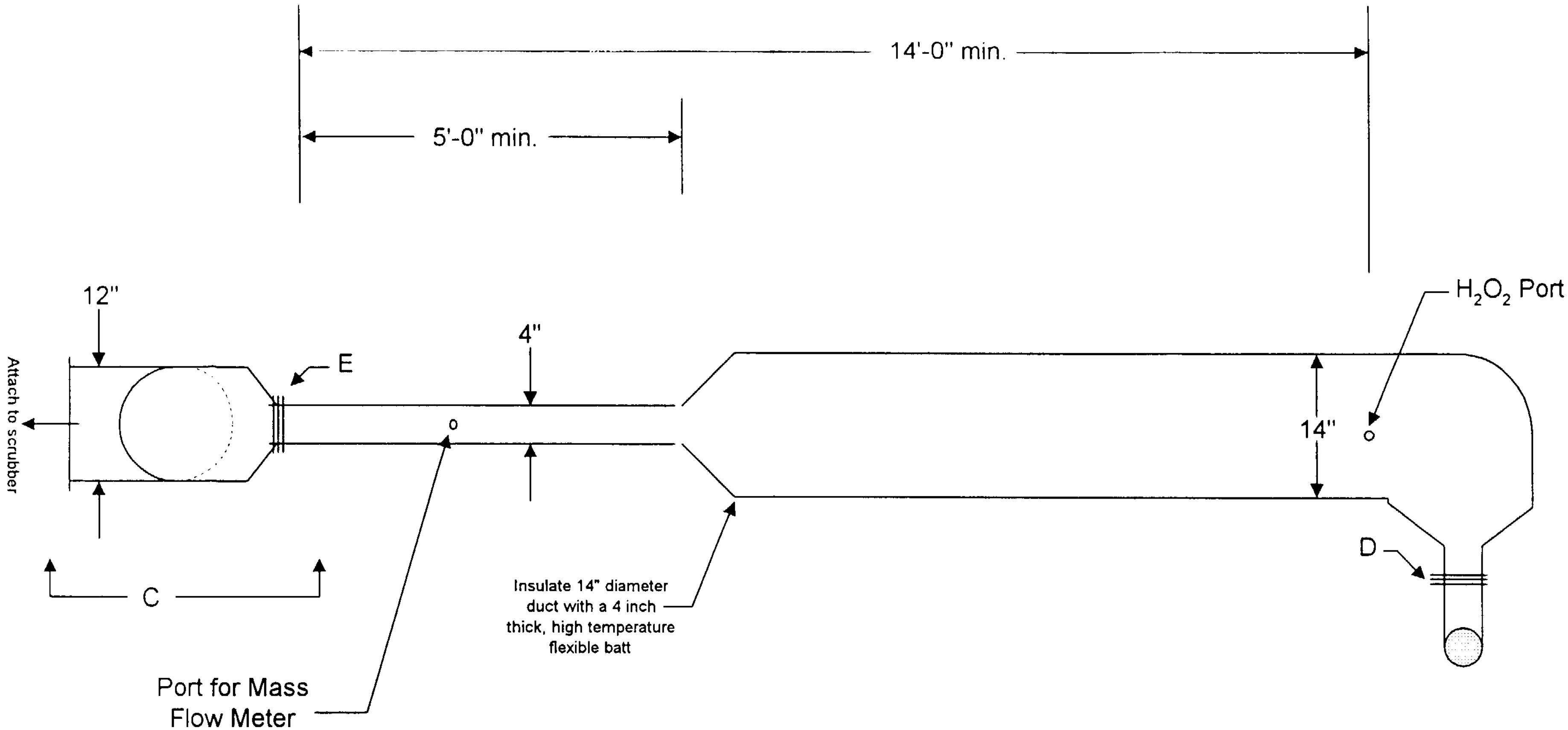
System Point 5, Figure 1 - Slip Stream Gas After Quenching						
Constituent	lb-moles/hr	%wet basis	% dry basis	Mole Fraction		ppm
O2	0.86	1.44	2.42	1.44E-02		
N2	30.92	51.66	87.18	5.17E-01		
CO2	3.68	6.15	10.37	6.15E-02		
H2O	24.39	40.74	N.A.	4.07E-01		
NO	0.000857	0.001431	0.002415	1.43E-05		14
NO2	0.002914	0.004868	0.008216	4.87E-05		49
HNO2	0.002570	0.004293	0.007244	4.29E-05		43
HNO3	0.002570	0.00	0.0072	4.29E-05		43
Totals	59.86	100.00	100.00	1.00E+00		
Gas flow rate (cfm) = 458						
Temperature (deg. F) = 168			Pressure (atm) = 1			



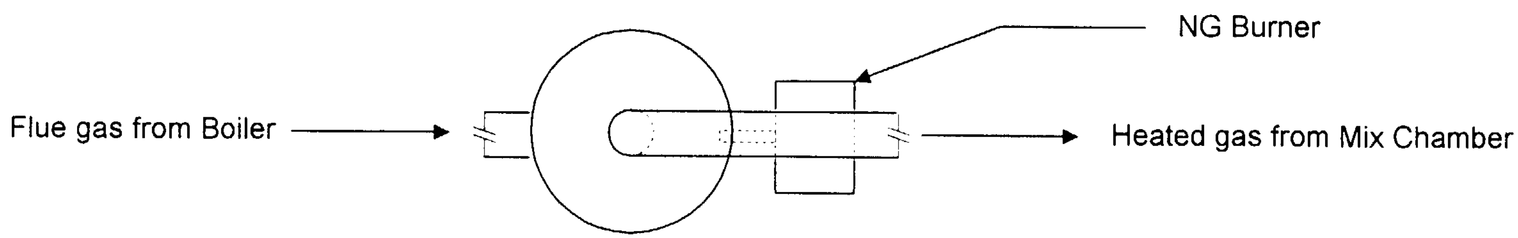
Isometric Drawing of Ducting/Piping, N.T.S.

Reaction Zone

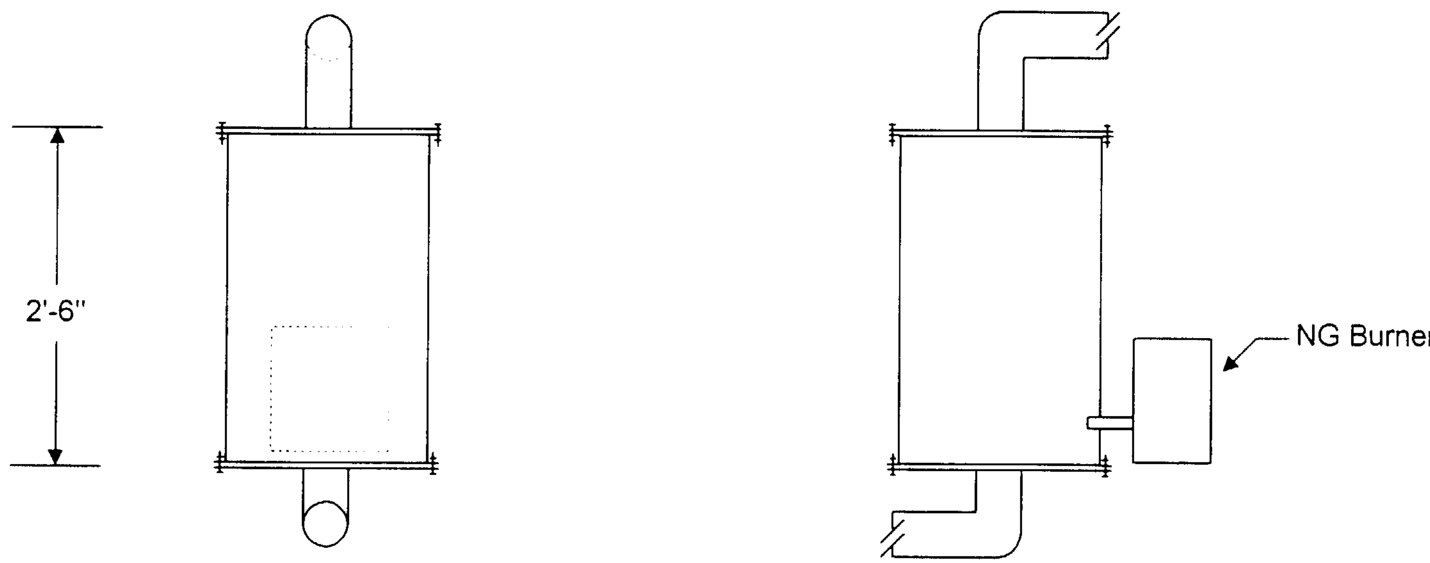




Detail A from Isometric Drawing of Ducting/Piping, N.T.S.



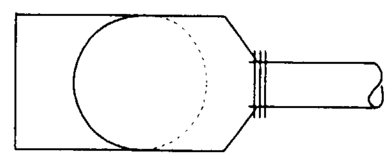
Plan View (Note: flanges on top and bottom of mixing chamber are not shown



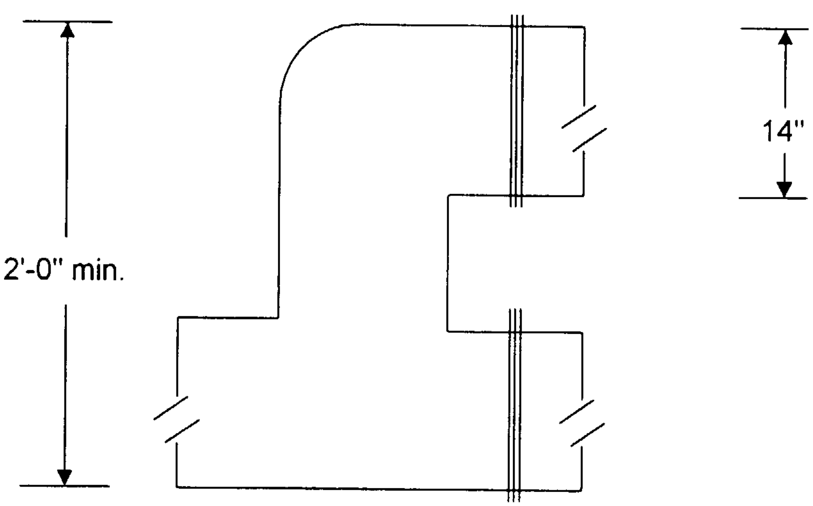
Front view

Profile View

Detail B - Mixing Chamber, Scale 1/16 in. = 1 in.



Plan View



Front view

Detail C - Duct Section, N.T.S.

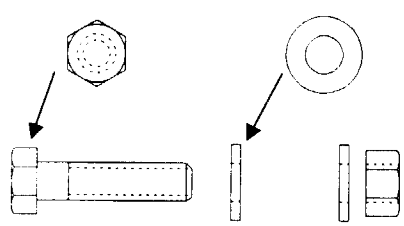
Notes:

1. All duct and materials to be of 304 or 316 Stainless Steel, 14 gauge or schedule 10.

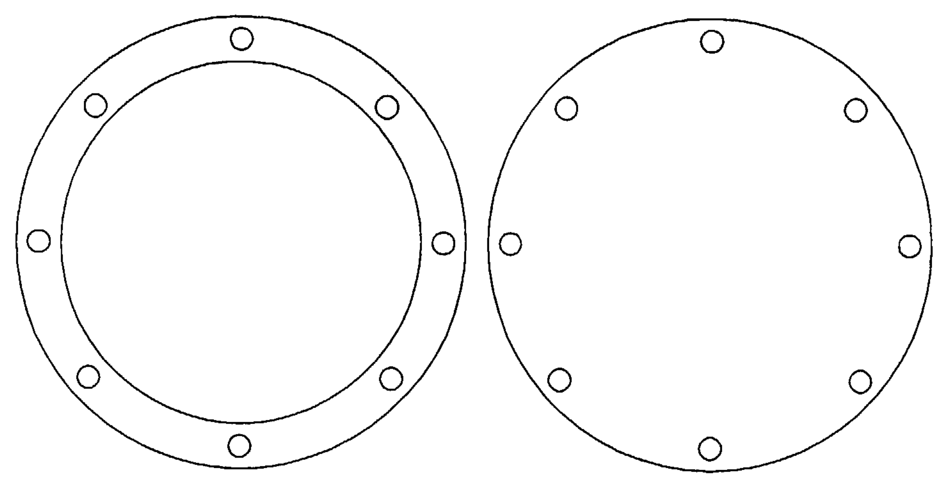
2. Duct joints and fittings shall be welded or flanged. Flange width should be a minimum of 7/8". Flange holes should be a minimum of 7/16" I.D., spaced evenly between the outside edge of the flange and the inside edge to allow room for the washers, and the holes should be spaced 3-4 inches apart on-center.

3. Field fit all sections. Utilize flexible duct as necessary to allow for slight adjustments.

4. Flanged joints shall have high temperature gasket material between them.



3/8 in. screw (x1-1/4 in.), washer (3/4" O.D.), nut assembly (Typ.), NTS



Detail D - Spacer/Blind Flanges, Scale 1/2 in. = 1 in.

EQUIPMENT LIST

Section I - Boiler to Quencher:

1. 304 stainless steel duct & fittings (4", 12", and 18"), stainless steel clamps, and flexible ducting. Bolts, nuts, and washers.
2. Shut-off valve with manual actuator and auto controls from the NG regulator and temperature probe downstream of the quencher. Power supply for actuator.
3. NG burner, striker, and two air ports. Power supply for striker.
   a. KAO wool for interior of burner section (pins to attach to roof), opt.
   b. Pressure regulator.
   c. Flow valve with manual control and auto control from computer and temperature sensor downstream of the quencher. Power supply for auto control.
   d. Sight glass.
   e. Tapping valve for NG main line, screwed plug (for disconnection), piping (3/4"), and piping connectors.
   f. Manual isolation valve upstream from solenoid valve.
   g. Solenoid valve, N.C.. Power supply for actuator.
   h. Pressure gage (visual indicator only) up stream of regulator valve.
4. Minimum of three temperature probes. See how many ports we put in for concentration measurement (possibly 14 total). Bushings. Transducers? Power supply for probes.
5. Threaded 2-piece bushings or bulkheads (Swagelok) and quick connects for concentration measurement device (12 total).
6. Power Supply.
7. Insulation with sheathing for outside of duct and clamps for sheathing or duct tape.
8. High temperature gasket material.
9. Flow meter.

Item	Description	Supplier	Cost & Freight	Lead Time
1	Duct, 304 stainless steel, 20 gauge, single wall, 43 l.f. w/ 7 fittings	United McGill Corp. Kevin 841-7953	$1,550 $125 shipping	2-3 weeks
2	Shut-off valve	open		
3	NG burner with striker, fan, and site glass. OR Heating Elements (3 ea.) #22060/20/240/1	Aerotech USA AL 1-800-333-8883 Wahlco, Inc. Bob Charlton 1-800-423-5432	$505 $25 shipping $780x3	1 week 5-6 weeks
4	Thermocouple, ANSI Type K, Special LofE, 30 gauge, Inconel 600 sheath, grounded junction, tapered tip, ¼", high temp jack (3 prong). 6 each. Swagelok B.T. thermocouple fitting. 6 each.	Wahlco, Inc. Bob Charlton 1-800-423-5432 Swagelok Steve	Approx. $200 Approx. $20	1 week
5	Swagelok threaded quick connect (2 sets and 12 half sets)	Swagelok Steve	Approx. $ 50 per set and $25 per half set.	
6	Model A-700 (110/120/220/230-240 to 24-28VDC) or Model A-701 digital panel meter with power supply	Dwyer (847) 541-3232		
7	KAOWOOL #8, 2ft wide by 25 ft long roll (2 ea.) OR Owens Corning High temperature flexible batt insulation #1280	North Bros. Greg Thomas 293-9221 Owens Corning Bob Place (419) 248-6476	$93 per roll	
8	High temperature gasket material	Technical Specialties Co., Inc. 800-874-0877		
9	Insertion mass flow meter, High temp (500 C), 12" #452 or 24" #155JR, and addt'l RS232.	Kurz Instruments Manning 1-800-424-7356	$3,500 Addt'l $115 Addt'l $350	3-5 weeks

Section II - Overall Process:

1. Piping for hydrogen peroxide.
2. Transmitter for peristaltic pump and power supply.
3. NO and SO_2 cylinders, regulators, and cylinder mounting brackets.
4. Flow meters for NO and SO_2 piping, transmitters (?), and power supply.
5. NO and SO_2 piping and isolation valves mounted to ductwork.
6. Spiral-cut cable wrap and cable mounts for running the cables.
7. Variable speed fan, transmitter, and power supply.
8. Gas flow meter, transmitter, and power supply.
9. Rainhat for exhaust and metal flanged slip for running exhaust through metal wall or valve, controls, and flange to run exhaust back into the boiler.
10. Labview software and connectors.
11. Metal signs saying "Test in progress - DO NOT TOUCH", "Caution caustics in use - Locate eyewash in emergency", "Hot surfaces - DO NOT TOUCH", and post sign with testing period and points of contact.
12. Yellow and black tape for marking off the area.
13. Portable eyewash.

Item	Description	Supplier	Cost & Freight	Lead Time
1	Piping for hydrogen peroxide	BOC Logistics		NA
2	Transmitter for peristaltic pump and power supply			
3	NO and SO_2 cylinders, regulators, and cylinder mounting brackets			
4	Flow meters for NO and SO_2 piping, transmitters, and power supply			
5	NO and SO_2 piping and isolation valves			
6	Spiral-cut cable wrap and cable mounts			
7	Variable speed fan, transmitter, and power supply			
8	Gas flow meter, transmitter, and power supply			
9	Rainhat for exhaust and metal flanged slip			
10	Labview software and connectors	National Instruments		
11	Metal signs: "Test in progress - DO NOT TOUCH" "Caution caustics in use - Locate eyewash in emergency" "Hot surfaces - DO NOT TOUCH"	EG&G Paint Shop		
12	Sign with testing period and points of contact	Michelle	NA	NA
13	Yellow and black tape	BOC Logistics		NA
14	Portable eyewash	EG&G	NA	NA

Section III - Scrubber Design:

1. Piping from water line to quencher, visual pressure gage, and flow meter with transmitter, power supply, and isolation valves.
2. Spray nozzles for quencher.
3. Tower casing, packing and supports, piping and valves, and spray nozzles.
4. Reservoir with liquid level sensor (tied into the pump controller) optional.
5. Indicating magnahelic pressure transmitters (3), Dwyer Series 604D, or 605, and power supply.
6. Liquid flow meter, transmitter and power supply.
7. Pump, controller, and power supply.
8. Minimum of two temperature probes (or will we need one at every conc. point) one for liquid and one for gas. Bushings. Transducer? Power supply for probe.
9. Threaded 2-piece bushings or bulkheads (Swagelok) and quick connects for concentration measurement device (3 total).
10. Power Supply, Dwyer, Model A-700 (110/120/220/230-240 to 24-28VDC) or Model A-701 digital panel meter with power supply.
11. Pallet for scrubber and associated equipment with support stands.
12. Caustic supply, metering pump with controller and power supply, piping, and isolation valve.

Item	Description	Supplier	Cost & Freight	Lead Time
1	Piping from water line to quencher, visual pressure gage, and flow meter with transmitter, power supply, and isolation valves			
2	Spray nozzles for quencher			
3	Tower casing, packing and supports, piping and valves,and spray nozzles			
4	Reservoir with liquid level sensor			
5	Indicating magnahelic pressure transmitters (3), Dwyer Series 604D, or 605, and power supply	Dwyer		
6	Liquid flow meter, transmitter and power supply			
7	Pump, controller, and power supply			
8	Temperature probes (2), bushings, transducer, and power supply			
9	Threaded 2-piece bushings or bulkheads and quick connects for concentration measurement device (3 total)	Swagelok		
10	Power Supply, Dwyer, Model A-700 (110/120/220/230-240 to 24-28VDC) or Model A-701 digital panel meter with power supply	Dwyer		
11	Pallet for scrubber and associated equipment with support stands	EG&G Weld Shop		
12	Caustic supply, metering pump with controller and power supply, piping, and isolation valve			

Section I - Boiler to Quencher:

Variables:

1. Nitrogen oxide Concentration (100 ppm, 200 ppm, and 300 ppm).
2. Sulfur dioxide Concentration (0 ppm, 800 ppm, and 1600 ppm).
3. Hydrogen peroxide Concentration 33% and 50%, (400 ppm, 500 ppm, and 600 ppm.
4. Temperature (830 °F, 930 °F, and 1030 °F) .
5. Reaction Time or Rxn Zone Length. This will not be varied; it will be measured at discreet points along the length of duct for all tests.

Notes:

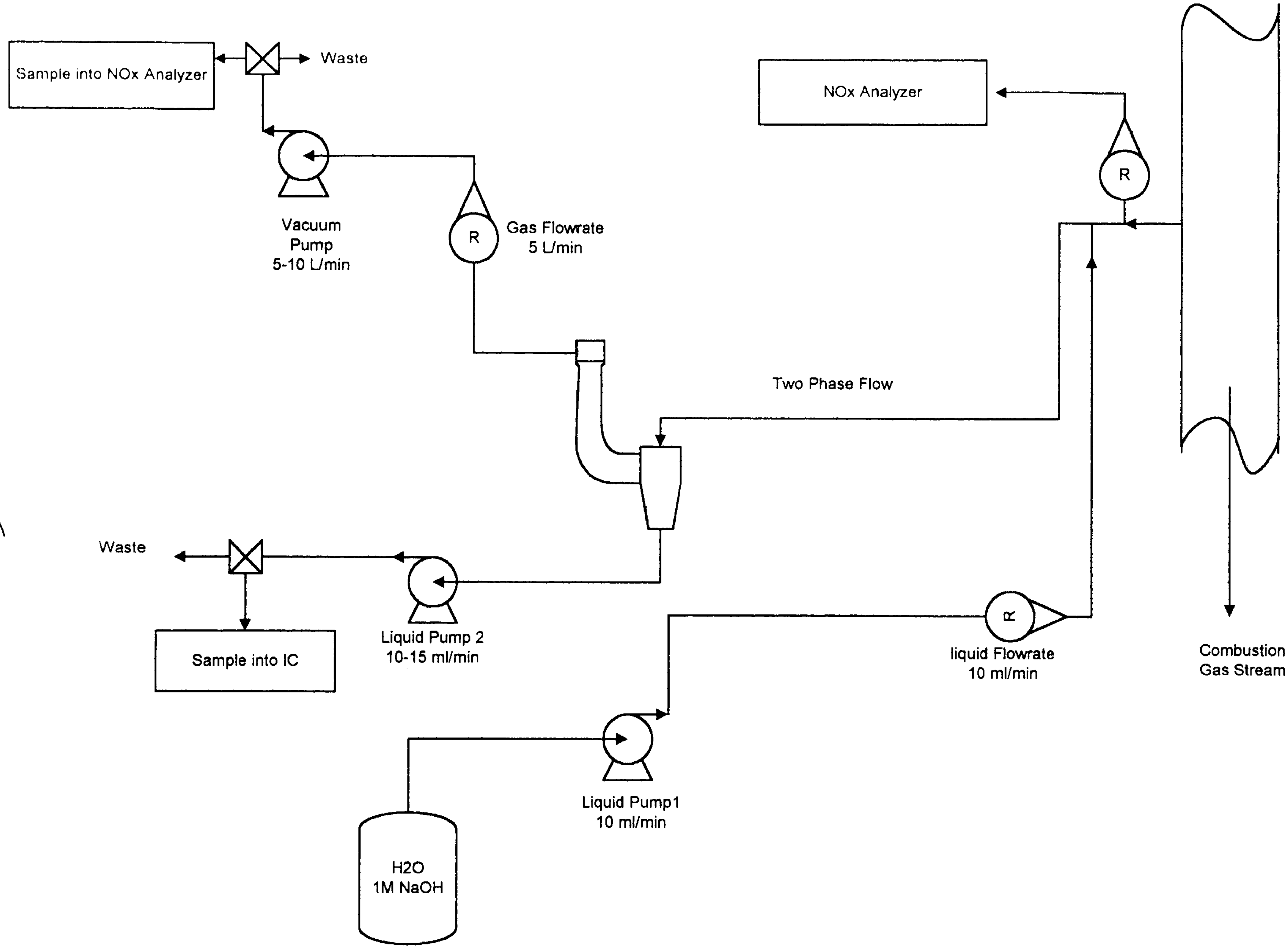
1. Sequence of experiments should be randomized. Determine if any of the variables cannot not be accurately changed within a short period of time, i.e. temperature may require unacceptable long cooling down period in order to change from high to low values in two successive tests. The number of individual tests listed int he table are 81
2. Duplicate tests will be conducted at the midpoint (approx. 8 each).
3. Tests will be conducted up front for more than three temperatures and three hydrogen peroxide concentrations to determine the sensitivity of these variables and to narrow down the optimum three points at which to run the formal testing (approx. 15 total).
4. Need to determine a basis for selecting the sulfur dioxide concentrations to be used. Will start with values shown as they relate to power plant concentrations.

Section I - Boiler to Quencher:

Parameters To Be Measured:

1. Flow rate of the gas stream.
2. Temperature of the gas stream.
3. Flow rate of Natural Gas.
4. Flow rate of Nitrogen oxide.
5. Flow rate of Sulfur dioxide.
6. Flow rate of Hydrogen peroxide.
7. Nitrogen oxide concentration (from the NOx Analyzer) upstream of the Hydrogen peroxide injection, upstream of the quench, and downstream of the scrubber.
8. Concentration of the gas stream upstream and downstream of the Hydrogen peroxide injection (NO, NO_2, HNO_2, HNO_3, and pressure/flow).
9. Indirect measurement of the reaction zone length of reaction time, f(conc.).

Measured Parameter	Units	Auto/Manual	Output	
Flow rate of the gas stream	CFM	Auto		
Temperature of the gas stream	°F	Auto		
Flow rate of Natural Gas	CFM	Auto		
Flow rate of Nitrogen oxide	Liters/min	Auto		
Flow rate of Sulfur dioxide	Liters/min	Auto		
Flow rate of Hydrogen peroxide	Liters/min	Auto		
Nitrogen oxide concentration upstream of H_2O_2 injection	ppm	Manual		
Nitrogen oxide concentration upstream of the quench	ppm	Manual		
Nitrogen oxide concentration downstream of the scrubber	ppm	Manual		
Concentration of the gas stream upstream of H_2O_2 injection	ppm	Manual		
Concentration of the gas stream downstream of H_2O_2 injection	ppm	Manual		



System Configuration for Determination of NO species Concentration in the Gas Stream

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APPENDIX II

EXPERIMENTAL DESIGN

Experimental Design for Parameter Variation

NO PPM	SO2 PPM	H2O2 PPM	TEMPERATURE F	NO PPM	SO2 PPM	H2O2 PPM	TEMPERATURE F	NO PPM	SO2 PPM	H2O2 PPM	TEMPERATURE F
		50	830			200	830			350	830
			930				930				930
			1030				1030				1030
		100	830			400	830			700	830
	0		930		0		930		0		930
			1030				1030				1030
		200	830			800	830			1400	830
			930				930				930
			1030				1030				1030
		250	830			400	830			550	830
			930				930				930
			1030				1030				1030
		500	830			800	830			1100	830
100	400		930	400	400		930	700	400		930
			1030				1030				1030
		1000	830			1600	830			2200	830
			930				930				930
			1030				1030				1030
		450	830			600	830			750	830
			930				930				930
			1030				1030				1030
		900	830			1200	830			1500	830
	800		930		800		930		800		930
			1030				1030				1030
		1800	830			2400	830			3000	830
			930				930				930
			1030				1030				1030