MARTIN MARIETTA CORPORATION

DENVER DIVISION

ENGINEERING PROPULSION LABORATORY

NITROGEN TETROXIDE VAPOR SCRUBBER USING A RECIRCULATING LIQUID

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FOREWORD

The work described herein was conducted by Martin Marietta Corporation, Denver Divison, under NASA Contract NAS10-9095, under the management of the NASA Project Manager, Mr. H. H. Franks, Spacecraft and Storables Section, NASA-Kennedy Center, Florida.

1.0 INTRODUCTION

The Martin Marietta Corporation was placed on contract by the John F. Kennedy Space Center (KSC) in January 1977, to design, manufacture, test and deliver four (4) Hypergolic Oxidizer Vapor Scrubbers. Delivery of the scrubbers was completed in October 1977.

The scrubbers are required to reduce N_2O_4 contamination of nitrogen vent gas streams to a safe level to preclude health hazard to personnel and to preclude adverse environmental effects. The scrubber principle involved is to absorb and neutralize the N_2O_4 component in a closed circuit circulating water/chemical solution in a vertical counter-flow, packed-tower configuration.

The operational and performance test requirements for the scrubbers are defined in KSC Specification No. 79K08492. Basically, this consists of demonstrating that the exit gas contamination level from the scrubbers does not exceed 150 ppm oxidizer under any flow conditions up to 400 scfm with inlet concentrations of up to 100,000 ppm oxidizer.

Early developmental work involving chemical analysis and scrubber liquor selection was performed by the Florida Institute of Technology (FIT). Some of this work consisting of prototype testing was done by Martin Marietta under contract to the FIT.

The basic scrubber concept design was developed by the Planning Research Corporation (PRC) for KSC. This design was identified in KSC Specification No. 79K08492, which specified the functional and physical characteristics of the scrubbers, including: scrubber liquors and concentrations, sump liquor flow rates, scrubber capacity, physical size and shape, construction material, environmental conditions, and quality conformance inspections involving the use of Drager tubes for concentration measurements. This specification provided the design criteria for the detail design produced by Martin Marietta.

During the detail design development, it was evident that several concept changes were required. These were coordinated with KSC and incorporated.

Several problems were encountered during the performance testing that led to a series of investigations and supplementary testing. It was finally necessary to change the scrubber liquors in oxidizer scrubber to successfully achieve performance requirements.

This report provides a description of the scrubbers, thetest configuration, and the various tests performed. Schedule limitations precluded performing the complete test matrix using the final scrubber liquor. Sufficient testing was accomplished, however, to demonstrate that the oxidizer scrubbers fully comply with the performance specification.

2.0 SUMMARY

An Oxidizer Hypergolic Toxic Vapor (HTV) Scrubber has been developed at the Martin Marietta Engineering Propulsion Laboratory in Denver, Colorado. Performance testing was conducted during May through July 1977.

The purpose of the test program was to operate the scrubber with varying inlet propellant concentrations and flow rates and demonstrate that exit gas concentrations were reduced to less than 150 ppm for oxidizer. The oxidizer scrubber inlet concentrations were varied over a range of 440 to 259,000 ppm with flow rates varying from 50 to 400 scfm. In addition, worst case conditions were testing consisting of high and low flow rates with high propellant vapor concentrations.

Several problems were encountered during the performance testing of the scrubber. It was evident from the first series of tests that the performance requirements were not being met. This led to a series of investigations and supplementary testing to determine the cause of below specification performance. This activity included:

1. Upgrading the sump liquor flow rates by adjusting the pump clearances.
2. Incorporating a viewport in three of the packed towers to observe the uniformity of liquor spray over the packed beds.
3. Evaluating the mixing of the N_2 and N_2O_4 inlet gases.
4. Inspecting the tower nozzles to determine if any clogging of the nozzles had occurred.
5. Evaluating the nozzle spray patterns to determine the spray distribution.
6. Conducting smoke tests to evaluate gas flow through the packed towers.
7. Conducting tests to determine if the packed towers were flooding.
8. Consulting with the packing material manufacturer to determine if application of the packing was proper.
9. A thorough evaluation of the gas sampling techniques.

While these investigations improved the knowledge and understanding of the scrubber operation, the scrubber performance was not significantly improved and it was still not per specification.

2.0 SUMMARY (cont'd)

Consultation with the Florida Institute of Technology revealed that a 10-percent solution of sodium sulfite (Na_2SO_3) may be a better scrubber liquor. The scrubber liquor was changed from sodium hydroxide to sodium sulfite and additional testing was performed. The scrubber performance was within specification under all conditions tested. The use of sodium sulfite, however, presented additional problems:

1. The scrubber did not have the capacity to scrub 600 pounds of N_2O_4 as required; and

2. After extended running, a solid precipitate was noted in the bottom of the sump.

Chemical analysis revealed that both of these problems could be eliminated by using a sump liquor consisting of a mixture of sodium sulfite and sodium hydroxide. Additional testing was performed with successful results, i.e., the capacity was adequate, there was no precipitate formed and the scrubber performance was within specification.

The scrubber performance was determined by analyzing scrubber exit gas samples using detector tubes (Kitagawa and Drager) as required by specification. It was necessary to measure the inlet gas concentrations using a wet chemistry method because of the high concentrations. The wet chemistry method was also used for exit gas analysis as a backup to the detector tube method and to obtain quantitative data. Throughout the test program, good correlation between the two analysis methods was not achieved. The discrepancy is academic, however, because the performance was within specification for both methods of analysis.

3.0 HARDWARE DESCRIPTION

3.1 Scrubber Description

The scrubber contains wet packed bed scrubbing towers, a storage (sump) tank for the chemical solution (liquor) and pneumatic and electrical systems. The scrubber is approximately 8 feet by 8 feet by 11 feet high and weighs approximately 7,000 pounds empty, 10,500 pounds with stoneware loaded, and 18,500 pounds with stoneware and 750 gallons of 18% sodium sulfite and 5% sodium hydroxide solution loaded in the storage tank. The scrubber is shown schematically in Figure 1. It has 4 towers connected in series to minimize the total height and insure good gas/liquid contact. Tower bed packing materials are commerical grade chemical stoneware intalox saddles. The nominal sizes of saddles utilized are 1/2 inch, 3/4 inch and 1 inch. A polypropylene mesh demister is located in the top of twoer #4 to remove liquid droplets from the existing gas stream. The chemical solution is held in the storage tank in the base of the scrubber. When the pump is started, the solution is pumped to a 125 degree teflon spray nozzle at the top of each tower. The chemical solution then counterflows the exhaust gas stream and gravity drains back to the sump.

There are two modes of operation for the scrubber. In the first mode, designated the operative mode, the exhaust gas to be scrubbed flows through the scrubber 6-inch inlet line to the towers. In the second mode, designated the inoperative mode, pneumatic valves are positioned to close the 6-inch inlet line and open the 3-inch line. The exhaust gas then enters the storage tank below the chemical solution liquid leve, bubbles through the solution and exits out the last tower.

3.2 Performance Test Setup

The schematic for the oxidizer scrubber test setup is in Figure 2. A photograph of the test setup used for these tests is shown in Figure 3.

Input N_2O_4 vapors to the scrubber were generated in a water jacketed tank that held liquid N_2O_4. The water was heated to approximately 130°F for the N_2O_4 to get the liquid propellant above its boiling point at the necessary pressure for transfer. The vapors flowed through tubing (which had been warpped with heater tape and insulated) to a mixing pipe where the vapors were mixed with heated nitrogen gas at selected flow rates. A hand valve in the propellant flow line was used to throttle the amount of vapor reaching the scrubber.

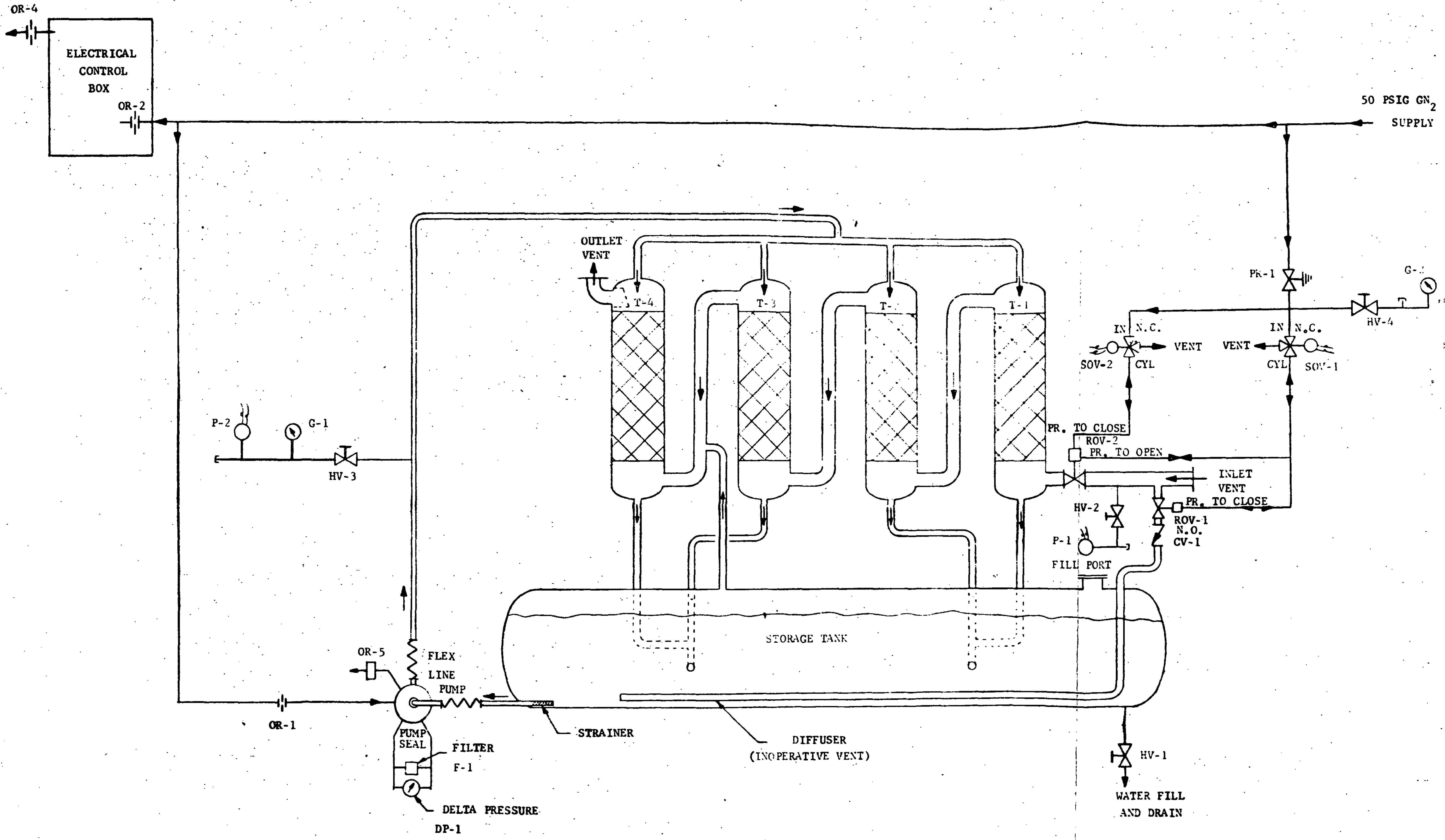

FIGURE 1 SCHEMATIC - OXIDIZER TOXIC VAPOR SCRUBBER

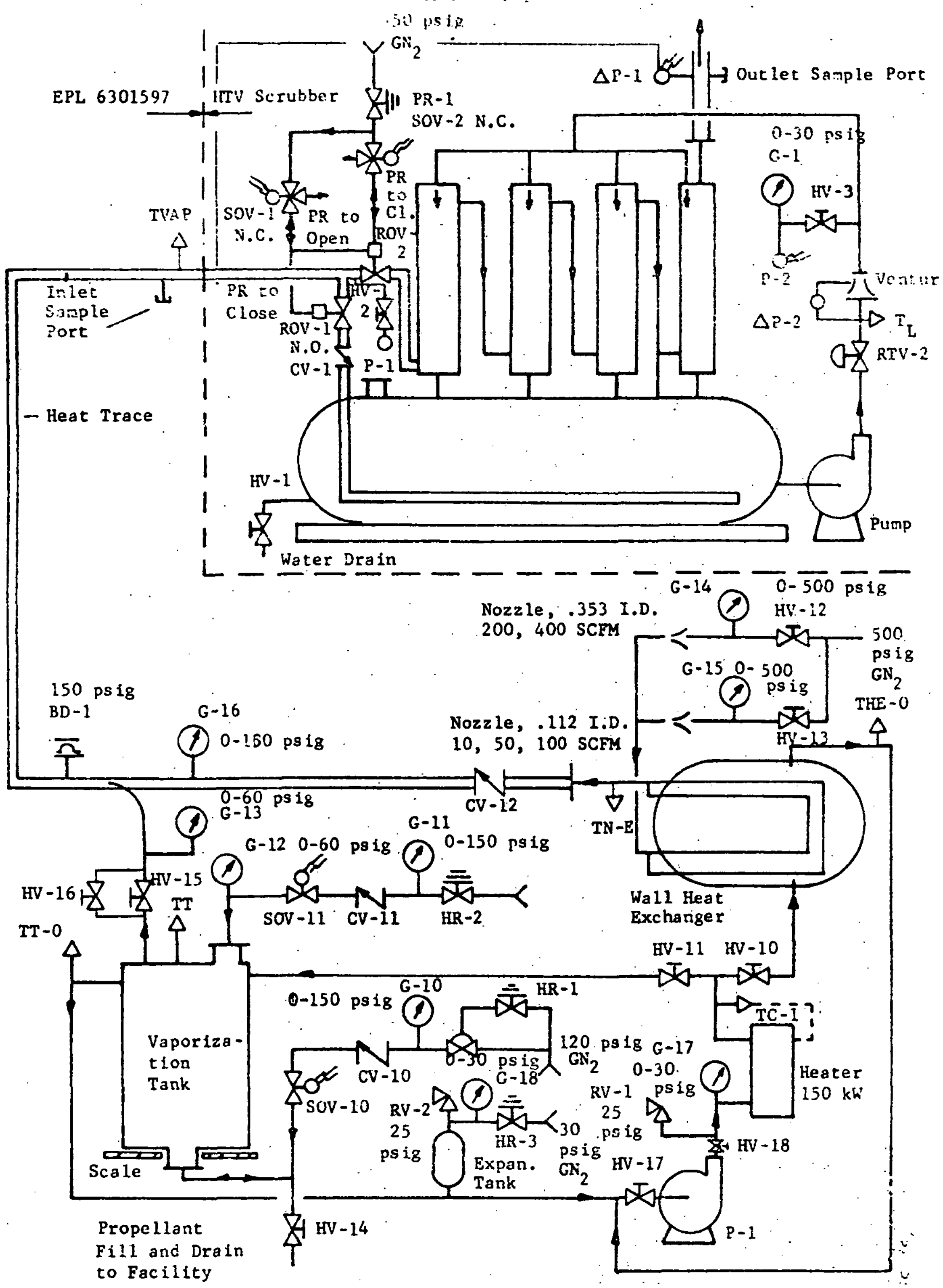

Figure 2 Scrubber Performance Test Fixture Setup

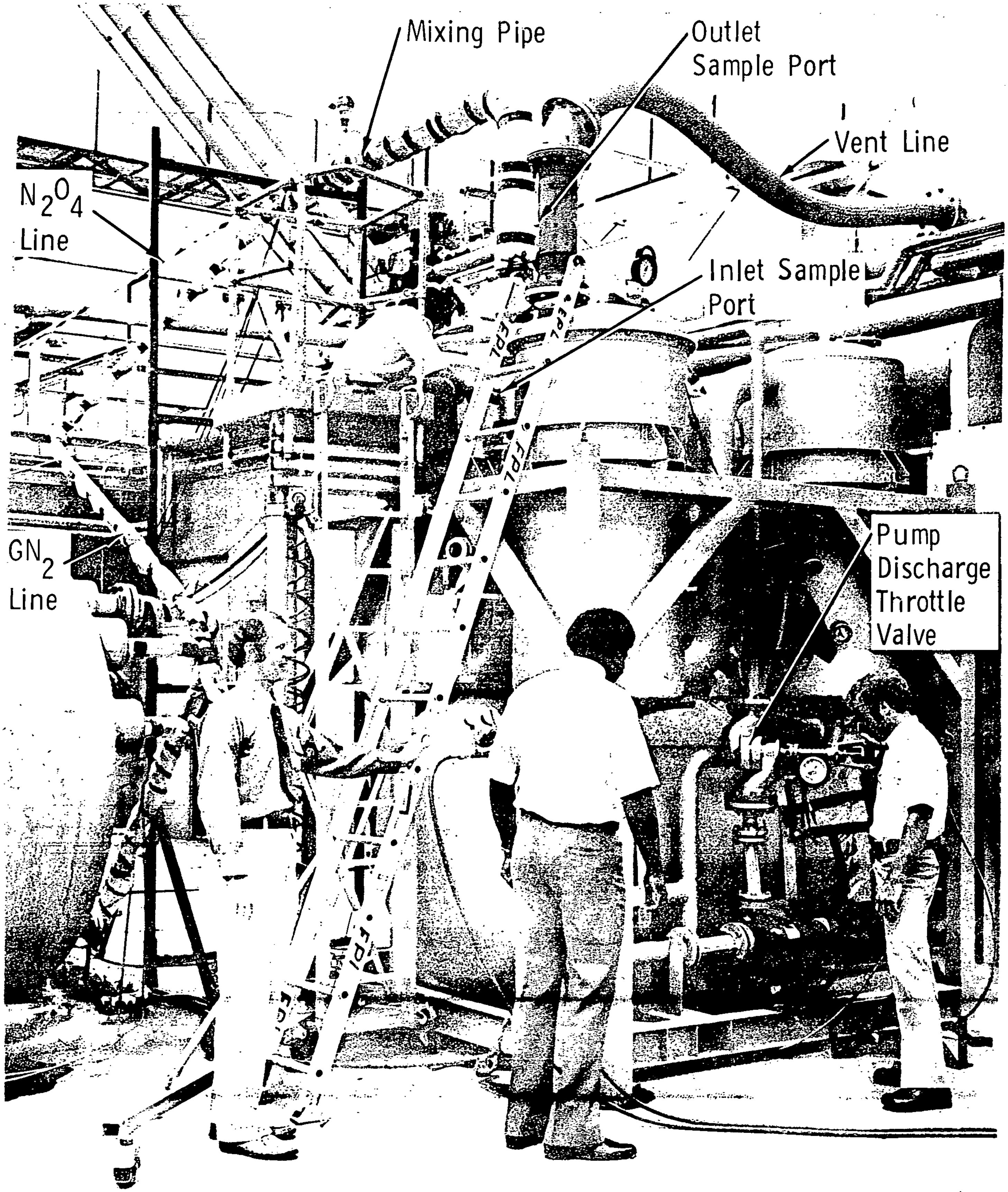

FIGURE 3 N_2O_4 Scrubber Test Setup

3.2 Performance Test Setup (cont'd)

Input gas samples for the wet chemistry analysis were taken with a gas sample syringe inserted through a rubber septum into the input gas flow approximately 1-12/ feet upstream of the scrubber inlet port. Output gas samples were taken with a separate syringe inserted through a rubber septum into the vent gas flow approximately 2 feet downstream of the scrubber outlet port. The sampling approach was to take three samples of the inlet and outlet gas concentrations for one steady state condition. The samples were taken in the same manner by the same person for each data point with a time of two to five minutes between each of the three points. The gas concentrations were then analyzed by the wet chemistry methods described in Reference 1.

Gas detector tube measurements were made in the outlet gas flow stream through a 3/8-inch AN port at the same elevation as the wet chemistry sample port.

The sump liquor flow was varied by adjusting the remotely controlled throttle valve on the scrubber pump discharge line. This valve was installed for test purposes only.

The performance test matrix for the N_2O_4 scrubber is defined in Table 1.

Table 1. Test Matrix - N_2O_4 Performance Tests

N_2O_4 Input Vapor Concentrations, ppm	Nitrogen Gas Flow Rate, scfm			
	50	100	200	400
500	X	X	X	X
↓	X	X	X	X
	X	X	X	
	X	X		
	X	X		
	X	X		
	X			
100,000	X			

X = 100, 150 and 200 gpm liquid flow rates.

Worst Case Condition No. 1

Nitrogen Flow Rate: 10 scfm

N_2O_4 Input Vapor Concentration: 900,000 ppm

Liquid Flow Rate: Maximum

Worst Case Condition No. 2

Nitrogen Flow Rate: 400 scfm

N_2O_4 Input Vapor Concentration: 100,000 ppm

Liquid Flow Rate: Maximum

4.0 TEST DESCRIPTION FOR N_2O_4 SCRUBBER

The testing of the N_2O_4 scrubbers consisted of three separate phases. These phases were test runs made to evaluate the scrubber using three different sump liquors: sodium hydroxide (NaOH), sodium sulfite (Na_2SO_3) and a mixture of NaOH and Na_2SO_3.

4.1 Sodium Hydroxide (NaOH)

Forty-seven runs were made during the period from 04/27/77 through 06/16/77. During the forty-seven runs, the sump liquor flow rate was varied from 85 gpm to 181 gpm. The strength of the sump liquor varied from 7.95% NaOH to 2.16% NaOH. The scrubber was run in the operative and in the inoperative modes. Summaries of the test results for the NaOH sump liquor operative and inoperative mode test runs are found in Tables 2 and 3.

4.1.1 Post Test Inspection - After run 47 was completed, the NaOH sump liquor was drained. The towers were inspected and it was noted that the stoneware had settled 1 to 1-1/2 inches in all four towers. There was no caking of precipitates on the stoneware or the nozzles. Liquid was detected in the test setup vent line and identified as nitric acid. The scrubber pump was disassembled. Stoneware chips had been circulated by the pump and scoring of the impeller, impeller housing and pump shaft was noted.

4.1.2 Conclusions: NaOH Sump Liquor Test Series

1. The desired outlet gas concentration of 150 ppm NO_2 or less could not be obtained with the NaOH solution.
2. Higher pump flow rate gives a lower outlet gas concentration.
3. Higher inlet gas concentration gives a higher outlet gas concentration.
4. Higher nitrogen flow rate gives a higher outlet gas concentration.
5. Proper circulation is occurring in the sump as designed.
6. Inoperative mode scrubs less efficiently than operative mode.
7. When scrubber pump is shut off, scrubber bed will contain enough sump liquor to scrub for a minimum of four minutes at selected flow rates of nitrogen and inlet gas concentrations.
8. Best scrubbing performance is with low sump strength (2 to 3% NaOH) rather than high sump strength (6 to 8% NaOH).
9. Majority of scrubbing is performed in the first tower.

Table 2 Test Data Summary, N_2O_4 Scrubber with NaOH Sump Liquor, Operative Mode

GN_2 Flowrate, scfm	Date	Run	Wet Chemistry		Average Liquor Flowrate, gpm	Outlet Gas Detector Tube, ppm		Liquor Strength	
			Average Inlet Gas, ppm	Average Outlet Gas, ppm		Drager	Kitagawa	pH	% Conc.
10	5-27-77	3	91,200	280	133		750		
	5-27-77	2	95,500	443	171		500		
	5-27-77	4	98,100	107	95		850		3.96
	5-27-77	1	217,000	3,330	172		500		7.88
	6-6-77	31	484,000	636	160				
50	6-1-77	13	1,960	398	128				
	6-1-77	12	2,350	299	144				
	6-1-77	7	5,310	275	135				
	6-1-77	6	6,680	342	149				
	6-1-77	5	7,990	301	181				6.64
	6-1-77	11	34,200	276	181				
	6-7-77	33	34,900	258	157				6.48
	6-16-77	46	47,200	179	165				2.88
	6-6-77	26	54,700	304	154				7.92
	6-8-77	37	58,500	199	172				5.04
	6-3-77	23	229,000	107	178	500			
	6-3-77	25	249,000	65	115	1,000			2.76
	6-3-77	24	259,000	32	145	1,000			
100	6-1-77	10	6,440	454	172	50			
	6-1-77	9	7,080	504	148	100-150			
	6-1-77	8	7,600	501	110				
	6-16-77	47	18,800	504	167				2.16
	6-7-77	34	22,200	634	157				6.1
	6-1-77	16	23,800	951	129	500			
	6-1-77	14	24,400	693	181	500			
	6-1-77	15	26,800	957	154	500			
	6-6-77	27	30,900	653	157				
	6-8-77	38	31,100	538	176				
150	6-6-77	29	22,600	1,100	160				
200	6-7-77	35	12,800	1,040	157				
	6-8-77	39	17,000	951	181				
	6-6-77	28	17,700	1,070	159				
	6-3-77	17	20,100	928	158				
	6-3-77	18	20,700	1,130	131				
	6-3-77	19	22,500	1,040	102				
400	6-3-77	20	4,910	1,680	72				
	6-3-77	21	5,530	1,390	128	1,000+			
	6-3-77	22	6,470	1,570	167				
	6-7-77	36	7,100	1,140	159				
	6-6-77	30	12,000	903	160				6.36
	6-6-77	32	80,000	2,400	160				

Table 3 Test Data Summary, N_2O_4 Scrubber with NaOH Sump Liquor, Inoperative Mode

GN_2 Flowrate, scfm	Date	Run	Wet Chemistry: Average Inlet Gas, ppm	Wet Chemistry: Average Outlet Gas, ppm	Outlet Gas Detector Tube, ppm: Drager	Outlet Gas Detector Tube, ppm: Kitagawa	Liquor Strength: pH	Liquor Strength: % Conc.
10	6-9-77	44	922,000	3,720				
50	6-9-77	40	42,500	538				4.56
100	6-9-77	45	22,100	400				
	6-9-77	41	24,700	1,760				3.72
200	6-9-77	42	12,300	2,810				
400	6-9-77	43	74,400	9,100				

4.0 TEST DESCRIPTION FOR N_2O_4 SCRUBBER (cont'd)

4.2 Scrubber Tower Operation Tests

The desired output of 150 ppm NO_2 or less was not obtained with the NaOH sump liquor. Several possibilities were investigated to evaluate if the scrubber towers were flooding at certain test conditions or if the gas was channeling in the towers so that maximum scrubbing would not be achieved. It was hoped that these tests could help explain the high outlet gas concentrations.

A dry bed smoke test was performed to observe the gas flow in a dry tower. With the pump off and the valves in the operative mode position, nitrogen was flowed at 10 to 400 scfm through the scrubber. A smoke candle was moved across the diameter of the tower along the surface of the packed bed and the gas flow observed. At 10 scfm, a smoke candle indicated that the flow at the edges of the tower was more pronounced than in the center. At 400 scfm, the flow dispersion in the tower was nearly uniform.

A wet bed smoke test was also performed to determine the gas flow characteristics in an operational or wet bed tower. With the lid and demister of tower #4 removed, a nozzle was installed to spray at approximately the same height as the nozzle in tower #4 when the lid is installed. The pump was turned on and tower #4 was thoroughly soaked, the pump shut off and GN_2 flow measurements were made with a smoke candle for 1 to 2 min utes as the water gravity drained through the tower. This technique was repeated for GN_2 flows of 10, 50, 100, 200 and 400 scfm. At 10 scfm, the GN_2 flow was uniform over the bed surface as measured by a smoke candle. At 50 and 100 scfm, the flow around the edges of the tower was slightly less than the flow in the center. At 200 and 400 scfm, the flow pattern seemed uniform as measured by the smoke candle.

Another test was performed to determine if flooding had occurred in tower #1. In order to increase the liquid flow rate to Tower 1, the nozzles in towers #3 and #4 were removed and the supply line capped. The scrubber pump was turned on and 60 gpm was flowed through tower #1 spray nozzle. Nitrogen flow was varied from 10 scfm to 400 scfm. No flooding of the tower was observed under these conditions.

A test to evaluate the spray pattern of the scrubber teflon nozzles was conducted to determine the distribution of liquor to the packed bed surface during scrubber operation. The 2-piece nozzle was tested with the inner diffuser vane pinned and with it free to rotate. A series of plastic cups were arranged along a line representing the diameter of the tower. A teflon spray nozzle was positioned at a height above the cups that approximated the nozzle height above the scrubber bed. The nozzle was connected to a water line with a flow capacity of 40 gallons per minute. The water was turned on for a brief period to partially fill the cups. From the amount of liquid in the cups, a distribution was determined. The results obtained indicated that the center portion of the tower packed bed surface received about 1/3 more water than the outer portions of the surface with inner diffuser vane pinned and with the diffuser vane free to rotate.

4.2 Scrubber Tower Operation Tests (cont'd)

It was concluded from these tests that the gas and liquid flow distribution in the towers was good for the conditions tested and no changes to the tower configuration needed to be made. The spray nozzles in the towers are satisfactory and should continue to be used in the scrubbers.

4.3 Sodium Sulfite (Na_2SO_3) Sump Liquor

The initial tests of the oxidizer scrubber were performed utilizing a solution of sodium hydroxide as the sump liquor. This test series indicated that the desired output of 150 ppm NO_2 or less could not be obtained with the NaOH solution. References in the report, "Hypergolic Propellant Vapor Disposal", Florida Institute of Technology, Contract NAS10-8399, indicated good results could be obtained by use of sodium sulfite solution as the scrubbing liquor.

Thirty-eight (38) test runs using sodium sulfite as the sump liquor were made during the period from 06/23/77 through 07/06/77. Tests were made with sump liquor concentrations at 10% and 25% Na_2SO_3. The actual concentration of the Na_2SO_3 could not be easily measured so pH readings were used as an indication of sump liquor strength. Na_2SO_3 was also added to partially depleted sump solution to determine if liquor strength could be increased during usage without a complete drain and refill operation. Summaries of the test data for the Na_2SO_3 sump liquor operative and inoperative mode test runs are presented in Tables 4 and 5.

Conclusions: Na_2SO_3 Sump Liquor Test Series

As a result of the tests conducted, the following conclusions were reached:

1. Sodium sulfite gave much better overall performance than sodium hydroxide as a sump liquor and met the scrubber specification requirement that the output gas concentration be less than 150 ppm of NO_2.

2. Sodium sulfite formed a one-inch layer of precipitate in the bottom of the sump tank during the capacity test.

3. Higher pump flow rate gives a lower outlet gas concentration.

4. Higher inlet gas concentration gives a higher outlet gas concentration.

5. Higher nitrogen flow rate gives a higher outlet gas concentration.

6. Inoperative mode scrubs less efficiently than operative mode.

Table 4 Test Data Summary N_2O_4 Scrubber with Na_2SO_3 Sump Liquor, Operative Mode

GN_2 Flowrate, scfm	Date	Run	Wet Chemistry: Average Inlet Gas, ppm	Wet Chemistry: Average Outlet Gas, ppm	Average Liquor Flowrate, gpm	Outlet Gas Detector Tube, ppm: Drager	Outlet Gas Detector Tube, ppm: Kitagawa	Liquor Strength: pH	Liquor Strength: % Conc.
10	6-25-77	15	606,000	0	150		0	7	
50	6-25-77	11	634	0	148		0	9	
	6-24-77	5	1,490	0	151		0	8-9	
	6-29-77	17	9,570	0	150			10	
	6-24-77	9	11,300	0	151		0	8-9	
	6-23-77	3	16,800	2.0	147	<5	0	8	
	6-23-77	1	21,200	3.1	150			9-10	
	7-1-77	28	22,000	413*	127				
	6-23-77	4	22,400	6.1	154	0	0	8-9	
	7-1-77	30	28,900	453*	146			7	
	7-6-77	31	29,300	0	147			10	
	6-29-77	18	25,500	0	153			8-9	
	7-1-77	27	30,200	377*	154				
	7-1-77	25	30,700	187	154				
	6-23-77	2	30,700	6.1	154	<5	<10	8	
	7-1-77	26	31,300	377*	154				
	7-1-77	29	31,700	893*	103			7-8	
	7-6-77	33	147,000	417	148				
100	6-24-77	6	442	5.3	154		0	8	
	6-25-77	12	6,950	0	154		0		
	6-24-77	10	7,050	0	146		0	8-9	
	6-29-77	19	12,400 24,600	46 0	98 153				
	7-6-77	36	24,800	183	113		10	9-10	
	7-6-77	37	29,500	193	146			8-9	
200	6-24-77	7	683	0	151		0	8	
	6-25-77	13	4,770	0	154		0	8	
	6-29-77	20	5,230 5,720 5,550	30 44 48	148 127 106			8-9	
400	6-24-77	8	561	1.2	154		0	8-9	
	6-25-77	14	3,110	0	151		0	8	
	6-30-77	21	4,360 4,000 3,880	0	149 128 98			9-10	
	6-25-77	16	41,600	0.7	149		0	7-8	

*Made during latter part of capacity run with sump liquor partially depleted.

Table 5 Test Data Summary, N_2O_4 Scrubber with Na_2SO_3 Sump Liquor, Inoperative Mode

GN_2 Flowrate, scfm	Date	Run	Wet Chemistry: Average Inlet Gas, ppm	Wet Chemistry: Average Outlet Gas, ppm	Outlet Gas Detector Tube, ppm: Drager	Outlet Gas Detector Tube, ppm: Kitagawa	Liquor Strength: pH	Liquor Strength: % Conc.
10	7-6-77	35	565,000	680				
50	6-30-77	22	14,900	0			9	
100	6-30-77	23	18,400	15				
200	6-30-77	24	10,200	54				
400	7-6-77	34	51,100	53				

4.0 TEST DESCRIPTION FOR N_2O_4 SCRUBBER (cont'd)

4.3 Sodium Sulfite (Na_2SO_3) Sump Liquor

7. A sharp breaking point of reduced scrubber efficiency did not occur as the 600 lb N_2O_4 goal was reached in the capacity run.

8. When the scrubber pump is shut off, the scrubber bed will contain enough sump liquor to scrub for a minimum of five minutes at selected flow rates of nitrogen and inlet gas concentrations.

4.4 Sodium Hydroxide (NaOH)/Sodium Sulfite (Na_2SO_3) Sump Liquor

A mixture of Na_2SO_3 and NaOH was made in the sump to determine if capacity could be increased and the precipitate from the sodium sulfite kept in solution. Twenty runs were made during the period from 07/07/77 through 07/09/77. One sump solution mixture was used for the entire series. The sump pH remained at 10 for the twenty runs. The scrubber was run in the operative and inoperative mode. Summaries of the test results for the NaOH/Na_2SO_3 sump liquor operative and inoperative mode test runs are found in Tables 6 and 7.

Post Test Inspection - The sump liquor was drained and no salts were noted. The drop in sump liquor flow rate from 172 gpm to 139 gpm between run 8 and previous runs could be explained by partially plugged tower spray nozzles. An examination of the tower spray nozzles were made and whole 1/2-inch saddles from the packed bed were found in the following quantities: Tower 1, 4 saddles; tower 2, 16 saddles; tower 3, 3 saddles; tower 4, 1 saddle. Apparently, 1/2-inch saddles had migrated downward through the 1-inch saddles and holding screen into the sump storage tank. During the inoperative mode, runs 5, 6 and 7, the saddles were suspended in the sump solution by the agitation in the sump from the inlet nitrogen bubbling through the inlet diffuser in the sump storage tank bottom. When run 8 was performed and the scrubber pump turned on, the saddles were passed through the pump and into the tower spray nozzles. Runs 8 through 20 were performed at reduced sump liquor flow rate.

5.0 CONCLUSIONS: $NaOH/Na_2SO_3$ SUMP LIQUOR

As a result of the tests conducted, the following conclusions were reached:

1. The sump liquor was as efficient as Na_2SO_3 for scrubbing in the inoperative mode.

2. $NaOH/Na_2SO_3$ did not precipitate a solid.

3. Half inch saddles appeared in the sump tank during the test and were ingested through the pump and lodged in the nozzles. This indicated the need to prevent the pump from ingesting the saddles, either by filtering the pump suction line or by insuring that the half inch saddles would not migrate through the one inch saddles and support plates in the towers.

4. Six hundred sixteen pounds of N_2O_4 can be absorbed by the sump liquor although the efficiency drops after 560 pounds of N_2O_4 is absorbed.

5. The operative mode test results for the $NaOH/Na_2SO_3$ mixture were generally not as good as for the Na_2SO_3 by itself.

6. Early in the test (after run 7), the nozzles became partially clogged with whole stoneware saddles which had been ingested through the pump. This reduced the sump liquor flow rate and probably distorted the spray patterns in the towers. It this problem had not existed, results probably would have been better. Test results show that after 560 pounds of oxidizer had been reacted in the unit, the measured concentration of the outlet gas was 124 ppm for an input concentration of 137,000 ppm. Not until 600 pounds had been reacted, did the outlet concentration indicate that the specification of less than 150 ppm had been exceeded. Visual observations of the vent stack during all of these tests was made by the entire test crew and no brown vapors were observed at any time. On the basis of these results, it is believed that with full liquor flow and unclogged tower nozzles, that the mixture of sodium sulfite and sodium hydroxide would scrub as well as the sodium sulfite by itself and that the capacity to react 600 pounds of oxidizer could be achieved.

7. A mixture of 5% NaOH and 18% Na_2SO_3 in water is recommended as the sump liquor to be used in the oxidizer scrubber.

Table 6 Test Data Summary, N_2O_4 Scrubber with $NaOH/Na_2SO_3$ Sump Liquor, Operative Mode

GN_2 Flowrate, scfm	Date	Run	Wet Chemistry: Average Inlet Gas, ppm	Wet Chemistry: Average Outlet Gas, ppm	Average Liquor Flowrate, gpm	Outlet Gas Detector Tube, ppm: Drager	Outlet Gas Detector Tube, ppm: Kitagawa	Liquor Strength: pH	Liquor Strength: % Conc.
10	7-9-77	12	489,000	258	133				
50	7-9-77	16	1,070	14	133				
	7-7-77	1	4,230	5	172			10	
	7-9-77	20	117,000	752	133				
	7-9-77	19	132,000	825	135				
	7-9-77	18	137,000	124	133				
	7-9-77	17	176,000	949	133				
100	7-9-77	15	6,170	39	133				
	7-7-77	9	12,900	36	133			10	
	7-9-77	10	22,400	153	139				
200	7-7-77	8	3,270	0	139				
	7-9-77	14	4,770	23	133				
400	7-9-77	13	3,900	38	132				
	7-9-77	11	27,500	546	139				

Table 7 Test Data Summary, N_2O_4 Scrubber with $NaOH/Na_2SO_3$ Sump Liquor, Inoperative Mode

GN_2 Flowrate, scfm	Date	Run	Wet Chemistry: Average Inlet Gas, ppm	Wet Chemistry: Average Outlet Gas, ppm	Outlet Gas Detector Tube ppm: Drager	Outlet Gas Detector Tube ppm: Kitagawa	Liquor Strength: pH	Liquor Strength: % Conc.
10	7-7-77	3	737,000	61				
50	7-8-77	5	11,600	0			10	
	7-7-77	4	49,900	-			10	
100	7-8-77	6	10,800	0				
200	7-8-77	7	5,830	0				
400	7-7-77	2	49,900	60				

REFERENCES:

1. Test Report for Performance Test of Hypergolic Propellant Vapor Scrubbers, T. A. Murdock, October 1977.

APPENDIX A - ABBREVIATIONS

cc	Cubic centimeter
DR	Drager Gas Detector Tube
EPL	Engineering Propulsion Laboratory Martin Marietta Corporation Denver, Colorado
FIT	Florida Institute of Technology Melbourne, Florida
gal.	Gallon
GN_2	Gaseous nitrogen
gpm	Gallons per minute
HTV	Hypergolic Toxic Vapor
KIT	Kitagawa Gas Detector Tube
KSC	Kennedy Space Center
LN_2	Liquid Nitrogen
ml	Milliliter
MMC	Martin Marietta Corporation
N_2O_4	Nitrogen tetroxide
NaOH	Sodium Hydroxide
Na_2SO_3	Sodium sulfite
NO_2	Nitrogen dioxide
pH	Measure of acidity and alkalinity
psid	Pounds per square inch, differential
psig	Pounds per square inch, gage
P/N	Part number
ppm	Parts per million
scfm	Standard cubic feet per minute
	Microns

APPENDIX B - SCHEMATIC SYMBOL LIST

Symbol	Designator	Meaning
	BD	Burst Disc
	CV	Check Valve
	G	Gage
	HV	Hand Valve
	P	Pressure Transducer
	ΔP	Differential Pressure Transducer
	PR	Pressure Regulator
	ROV	Remote Operated Valve
	RTV	Remote Throttle Valve
	RV	Relief Valve
	SOV	Solenoid Valve
	TC	Thermocouple
	THE-O	Temperature, Heat Exchanger
	TL	Temperature, Line
	TT	Temperature, Tank
	T_{VAP}	Temperature, Vapor