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Cyclinder Supplied Ammonia Scrubber Testing in IDMS

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SUMMARY

This report summarizes the results of the off-line testing the Integrated DWPF Melter System (IDMS) ammonia scrubbers using ammonia supplied from cylinders. Three additional tests with ammonia are planned to verify the data collected during off-line testing. Operation of the ammonia scrubber during IDMS SRAT and SME processing will be completed during the next IDMS run.

The Sludge Receipt and Adjustment Tank (SRAT) and Slurry Mix Evaporator (SME) scrubbers were successful in removing ammonia from the vapor stream to achieve ammonia vapor concentrations far below the 10 ppm vapor exit design basis. In most of the tests, the ammonia concentration in the vapor exit was lower than the detection limit of the analyzers so results are generally reported as <0.05 parts per million (ppm). During SRAT scrubber testing, the ammonia concentration was no higher than 2 ppm and during SME testing, the ammonia concentration was no higher than 0.05 ppm.

Two problems were noted during IDMS testing; flooding and solids buildup. First, flooding was achieved in the SRAT scrubber during water runs and ammonia testing. Flooding was most severe in the SRAT scrubber. Flooding occurred at liquid flows above the design basis for both the SRAT and SME scrubbers. Additional flood testing was completed in the SME scrubber and flooding was duplicated at nominal vapor flow and high liquid flow (200% of design). Second, solids may have partially plugged the scrubber. Solids were noted in the liquid samples, during inspection of the SRAT scrubber, and the differential pressure rose approximately 50% in the four days of testing the SME scrubber. If plugging is experienced in DWPF, back-flushing with process water may be necessary.

INTRODUCTION

The IDMS ammonia scrubber was installed to (1) remove ammonia from the vapor to minimize the deposition of ammonium nitrate (a potential explosive[1]) in the downstream vent piping, and (2) allow testing of a scaled DWPF ammonia SRAT and SME scrubber. Testing of the SRAT and SME scrubber baskets was planned using (1) ammonia supplied from a cylinder and (2) ammonia generated during IDMS SRAT and SME operations.

The conceptual design for the scrubber was summarized[2,3] and included with the Defense Waste Processing Facility (DWPF) design documents[4,5,6] to ensure that the scaled IDMS scrubbers were as prototypic of the DWPF scrubbers as practical. The original design was performed by Ebasco[7]. A cut in Defense Waste Processing Technology (DWPT) funding in FY93 caused the design completion to be delayed approximately nine months[8]. The scrubber was fabricated and installed by construction. Construction turned over the scrubber to TNX on May 15, 1994.

The ammonia scrubber installation is part of DWPF Technical Issue 3.7, Control of Ammonium in DWPF Preparation Processes[9]. DWPF summarized their technical concerns before the scrubber design began[10]. The testing was organized[11] and specific objectives for testing were documented[12]. Data collected during testing was recorded in a laboratory notebook[13].

RESULTS

Background

The ammonia scrubber was installed in IDMS to (1) remove ammonia from the vapor to minimize the deposition of ammonium nitrate in the downstream vent piping, and (2) to allow testing of a scaled DWPF ammonia SRAT and SME scrubber. Testing of the SRAT and SME scrubber baskets was planned using (1) ammonia supplied from a cylinder and (2) ammonia generating during IDMS SRAT and SME operations. This report summarizes the testing completed using ammonia supplied from a cylinder.

A schematic of the IDMS ammonia scrubber is shown in Figure 1. The vapor exiting the SRAT/SME condenser is fed in the bottom of the scrubber through a vapor distributor. The vapor must travel through a packed column of 1" intalox saddles (111" in the SRAT or 60" in the SME) before exiting at the top of the scrubber. The scrubber exit vapor is next processed in the Process Vessel Vent System's (PVVS) Formic Acid Vent Condenser (FAVC). The ammonia is scrubbed from the vapor by spraying a nitric acid solution (pH 1 to 3) at the top of the scrubber to absorb the ammonia as ammonium. The scrubbing liquid exits the scrubber at the bottom and drains back to the Slurry Mix Evaporator Condensate Tank (SMECT). The liquid flow is provided by the SMECT pump and controlled by throttling a valve in the pump discharge line. pH control of the scrubbing liquid is maintained by adding nitric acid to the SMECT. The SMECT is unagitated so mixing is providing by recirculating most of the 40 gpm flow from the SMECT pump.

The following instrumentation is installed with the IDMS ammonia scrubber:

(1) Differential Pressure across the scrubber, inwc,
(2) Liquid Magnetic flowmeter, gpm,
(3) Vapor Orifice flowmeter, lb/hr,
(4) Liquid Temperature, °C,
(5) Two pH meters,
(6) Ammonia rotameter, scfm,
(7) Ammonia analyzer (developed by ADS) and other sample points, and
(8) Sample pumps for inlet and exit vapor samples.

The DWPF scrubber design was complete, so it was used as the basis for the IDMS scrubbers. The IDMS scrubbers and their design bases are summarized in Table 1. This table also compares the IDMS scrubbers to the DWPF scrubbers. The IDMS scrubbers are approximately 1:5.6 DWPF scale.

SRAT Scrubber Testing

SRAT Water Testing (May 20 - June 17, 1994)

Water testing was performed to verify that the system was leak-tight and all instrumentation functioned prior to the SRAT testing with ammonia. The water testing data is summarized in Table 2. Problems noted during water testing are summarized in Appendix A.

SRAT Ammonia Testing (June 20 - June 23, 1994)

Twelve SRAT scrubber experiments were performed using a statistical design[14]. The three sets of different conditions for liquid flow, vapor flow, ammonia addition flow, and SMECT liquid pH used are summarized in Table 3. The online measurements are summarized in Table 4, the field measurements are summarized in Table 5 and the lab analyses are summarized in Table 6.

The first four tests (SRAT-1 to SRAT-4) were completed at a scrub liquid pH of 5, 2 pH units above the design basis of pH 3. Even at this high pH, the ammonia concentration was less than the design basis of 10 ppm in three of the four experiments. In the one experiment that exceeded the 10 ppm limit (SRAT-4), the ammonia inlet concentration was 159% of the design basis and the liquid (72% of design) and vapor flow (43% of design) were much lower than the design basis. The next four tests were completed at a pH of 3. In test SRAT-6 the vapor exit ammonia concentration was 250 ppm. It is believed that a representative sample was not pulled (if valved improperly, both inlet and outlet vapor streams were combined). A repeat of the same conditions in test SRAT-8 had an exit concentration of 1 ppm ammonia. In testing at approximately pH 1, it was extremely difficult to measure ammonia. All ammonia concentrations are estimated to be <0.3 ppm, 30 times lower than the design basis.

The vapor exit ammonia concentration will be far less than the design basis (10 ppm) during operation of the ammonia scrubber at pHs from 1 to 3. The turndown ratio for both the liquid and vapor are high (operation at 1/3 the design vapor flow and 1/2 the liquid flow did not affect performance). pH control at a pH of 1 to 3 is achievable with concentrated nitric acid because it takes a large quantity of acid to drop the pH from 3 to 1. It was estimated that 60 gallons of 11 M nitric acid must be added to a 1400 gallon SMECT based on a titration. Calibration of the pH probes with a pH 1, 4, and 7 buffer should be adequate to ensure that the pH is low enough to ensure adequate scrubber performance.

Note that all reported ammonia results were measured using a Dräger tube analysis (a glass tube using a bromphenol blue indicator specific for ammonia) because the detection limit of the ADS developed ammonia analyzer was too high (estimated at >100 ppm detection limit). To improve the sensitivity of the Dräger tube analysis, first 30 volumes (3 liters) and later 100 volumes (10 liters) of sample were pulled through the Dräger tube to lower the ammonia detection limit. According to the manufacturer of the Dräger tube, the measurements have a relative standard deviation of 10 to 15%[15].

Problems Noted During SRAT Testing

The only problem noted during SRAT testing that may impact DWPF is that flooding was encountered during test conditions well below the design basis. Flooding is believed to have been caused by high liquid flow. Flooding was noted when changing flow conditions and in both instances very high liquid flow and high differential pressure were noted immediately and liquid flowing through the vapor line was noticed later. Flooding was reproduced in the SME scrubber at high liquid flowrates (see write-up in SME section).

Mass balance on ammonia

A mass balance was completed on the ammonia added to the scrubber to determine if all the ammonia could be accounted for. A calculated 4.85 lbs of ammonia (5.13 lbs of ammonium) was added to the scrubber as measured by a rotameter during all the SRAT testing. Attempts to quantify the ammonia added during each run were unsuccessful because the liquid sample was pulled at the exit of the scrubber instead of the entrance to the scrubber. This sample is higher in ammonium than the SMECT because it has scrubbed the ammonia from the vapor. As a result, a mass balance could not be completed for each run. However, a calculated addition of 4.95 lbs of ammonium was added based on a 1405 gallon SMECT and a sample analysis of 421 mg/L prior to SME testing. Table 7 summarizes the calculated mass of ammonia added during each test.

Inspection of SRAT Scrubber

The SRAT scrubber was inspected after replacement of the SRAT basket with the SME basket. The top of the scrubber looked extremely clean and free of solids. The liquid distributor and redistribution doughnut were both free of solids. Plugging of the liquid distribution is unlikely because of the small size of the solids. The bottom two or three inches of the packing and the vapor distributor were coated with very fine (dust-like) solids. These solids may eventually lead to plugging of the column but it appears it would be easy to backwash the solids using process water to clean the packing. Some evidence of liquid channels were noted during inspection of the basket after the packing had been removed.

Modications made prior to SME testing (7/12-7/27/95)

A number of modifications were made prior to beginning the SME scrubber testing. The SRAT scrubber basket was replaced with the five inch SME scrubber basket. Because the SME vapor flow is lower, the vapor orifice was replaced with an orifice plate sized for 0-150 lb/hr vapor flow. Because the SME ammonia design basis is higher, the ammonia rotameter was replaced with a new rotameter sized for 0 to 0.77 lb/hr ammonia (4.3 lb/hr DWPF basis). The pH meters were calibrated over a 0-10 span (instead of 2-12 span in SRAT testing) to allow measurements of pH below 2. The method for controlling liquid flow was changed to minimize the flow upsets noticed in SRAT testing. In addition, lower concentration Dräger tubes were purchased and a new ammonia analyzer was installed which bubbled the vapor through acid in an impinger tube. The solution was analyzed for ammonium to estimate the ammonia concentration in the exit stream. Note that the ADS developed ammonia analyzer was not in service during the testing because the modifications being performed by ADS to improve sensitivity were delayed.

SME Scrubber Testing

SME Water Testing (7/27/94)

Water testing was performed to measure the differential pressure across the scrubber under various liquid and vapor flow conditions. Water testing also verified that the system was leak tight and all instrumentation functioned prior to the SME testing with ammonia. The data is summarized in Table 8.

Flooding testing with SME basket (7/28/94)

Because of the flooding problems noted during SRAT testing, special testing was performed to understand flooding with the SME basket. Flooding in a packed column is defined as "the vapor velocity above which liquid accumulated uncontrollably in the packed bed and continued operation becomes impossible"[16]. Flooding testing was performed to determine when flooding occurs during high liquid and high vapor conditions. Flooding was achieved at nominal vapor flowrates and high liquid flowrates (200% of design) but not at nominal liquid flowrate and high vapor flowrate (200% of design). These flowrates are well above the DWPF design basis and are not expected to be in the DWPF operational envelope.

First, testing was performed at a constant vapor flow (~75 lb/hr). The liquid flow was slowly increased from 1.8 gpm to 3.6 gpm and the differential pressure was monitored. The differential pressure across the scrubber increased from 0.8 inches of water column (inwc) to >10 inwc. A general rule of thumb concerning flooding is that at a differential pressure >1 inwc per foot of packing there is a high probability of flooding[17]. At the measured differential pressure of >10 inwc in approximately five feet of packing, the differential pressure per foot was > 2 so flooding or the onset of flooding was achieved. Testing was not continued long enough to let the column fill up with water and eventually begin liquid flow through the vapor outlet sightglass.

Second, testing was performed at a constant liquid flow of 1.8 gpm. The vapor flow was slowly increased from 75 lb/hr to 150 lb/hr and the differential pressure was monitored. The differential pressure across the scrubber increased from 0.8 inwc to 3.0 inwc when the vapor flow increased to 150 lb/hr (maximum measurable by vapor flowmeter). At the measured differential pressure of 3 inwc, the differential pressure per foot was <0.5 and flooding was not achieved.

SME Ammonia Testing (8/9/94-8/12/94)

Twelve experiments were performed using the SME scrubber similar to the twelve SRAT experiments. The three sets of different conditions for liquid flow, vapor flow, ammonia inlet flow and SMECT liquid pH used are summarized in Table 9. The vapor exit ammonia concentration was < 50 ppb (<0.05 ppm) in all twelve SME scrubber tests. This is 1/200th the design basis concentration of 10 ppm.

The online measurements are summarized in Table 10, the field measurements are summarized in Table 11 and the lab analyses are summarized in Table 12.

Mass balance on ammonia

A mass balance was completed on the ammonia added to the scrubber to determine if all the ammonia could be accounted for. A calculated 13.2 lbs of ammonia (14.0 lbs of ammonium) was added to the scrubber as measured by a rotameter during all the SME testing. Attempts to quantify the ammonia added during each run were unsuccessful because the liquid sample was pulled at the exit of the scrubber instead of the entrance to the scrubber. This sample is higher in ammonium than the SMECT because it has scrubbed the ammonia from the vapor. As a result, a mass balance could not be completed for each run. However, a calculated addition of 11.4 lbs of ammonium was added based on a 1538 gallon SMECT and a sample analysis of 886 mg/L ammonium after SME testing. Table 13 summarizes the calculated mass of ammonia added during each test.

Problems noted during SME testing

The increase in differential pressure in the SME scrubber was caused by solids buildup in the packing. The differential pressure increased from 0.9 inwc to 1.5 inwc during testing at constant vapor and liquid flowrates (8/11/94). It was also noted that the solids content of the SMECT liquid was high during this testing and the liquid flow decreased slightly during this testing (Figure 2). The solids content of the SMECT samples continued to increase during the testing as more solids were stirred up and entrained in the liquid. The ratio of differential pressures on the last day of testing compared to the first day of testing ranged from 1.3 to 2.0. This is a significant increase in differential pressure.

The measured ammonia concentration in the vapor exit was so low during the SME testing that there is concern that a representative vapor sample was not analyzed. If there is any liquid entrainment, the liquid entrained will have a very low pH (1 to 3). If this liquid accumulates in the sample line it will scrub the ammonia from the vapor sample. Since no ammonia was detected in any of the testing and because liquid entrainment was noticed in the vapor sightglass, scrubbing of the vapor by entrained liquid must be suspected. Pulling a sample at the scrubber exit instead of going through a long sample line will eliminate this possibility. A modification of the sample line to allow sampling with a Dräger tube will eliminate this concern.

Future Planned Testing

Three additional cylinder tests will be completed with the SME scrubber after modifications are made in IDMS. The tests will focus on (1) ensuring that the ammonia samples pulled during SRAT and SME testing are representative, (2) confirm the ammonia addition with ammonium analysis of SMECT liquid, (3) monitor scrubber differential pressure, and (4) test the improved ADS ammonia analyzer. All tests will be planned for 6-8 hours of duration and will be completed at design basis liquid flow, vapor flow, and ammonia addition rates. pH will be controlled at pH 4 for the first test, pH 3 for the second test, and pH 1 for the last test. Vapor sampling will be completed every two hours at the scrubber exit using a Dräger tube analysis.

Modifications required prior to the testing include: (1) addition of a sample tap at the vapor exit line, (2) recalibration of the pH meters, (3) installation of the ADS developed ammonia analyzer, (4) installation of a sample valve on the liquid inlet line to the scrubber, and (5) installation of the process water regulator on the PW backflush line. At the completion of the testing, the scrubber will be back-flushed to demonstrate the removal of the solids from the packing.

The ammonia scrubber is now part of the IDMS vent system and will be operational during all future IDMS runs. Testing of the ammonia scrubber is planned to be completed during the upcoming PX-7 IDMS run.

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Appendix A - Problems Noted During Testing

SRAT Water Testing

During SRAT water testing, the closed valve in the scrubber vapor bypass line was determined to be leaking. This caused some of the flow to bypass the scrubber, especially at high liquid or vapor conditions. Installation of a blind flange in the vapor bypass line eliminated this leak path.

A number of other problems were noted and later repaired during water testing including (1) acid addition pump was not wired correctly, (2) the vapor flowmeter was piped backwards, (3) the SMECT pump would not start using control room control, and (4) the poor ammonia flow control required the installation of a needle valve in ammonia inlet line.

Other problems that could not be fixed prior to SRAT testing were: (1) ammonia analyzer does not communicate properly with Modicon and the ammonia analyzer could not detect ammonia in the vapor exit stream, (2) the PVVS blower sometimes stopped when starting or stopping the SMECT pump, (3) a large discrepancy between ammonia scrubber vapor flowmeter and FAVC flowmeters, (4) the design basis vapor flow could not be achieved with the SRAT scrubber because of blower and seal leg design constraints and (5) flooding was noted (as confirmed by high differential pressure across the scrubber and by liquid flow noted in vapor exit sightglass).

SRAT Scrubber Testing

The design basis vapor flowrate could not be achieved in the IDMS SRAT scrubber at the scaled design vapor flow of 300 lb/hr. At higher vapor flows, the IDMS Process Vessel Vent System (PVVS) blower was at >90% of maximum speed. When attempts were made to increase the blower speed, flow was lost through the scrubber. This would happen because one of the seal legs (a column of water) would be sucked into the tank when that tank was under high vacuum . Attempts were made to valve off all tanks except the SMECT and SRAT, but then the SMECT seal leg would relieve. There is no way to valve out the SMECT vent system, so testing had to be completed at slightly lower vapor flowrates. Testing should be completed at the design basis vapor flow in DWPF to ensure flooding is not a problem at design basis conditions.

SME Scrubber Testing

The pH meters were noted to be out of calibration after the SME testing was complete. The actual pH was approximately one pH unit above the measured pH. As a result, the tables have been annotated to list both the measured pH and the corrected pH. Testing was accomplished at a pH of approximately 2, 3 and 4 instead of 1, 2, and 3 as had been planned. pH control was easily maintained through the periodic addition of concentrated nitric acid.

Table 1
Design basis for DWPF and IDMS scrubbers

	DWPF		IDMS	
Design Parameter	SRAT	SME	SRAT	SME
Height, inches	111	60	111	60
Diameter, inches	18.812	11.938	7.981	5.047
Liquid Flow, gpm	20	10	3.60	1.79
Vapor Flow, lb/hr	1645	404	296	72
Ammonia, lb/hr	1.2	2.5	0.22	0.45
DWPF Scale			1:5.56	1:5.59

Table 2
SRAT Scrubber Water Testing Data

Liquid Flow 167 FT gpm	Vapor Flow 166FT lb/hr	Air Purge 161FT lb/hr	FAVC Flow 214FT lb/hr	FAVC Flow 217FT lb/hr
1.9	117	75	94	98
2.8	118	75	94	98
3.6	109	74	91	94
4.5	116	74	105	105
5.5	114	74	101	101
1.7	261	170	207	214
2.6	261	169	210	214
3.7	260	170	214	218
4.6	256	169	210	210
5.3	262	169	200	200
1.9	257	250	274	281
2.8	336	250	274	274

Table 3
SRAT Scrubber Testing Conditions

	Design Basis	Low	Medium	High
Vapor Flow , lb/hr	300	133	200	267
% Design Vapor Flow		44%	67%	89%
Liquid Flow, gpm	3.6	2.7	3.6	4.5
% Design Liquid Flow		75%	100%	125%
pH	3	1	3	5
Ammonia Addition, lb/hr	0.21	0.11	0.23	0.34
% Design Addition		53%	106%	159%

Table 4
IDMS SRAT Scrubber Online Test Results

Test #	Start	Stop	Liquid Flow, gpm	Vapor Flow, lb/hr	Online pH	Delta P, inwc
SRAT-1	6/20/94 8:10	6/20/94 12:20	4.5	133	5.00	4.9
SRAT-2	6/21/94 13:00	6/21/94 14:55	4.4	253	4.40	0.0
SRAT-3	6/21/94 15:37	6/21/94 17:00	2.6	269	5.77	3.8
SRAT-4	6/21/94 17:35	6/21/94 18:45	2.6	129	5.32	1.1
SRAT-5	6/22/94 14:00	6/22/94 16:15	3.7	197	3.10	6.1
SRAT-6	6/22/94 16:20	6/22/94 17:35	3.7	197	3.22	5.8
SRAT-7	6/22/94 17:40	6/22/94 18:40	3.7	198	3.27	5.9
SRAT-8	6/22/94 18:46	6/22/94 19:37	3.7	200	3.14	5.8
SRAT-9	6/23/94 9:20	6/23/94 10:55	2.6	269	<2	3.8
SRAT-10	6/23/94 11:00	6/23/94 13:30	1.8	268	<2	3.4
SRAT-11	6/23/94 14:03	6/23/94 15:50	4.4	129	<2	2.9
SRAT-12	6/23/94 16:10	6/23/94 18:32	2.6	136	<2	1.0

Table 5 - IDMS SRAT Scrubber Recorded Test Results

Test #	Rotameter	Inlet NH3, lb/hr	Outlet[1] NH3, ppm
SRAT-1	0.025	0.11	<5.0
SRAT-2	0.075	0.34	1.67
SRAT-3	0.025	0.11	1.30
SRAT-4	0.075	0.34	15
SRAT-5	0.050	0.23	2.00
SRAT-6	0.075	0.34	250[2]
SRAT-7	0.050	0.23	0.70
SRAT-8	0.075	0.34	1.00
SRAT-9	0.075	0.34	0.30
SRAT-10	0.025	0.11	0.10
SRAT-11	0.075	0.34	0.00
SRAT-12	0.025	0.11	0.05

Note: [1] Outlet Ammonia results are reporting using a Dräger tube analyzer using a one to ten liter sample with an estimated detection limit of 0.05 ppm or 50 ppb. This is reported as 50 moles of ammonia per one-billion moles of vapor. The inlet ammonia flowrate is calculated using the rotameter scale and a calculation of the correction factor for ammonia since an air rotameter was used.

Table 6
IDMS SRAT Scrubber Lab Results

Test #	Lab pH	Ammonium, mg/L	Sample #	Time
SRAT-1	5.90	<100	8188A, B	1115
SRAT-2	8.55	276	8189	1430
SRAT-3	8.20	217	8190	1640
SRAT-4	8.82	415	8191	1800
SRAT-5	3.51	185	8196	1558
SRAT-6	3.55	182	8197	1713
SRAT-7	3.60	178	8198	1838
SRAT-8	3.70	204	8199	1923
SRAT-9	1.14	574	8202A,B	1035
SRAT-10	1.56	519	8203A,B	1300
SRAT-11	1.40	552	8204A,B	1520
SRAT-12	1.75	546	8205A,B	1810

Table 7
Mass Balance on Ammonia - SRAT Testing

Test #	Duration of Test, hrs	Rotameter Addition Rate, lb/hr	Rotameter Calculation Added NH3, lb
SRAT-1	4.2	0.11	0.474
SRAT-2	1.9	0.34	0.655
SRAT-3	1.4	0.11	0.158
SRAT-4	1.2	0.34	0.399
SRAT-5	2.3	0.23	0.512
SRAT-6	1.3	0.34	0.427
SRAT-7	1.0	0.23	0.228
SRAT-8	0.8	0.34	0.290
SRAT-9	1.6	0.34	0.541
SRAT-10	2.5	0.11	0.285
SRAT-11	1.8	0.34	0.609
SRAT-12	2.4	0.11	0.269
Total NH3 Added			**4.85**
Total NH_4^+			**5.13**

Table 8
SME Scrubber Water Testing Data

Liquid Flow 167 FT gpm	Vapor Flow 166FT lb/hr	Differential Pressure, 158PT, inwc	Air Purge 161FT lb/hr	FAVC Flow 214FT lb/hr	FAVC Flow 217FT lb/hr
1.35	85	0.7	62	77	98
1.61	80	0.7	61	84	91
1.81	85	0.8	62	77	98
2.01	84	1.0	62	77	94
2.28	85	1.0	62	77	94
1.29	99	1.0	73	94	109
1.55	99	1.1	73	94	112
1.80	99	1.2	73	94	112
2.06	99	1.4	73	94	112
2.26	102	1.5	73	101	116
1.35	52	0.3	37	49	66
1.57	52	0.3	37	45	70
1.80	52	0.3	38	38	66
2.02	55	0.4	37	42	70
2.22	50	0.4	37	49	63

Table 9
SME Scrubber Testing Conditions

	Design Basis	Low	Medium	High
Vapor Flow , lb/hr	75	50	75	100
% Design Vapor Flow		67%	100%	133%
Liquid Flow, gpm	1.8	1.35	1.80	2.25
% Design Liquid Flow		75%	100%	125%
Measured pH	3	1	2	3
Corrected pH	3	2	3	4
Ammonia Addition, lb/hr	0.45	0.30	0.45	0.60
% Design Addition		67%	100%	133%

Table 10
IDMS SME Scrubber Online Test Results

Test #	Start	Stop	Liquid Flow, gpm	Vapor Flow, lb/hr	Online pH Measured/ Corrected	Delta P, inwc
SME-1	8/9/94 12:50	8/9/94 15:48	1.1	98	1.48 / 2.06	1.1
SME-2	8/10/94 9:02	8/10/94 10:35	2.2	102	1.18 / 1.84	2.0
SME-3	8/10/94 10:58	8/10/94 13:00	2.2	50	1.33 / 1.95	0.8
SME-4	8/10/94 13:08	8/10/94 15:10	1.2	50	1.55 / 2.12	0.3
SME-5	8/12/94 8:55	8/12/94 10:45	2.3	51	2.91 / 3.15	0.8
SME-6	8/12/94 10:45	8/12/94 12:50	2.2	99	3.10 / 3.29	2.3
SME-7	8/12/94 12:50	8/12/94 14:30	1.2	101	3.00 / 3.22	1.5
SME-8	8/12/94 14:30	8/12/94 15:30	1.3	49	2.84 / 3.09	0.4
SME-9	8/11/94 9:00	8/11/94 10:35	1.8	78	2.35 / 2.72	0.9
SME-10	8/11/94 10:40	8/11/94 12:30	1.7	77	2.95 / 3.18	0.9
SME-11	8/11/94 12:35	8/11/94 14:00	1.8	77	2.05 / 2.50	1.1
SME-12	8/11/94 14:05	8/11/94 15:40	1.7	76	2.29 / 2.68	1.5

Note: The first pH measurement is the online (uncorrected) pH and the second pH is the approximate corrected pH (Corrected pH = = 0.76 * measured pH + 0.94).

Table 11 - IDMS SME Scrubber Recorded Test Results

Test #	Rotameter	Inlet NH3, lb/hr	Outlet NH3, ppm
SME-1	5.0	0.77	<0.05
SME-2	2.5	0.38	<0.05
SME-3	2.5	0.38	<0.05
SME-4	5.0	0.77	<0.05
SME-5	2.5	0.38	<0.05
SME-6	5.0	0.77	<0.05
SME-7	2.5	0.38	<0.05
SME-8	5.0	0.77	<0.05
SME-9	3.8	0.57	<0.05
SME-10	5.0	0.77	<0.05
SME-11	3.8	0.57	<0.05
SME-12	5.0	0.77	<0.05

Note: Outlet Ammonia results are reporting using a Dräger tube analyzer using a five liter sample with an estimated detection limit of 0.05 ppm or 50 ppb. This is reported as 50 moles of ammonia per one-billion moles of vapor. The inlet ammonia flowrate is calculated using the rotameter scale and a calculation of the correction factor for ammonia since an air rotameter was used.

Table 12
IDMS SME Scrubber Lab Results

Test #	Lab pH	Ammonium, mg/L	Sample #	Time
SME-1	9.40	2105	8214	15:35
SME-2	8.86	1611	8215	10:25
SME-3	6.20	1005	8216	12:50
SME-4	8.11	1238	8217	15:00
SME-5	7.69	1434	8222	10:20
SME-6	8.65	1907	8223	12:40
SME-7	8.68	1919	8224	14:20
SME-8	9.18	2576	8225	15:30
SME-9	8.64	1513	8218	
SME-10	9.02	1891	8219	12:20
SME-11	8.46	1598	8220	13:55
SME-12	8.89	1968	8221	15:30

Table 13
Mass Balance on Ammonia - SME Testing

Test #	Rotameter Addition Rate, lb/hr	Time, hrs	Rotameter Calculation Added NH3, lb	Change in Cylinder Weight, lb
SME-1	0.77	2.97	2.27	
SME-2	0.38	1.55	0.59	
SME-3	0.38	2.03	0.78	
SME-4	0.77	2.03	1.56	
SME-5	0.38	1.83	0.70	
SME-6	0.77	2.08	1.59	
SME-7	0.38	1.67	0.64	
SME-8	0.77	1.00	0.77	
SME-9	0.57	1.58	0.91	
SME-10	0.77	1.83	1.40	
SME-11	0.57	1.42	0.81	
SME-12	0.77	1.58	1.21	
Total NH3 Added			**13.2**	**15.5**

Figure 1

AMMONIA SCRUBBER INSTALLATION IN IDMS

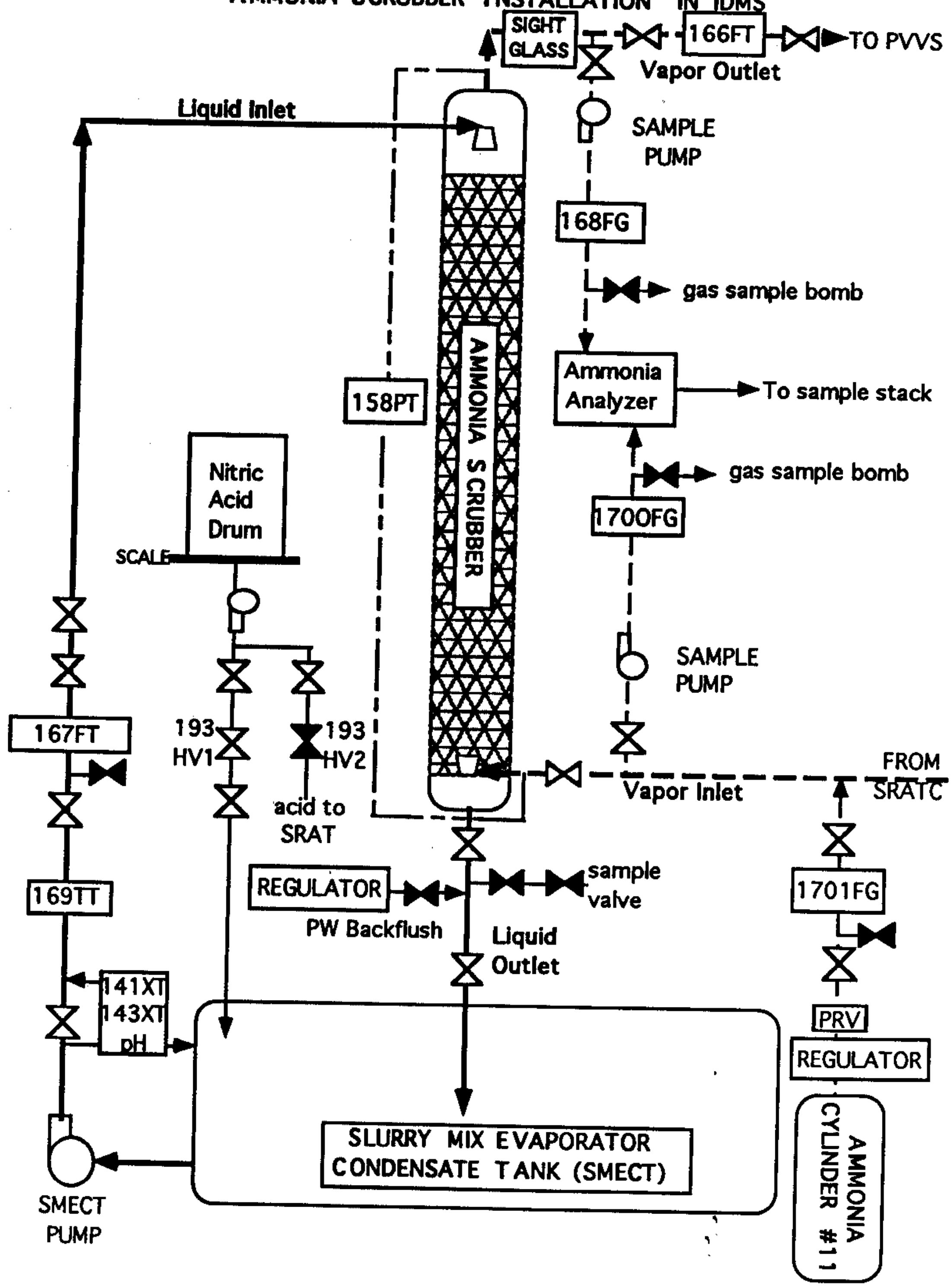
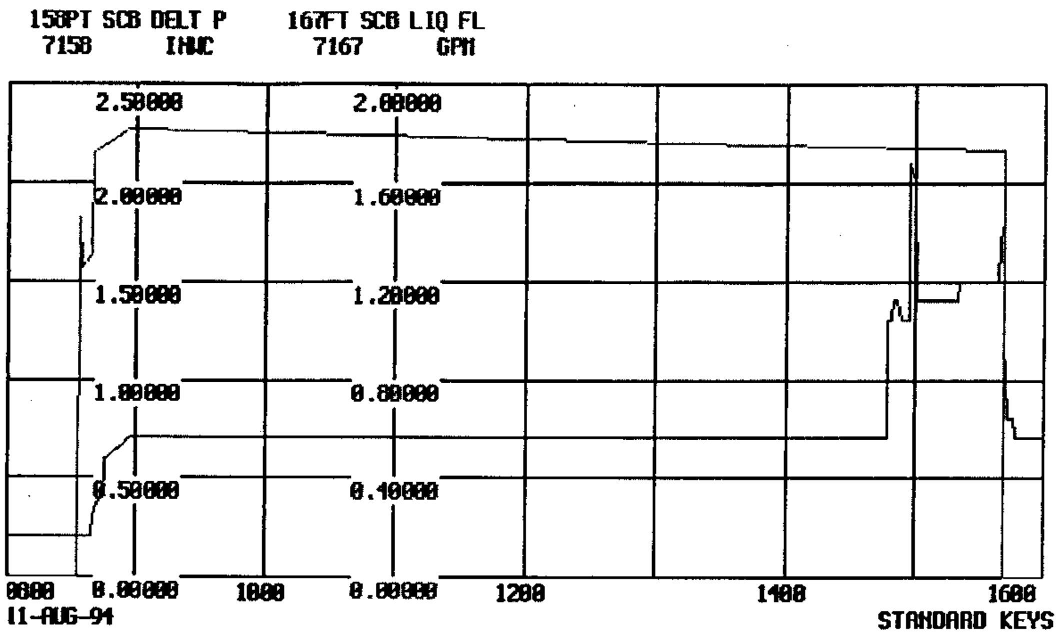


Figure 2
Differential Pressure and Liquid Flow at Constant Flow Conditions
Tests SME-5 to SME-8



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