Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

SVHSER 6185

SOLID AMINE DEVELOPMENT PROGRAM

by

John S. Lovell

Prepared Under Contract No. NAS 9-12957

by

HAMILTON STANDARD
DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

APRIL 1973

ABSTRACT

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HS-C is a regenerable solid amine material being developed (under NASA contract) to perform the functions of humidity control and CO_2 removal for a Space Shuttle type vehicle. Both small scale and large scale testing have shown this material to be competitive, especially for the longer Shuttle missions. However, it had been observed that HS-C off-gasses ammonia under certain conditions. This presented two concerns. The first, that the ammonia would contaminate the cabin atmosphere, and second, that the material is degrading with time.

It was because of these concerns that a program was undertaken to learn the nature and rate of the reactions involved. An extensive test program has shown HS-C to produce only trace quantities of atmospheric contaminants, and under normal extremes, to have no practical life limitation.

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FOREWORD

This report has been prepared by the Hamilton Standard Division of United Aircraft Corporation for the National Aeronautics and Space Administration's Lyndon B. Johnson Space Center in accordance with Contract NAS 9-12957. The report covers work accomplished between July 1, 1972 and the date of issue.

Appreciation is expressed to the Technical Monitors, Mr. Richard J. Gillen and Mr. Frank Collier of NASA, Lyndon B. Johnson Space Center, for their guidance and advice.

This program was conducted under the direction of Mr. Fred H. Greenwood, Program Manager, and Mr. John S. Lovell, Program Engineer, with the assistance of:

Mr. Frank Kester
Mr. William Conway
Mr. Ralph Petillo
Dr. G. A. Berchtold, MIT
Mr. L. Potter, Dow Chemical Company

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SUMMARY

Polyethyleneimine (PEI) 1800 which is a key constituent of HS-C undergoes a continuous process of cross-linking. In the process, ammonia is formed and released. The cross-linking process requires oxygen and is greatly accelerated by increased temperature.

Under normal conditions (80°F) the rate of cross-linking is low and does not present a problem either from the standpoint of atmosphere contamination, or life limitation. Temperature extremes of 150°F are acceptable if the exposure times are limited. Test experience showed no degradation after exposure to 120°F for 44 hours followed by 150°F for 36 hours.

Ammonia generation rates are less than 1% of those expected from metabolic sources, based on the generation rates determined from this program as compared to those from present Shuttle specifications.

One pound samples of HS-C were tested for off-gassing over a range of temperatures in both normal atmospheric and zero oxygen levels. These tests showed ammonia (NH_3) generation to be a strong function of temperature with the rate approximately doubling for every 10°F increase. Without oxygen the rate is greatly reduced. Ammonia generation decreases with time showing a loss of active imine. Total loss occurs in 1100 hours at a temperature of 150°F. Based on off-gassing rates this would extrapolate to 145,000 hours (16.5 years) at 70°F.

A quantity of material (6.65 pounds) sufficient to fill an existing canister was prepared and tested under simulated mission conditions and each mission consisted of heating to 120°F for four hours and then performance testing for four days. A total of eight missions was simulated. Subsequent to the mission testing the canister was exposed to hydrogen sulfide and 150°F temperatures.

The large scale tests confirmed that ammonia production rates were not excessive with nearly identical results as obtained from the off-gassing tests. The rate at 80°F is 36×10^{-6} grams/hour - lb HS-C. At this rate the concentration of ammonia produced by HS-C would reach maximum specification limits only after eight days and then only if no ammonia removal system were included. There was no performance degradation experienced after 1200 hours of test of which 44 hours were at 120°F and 36 hours were at 150°F. The total equivalent time based on off-gas rates is 3960 hours or sufficient for 23 seven-day missions. For long storage, HS-C could be stored in an oxygen free atmosphere.

No detrimental effect resulted from the exposure to hydrogen sulfide.

A ten-man system was sized, based on large scale testing, and a detailed design of the canister was made. The system would require two active canisters each containing 29.3 pounds of HS-C. The fan power required for the ten-man system is 65 watts at an airflow of 58.6 cubic feet per minute.

INTRODUCTION

Metabolic water vapor and carbon dioxide have historically been removed from the spacecraft cabin by a condensing heat exchanger and lithium hydroxide (LiOH), respectively. The condensing heat exchanger offers the possibility of water reclamation and the LiOH system adsorbs large quantities of CO_2 in a small bed. However, these advantages fade in the Space Shuttle because of the ready availability of fuel cell product water and the longer mission length and larger crew size, which require increasing quantities of the non-regenerable LiOH.

A new water vapor and carbon dioxide sorbent called HS-C now has been developed to remove the metabolic products from the cabin using a single sorbent bed. It can be regenerated on a continuous basis by a hard vacuum (50 microns) at the adsorption temperature, or by a mild vacuum (1/2 psia) at higher temperature (200°F) for a limited number of cycles.

HS-C is made from a spherical porous substrate (diameter about 0.5 mm), which is coated with a thick non-volatile liquid which chemically adsorbs CO_2 and H_2O.

HS-C is currently of interest to the designers of the Space Shuttle life support system for removal of metabolic water and carbon dioxide from the cabin. Competing systems are the flight-proven lithium hydroxide, which requires careful preflight preparation of the high capacity non-regenerable material plus the usual condensing heat exchanger for humidity control; and a silica gel, molecular sieve system which shares some of the HS-C's system advantages but can be poisoned with water vapor.

The HS-C system is especially desirable because it requires no liquid loop connections, needing only space vacuum and electrical connections to perform within the cabin environment. The material need not be replaced between flights.

This program is the third in a series designed to develop HS-C to a status acceptable for consideration on a flight program. Previous phases, contracts NAS 1-8944 and NAS 9-11971, have demonstrated the material to be competitive from a performance standpoint, and to pass most flight material specifications. This program was designed to evaluate off-gassing and life characteristics.

OBJECTIVES

The basic objective of this program was to evaluate the off-gassing and life characteristics of HS-C. It is the third in a series of tasks designed to develop HS-C to a status acceptable for consideration on a flight program.

The program consisted of three major tasks:

- Off-gas Investigation
- Mission Simulation
- Flight Concept Definition.

Off-Gas Investigation

This task was designed to identify the mechanism by which ammonia is generated and to quantify generation rates. The suspect mechanisms included contaminants in the PEI, oxidation, thermal decomposition and cross-linking.

Large Scale Mission Simulation

The objective of this task was to evaluate a full scale HS-C canister under worst case mission simulations. Of special interest were any signs of performance degradation and ammonia off-gassing rates. Effects of temperature extremes and acid gasses on performance also were considered.

Flight Concept Definition

The objective of this task was to develop a system design concept applicable to the Space Shuttle including a schematic, operating parameters, and fail operational, fail safe features.

CONCLUSIONS

1. Testing, to date, has shown HS-C to be acceptable for flight application. After 1100 hours of mission simulation including temperature extremes of 120°F and 150°F, the material shows no performance degradation.

2. Under normal operating conditions, the amount of ammonia generated by HS-C is negligible. A ten-man system will produce 0.025 grams per day as compared to an expected metabolic generation of 3.0 grams per day, per the present Shuttle specification.

3. HS-C can withstand limited exposure to temperatures as high as 150°F with little or no performance degradation. Thirty-six hours at 150°F did not cause the material to degrade.

4. HS-C does not degrade when exposed to hydrogen sulfide.

5. The imine used in HS-C is continually cross-linking to form a higher molecular weight imine. This process requires oxygen and is accelerated with increasing temperature. Ammonia is released by the process. Cross-linking goes to completion in 1100 hours at 150°F and is predicted to require 16.5 years at 70°F.

6. When fully cross-linked HS-C no longer has a capacity for CO_2 or water as demonstrated by samples exposed to 150°F for 1100 hours.

7. Manufacture of Shuttle mission quantities of HS-C is practical with the techniques developed under this program.

RECOMMENDATIONS

For development of a flight system, it is recommended that a representative breadboard Shuttle regenerable CO_2 and humidity control system be tested. The system would be sized and configured to meet Shuttle design criteria and be optimized for overall penalty. The HS-C canisters should be designed to be of flight size and of flight concept. Valves and ducting should be of proper size but could be commercial hardware.

The test facilities should include a chamber large enough to simulate a cabin volume. Test conditions should include both extreme and typical mission profiles.

Feasibility testing conducted under this and the preceding contract, NAS 9-1171, has indicated the basic HS-C material to be compatible with Shuttle requirements. The logical next phase in the development of HS-C is to investigate the system aspects of its application.

The information desired includes:

- Packaging methods
- Retention methods
- Canister filling methods
- Representative flight canister performance
- Operation in a simulated cabin volume
- Thermal interaction between desorbing and adsorbing beds
- Humidity control capability over a range of metabolic loads
- CO_2 removal capability over a range of metabolic loads.

Previous large scale testing was accomplished using a commercial, liquid cooled finned tube heat exchanger as the HS-C canister. The maximum bed thickness was three inches. Performance testing was done with a single canister under constant inlet condition. A flight concept canister would consist of a high performance plate fin heat exchanger. The thickness of each HS-C bed would be increased to four or five inches to improve packaging density and overall weight.

For greater system simplicity, cabin air would be used as the heat transport fluid. This same air would then go to the adsorbing HS-C bed. The temperature changes in the air and corresponding changes in HS-C performance can be determined only by testing of a two canister system with the proper

thermal response. It is recommended therefore, that future HS-C testing be conducted utilizing two flight-representative canisters.

In an actual cabin volume, carbon dioxide level and water partial pressure will vary during each adsorb cycle. At the beginning of the cycle, bed capacity is high and levels of CO_2 and H_2O will start high then drop to a minimum, rising to maximum levels at the end of the cycle. Bed performance will be somewhat different than that determined with constant conditions. Therefore, it is recommended that a simulated cabin volume be utilized for proper simulation.

OFF-GAS INVESTIGATION

The objective of the off-gas investigation was to determine the mechanism responsible for the off-gassing of ammonia from HS-C and to quantify ammonia generation rates.

DISCUSSION

The initial step in this investigation was to contact experts in the field of imine chemistry. These included Mr. Larry Potter, Imine Research, Dow Chemical Company, and Dr. G. Berchtold, M.I.T. From these consultations and based on research conducted at Dow Chemical Company, it was concluded that the most probable cause for ammonia generation was cross-linking of the polymer.

Other potential causes included thermal decomposition and contaminants introduced in the manufacturing process. A remote possibility was that the causes were microbiological in nature.

A test program to identify and quantify off-gassing was conducted. The parameters investigated included:

- Temperature
- Humidity Level
- Normal Oxygen Levels
- Oxygen Free Atmosphere.

Also investigated was the ability of HS-C to support microbiological growth, namely fungi.

Testing was conducted with one pound samples of HS-C produced during the previous program phase. The samples were placed in metalic containers and a continuous flow of gas maintained through the sample. Ammonia content was measured in the effluent gas stream. Temperature control was maintained by placing the sample containers in ovens.

There were five samples maintained at temperatures ranging from room temperature to 150°F with both normal and oxygen free environments.

Conclusions

The production of ammonia is a strong function of both oxygen content and temperature, the production rate at 70°F with oxygen being 18 x 10^{-6} grams/hour - lb HS-C. At 150°F this increases to 2400 x 10^{-6}, or 133 times as much. By contrast, in the absence of oxygen the rate at 150°F is 100 x 10^{-6} grams/hour - lb HS-C.

Ammonia production decreased with time indicating that the amount of active material is being depleted. At the end of 1100 hours at 150°F temperature the ammonia production rate was essentially zero indicating that the active imine was depleted. At room temperature this should increase to 145,000 hours (16.5 years).

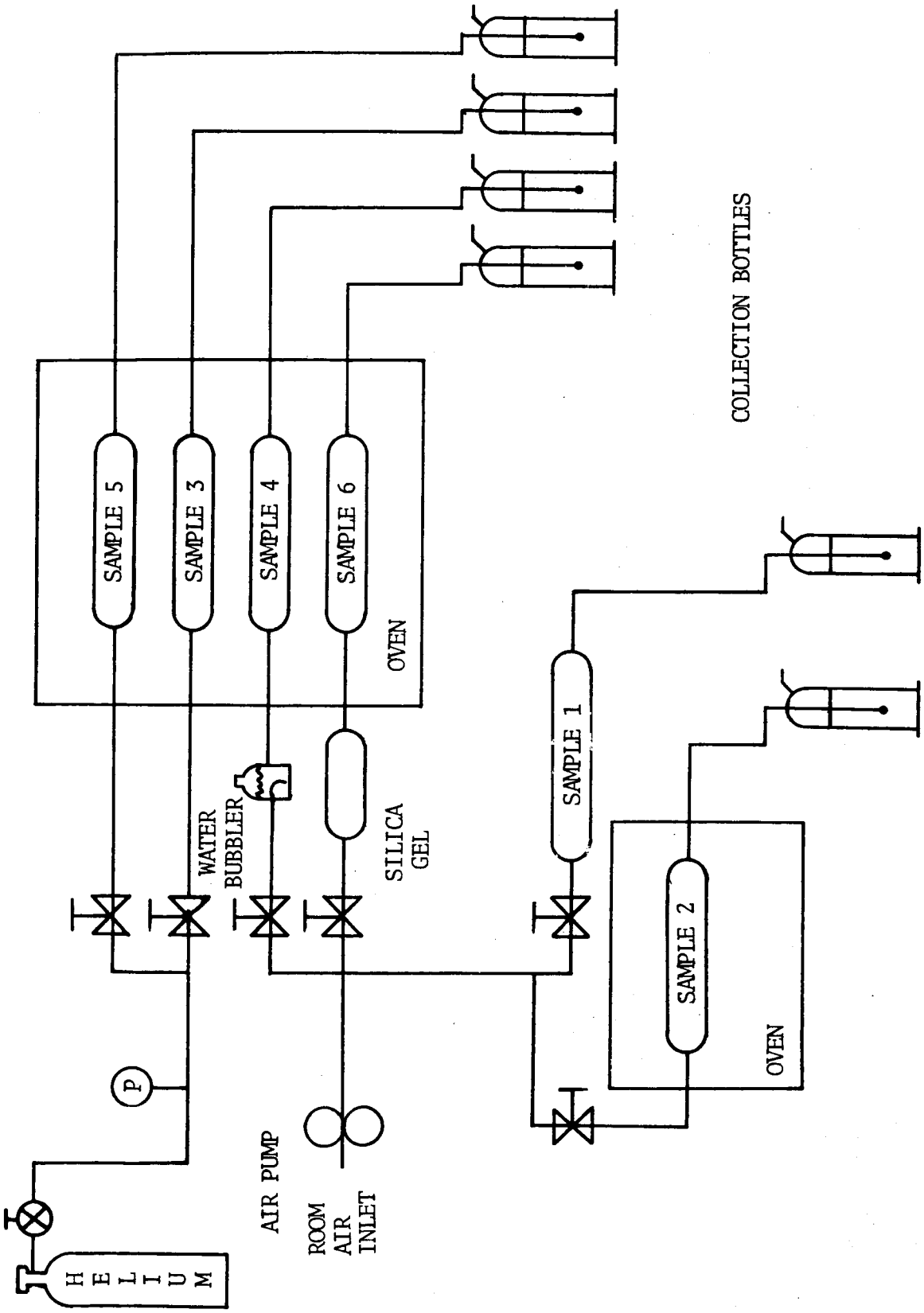
Based on the results of this testing and information from Dow Chemical Company, it was concluded that cross-linking of the polymer is responsible for the generation of ammonia from HS-C. Significant reaction rates take place only at elevated temperatures and in the presence of oxygen. Moisture level does not measurably affect the cross-linking process.

During the cross-linking process, the number of primary imine groups is decreased with the eventual state being all tertiary groups. Because only primary groups have been found to have an appreciable capacity for CO_2, it was assumed that fully cross-linked HS-C would no longer adsorb CO_2. This assumption was verified by test of a sample which had been exposed to oxygen at 150°F for 1100 hours. The material had essentially zero capacity.

It also was substantiated by test that HS-C will not support microbiological life forms.

Description of Test Apparatus

Five cylindrical containers were prepared by filling each with HS-C, Series III, material and one with PEI-18. These six samples were originally set up with sample numbers 1 and 2 in one oven and sample numbers 3, 4, 5, and 6 in a second oven. Samples 1, 3, and 5 were set up for helium gas purge and samples 2,4, and 6 were set up with room air as the purge gas. After 699.5 hours of purge time on sample 1, it was removed from the oven and set up on the work bench at room ambient temperature and the purge gas changed from helium to room ambient air. Figure 1 shows a schematic of the final test setup. Each container outlet had a tygon tube connecting to the gas scrubber collection bottles. A portable flow meter was used to measure the gas flow for each sample at the collection bottle outlet.



OFF-GAS TEST APPARATUS SCHEMATIC

FIGURE 1

Each container has a Hoke micro adjustment valve on the inlet line to permit flow adjustment. Sample 4 had a water bubbler in line to saturate the room air gas. Sample 6 had a steel cylinder filled with silica gel to dry the room air gas.

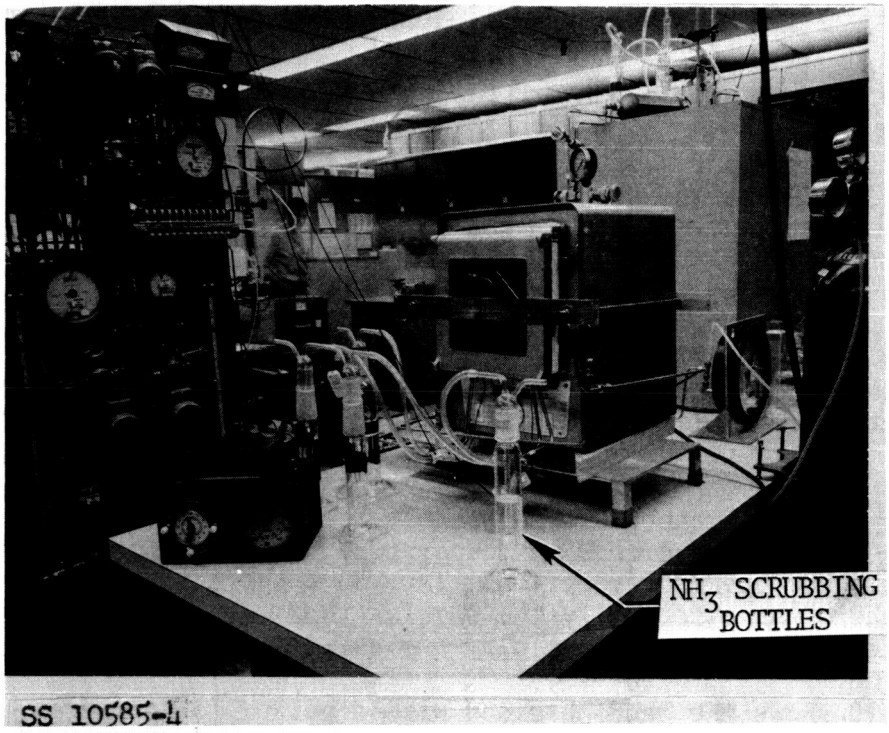
A helium bottle was used for helium gas supply and a Diapump was used for the room air gas supply. A Coleman Spectrophotometer 295 was used to measure the nitrogen-ammonia scrubbed out in the collection bottles. Photographs of the test setup are shown in figure 2.

The samples tested are shown in Table I.

TABLE I

OFF-GAS TEST SAMPLE IDENTIFICATION

Cylinder #1	Weight Atmosphere Flow rate Temperature	424 grams HS-C Room air 15 cc/min, nominal 72°F nominal
Cylinder #2	Weight Atmosphere Flow rate Temperature	369 grams HS-C Room air 15 cc/min, nominal 125°F
Cylinder #3	Weight Atmosphere Flow rate Temperature	417 grams HS-C Helium 15 cc/min, nominal 150°F
Cylinder #4	Weight Atmosphere Flow rate Temperature	391 grams HS-C Wet room air 15 cc/min, nominal 150°F
Cylinder #5	Weight Atmosphere Flow rate Temperature	110 grams PEI Helium 15 cc/min, nominal 150°F
Cylinder #6	Weight Atmosphere Flow rate Temperature	134 grams HS-C Dry room air 15 cc/min, nominal 150°F



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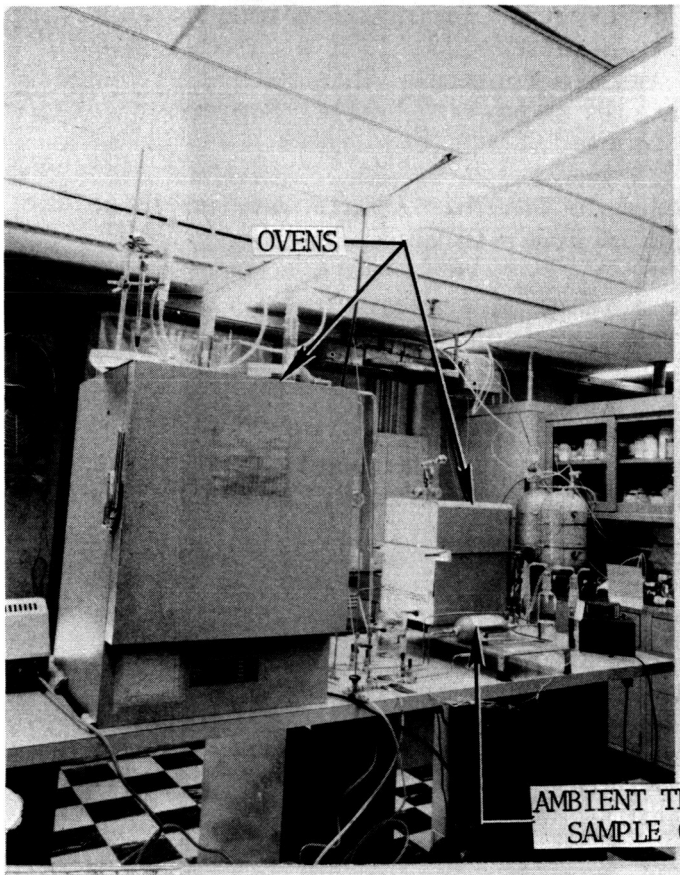

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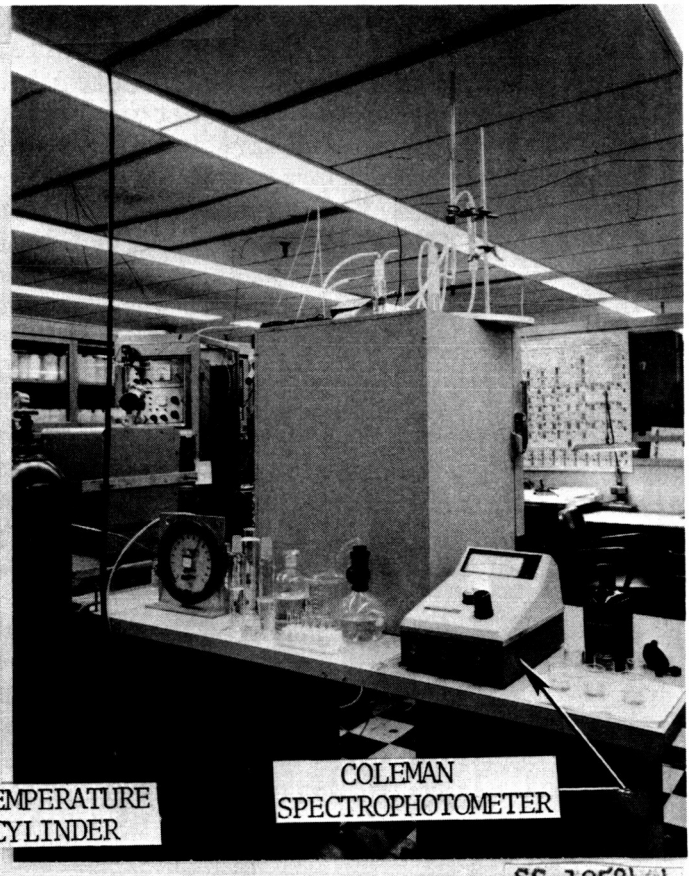

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OFF-GAS TEST APPARATUS

FIGURE 2

Test Results

Figures 3 through 8 show all test data points obtained. Prior to September 27, 1972 the ammonia scrubber had been attached only when a sample was being taken. This resulted in some flow variation. After the test procedure described in Appendix D was adopted, the amount of variation between test points was reduced.

Figures 9 and 10 were constructed for the combined data. Figure 9 shows ammonia production as a function of temperature in humid oxygen environment. Both the total test data extremes and a mean generation rate are shown.

The slope of the mean curve shows that reaction rate approximately doubles for every 10°F increase in temperature. This is not an unusual characteristic for chemical reactions. At 150°F the total band width for a dry atmosphere was essentially the same as that for the humid atmosphere indicating that moisture does not play a significant role in the reaction.

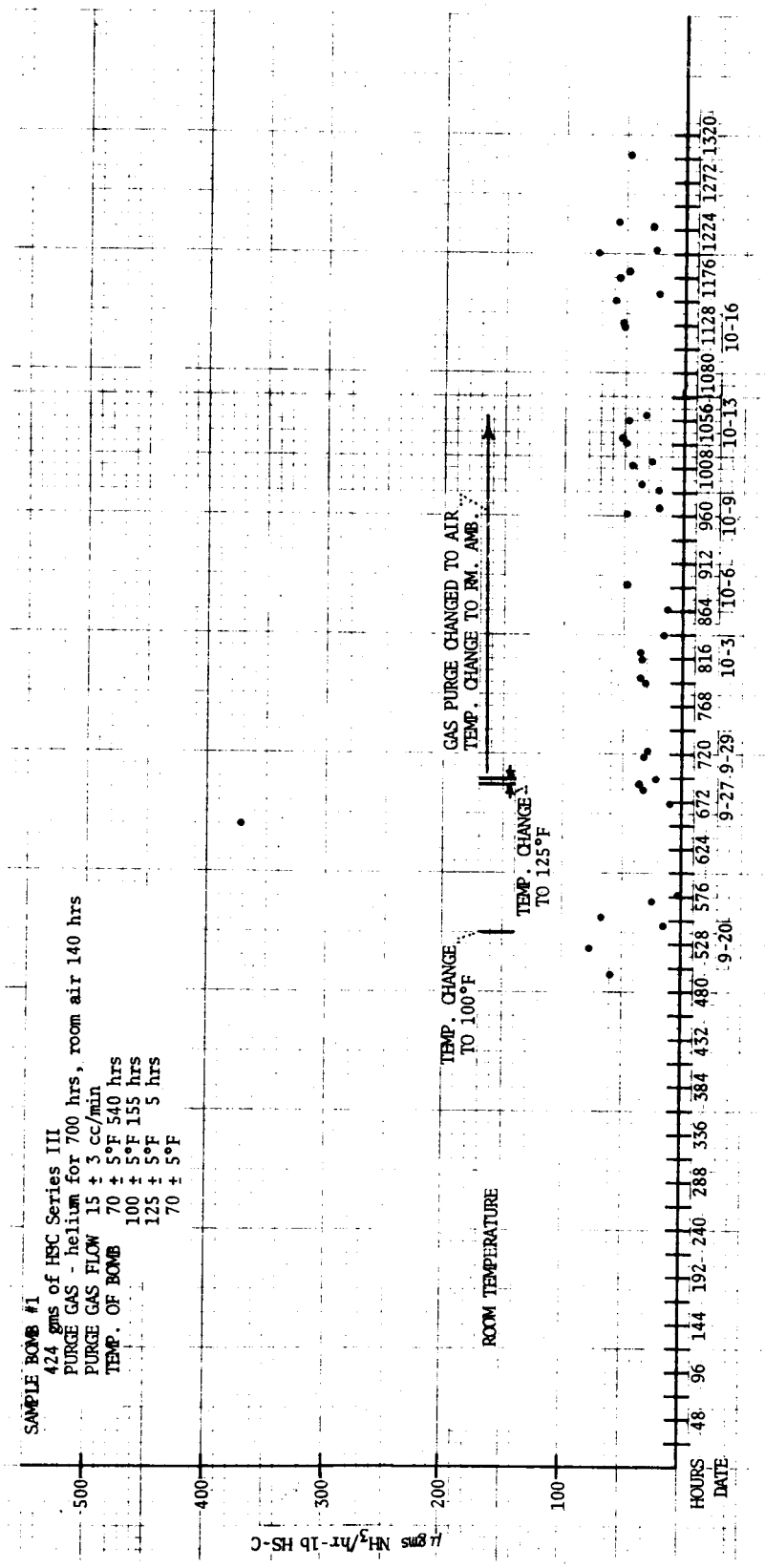
Figure 10 shows the band obtained with a helium (oxygen free) atmosphere. Ammonia production appears less dependent on temperature and is considerably less than that obtained in oxygen. Figures 3 through 8 show data for each of the samples. Prior to September 15, 1972 a chromatographic technique had been used to determine ammonia content. This method proved inaccurate and as a result no test data is shown until after September 15th, when the wet chemistry technique was adopted.

Figure 3 shows the results from sample 1. This sample was run in helium for 700 hours and then switched to air in order to obtain more air data.

Sample 2, figure 4, was run over a range of temperatures to obtain data at intermediate points. Data scatter appears quite large probably due to off-gassing occurring as a result of temperature change.

Sample 4, figure 5, shows the results of testing at 150°F in a normal atmosphere. Ammonia production decreases with time and would appear to reach zero at approximately 1100 hours. Sample 6, figure 6, was purged with dry rather than humid air but gives results nearly identical to those shown in figure 5 (note different scales).

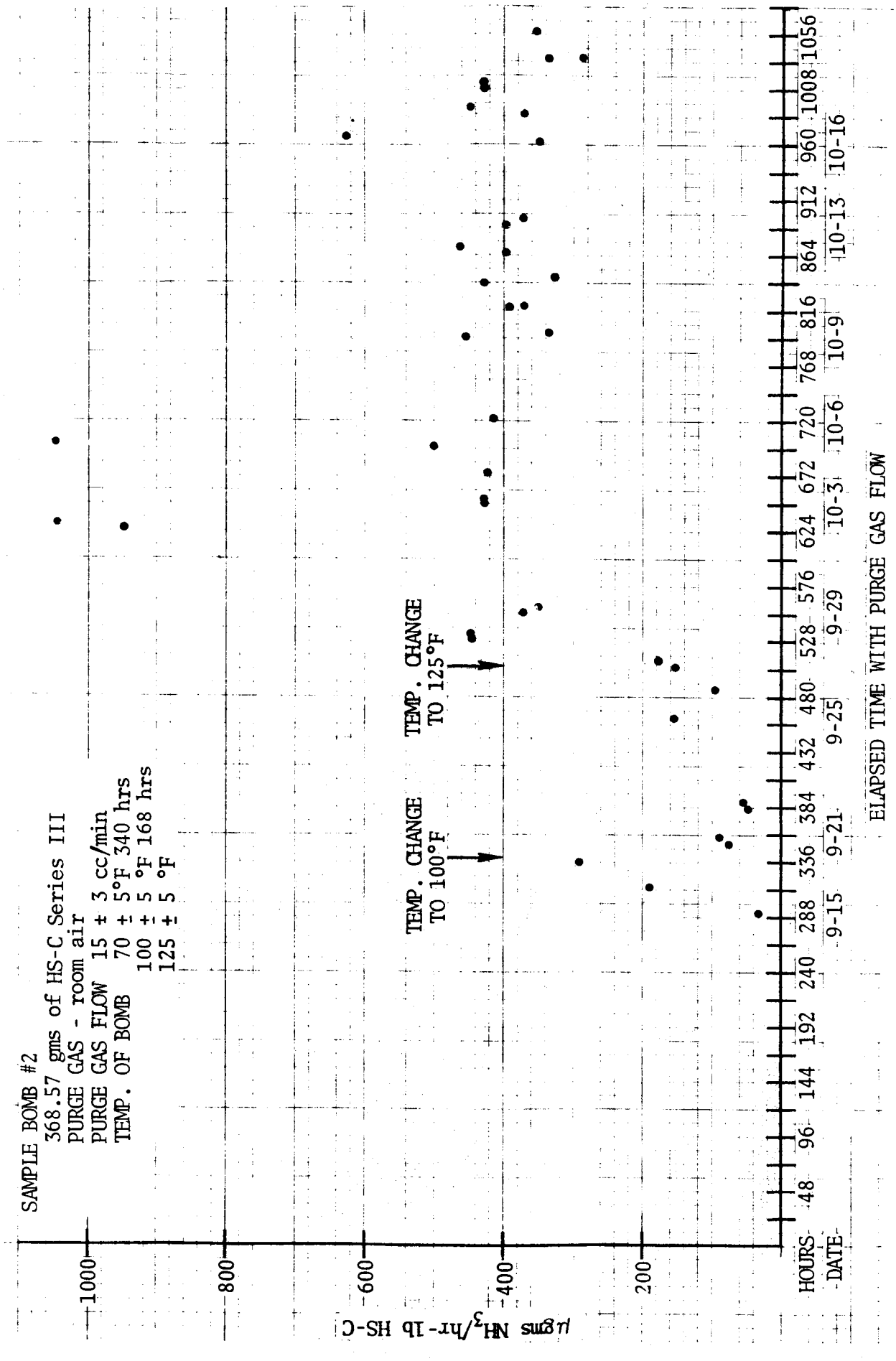
Sample 3, figure 7, was maintained at 150°F in a helium (oxygen free) atmosphere. Like with the samples exposed to oxygen, ammonia production rates decreased with time. It is suspected, however, that this is a result of off-gassing and not due to depletion of the active coating. Ammonia production rates would indicate that it would require 30,000 hours to deplete all active PEI at these conditions.



ELAPSED TIME WITH PURGE GAS FLOW

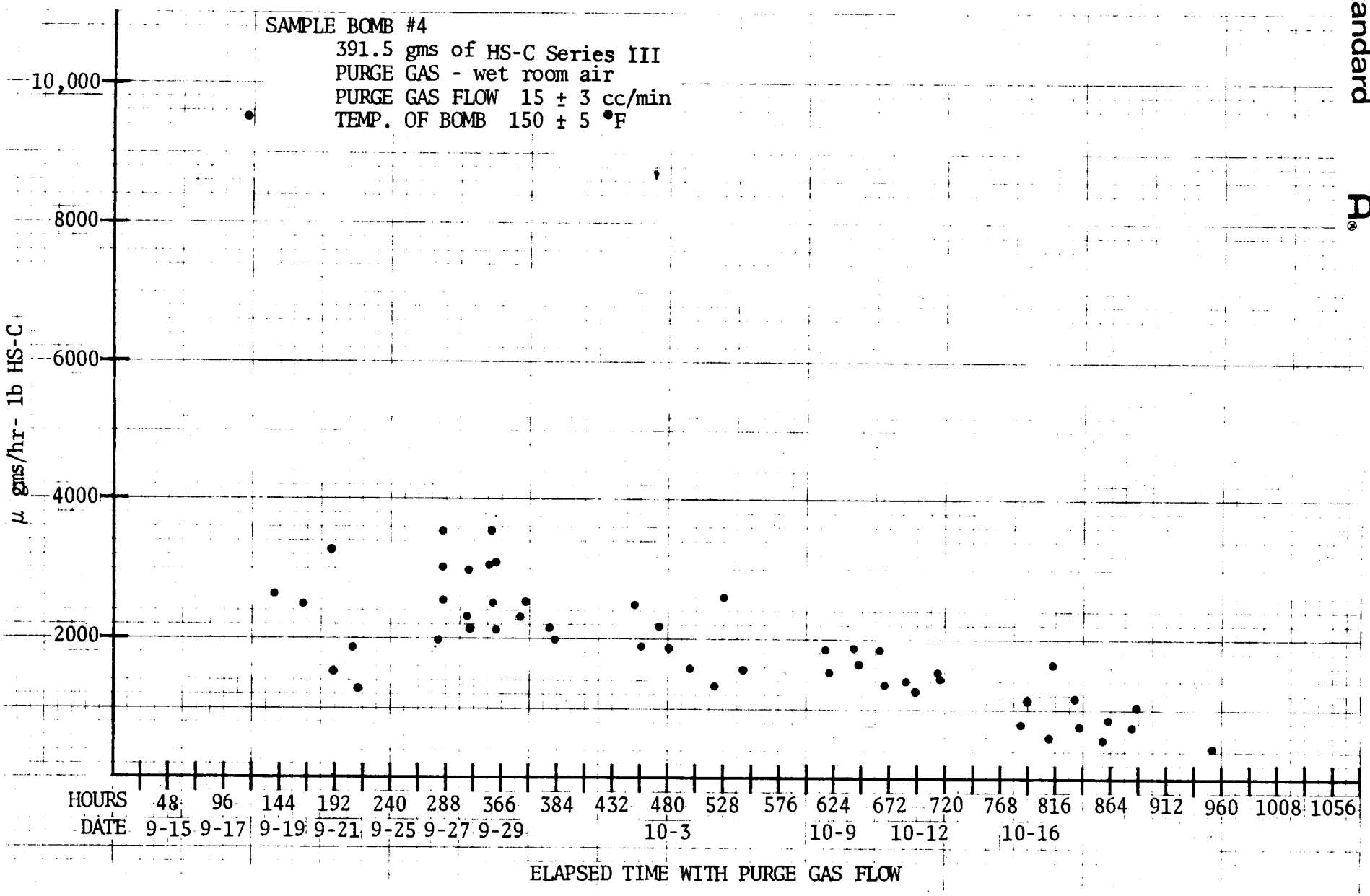
SAMPLE 1 OFF-GAS TEST DATA

FIGURE 3



SAMPLE 2 OFF-GAS TEST DATA

FIGURE 4



SAMPLE 4 OFF-GAS TEST DATA

FIGURE 5

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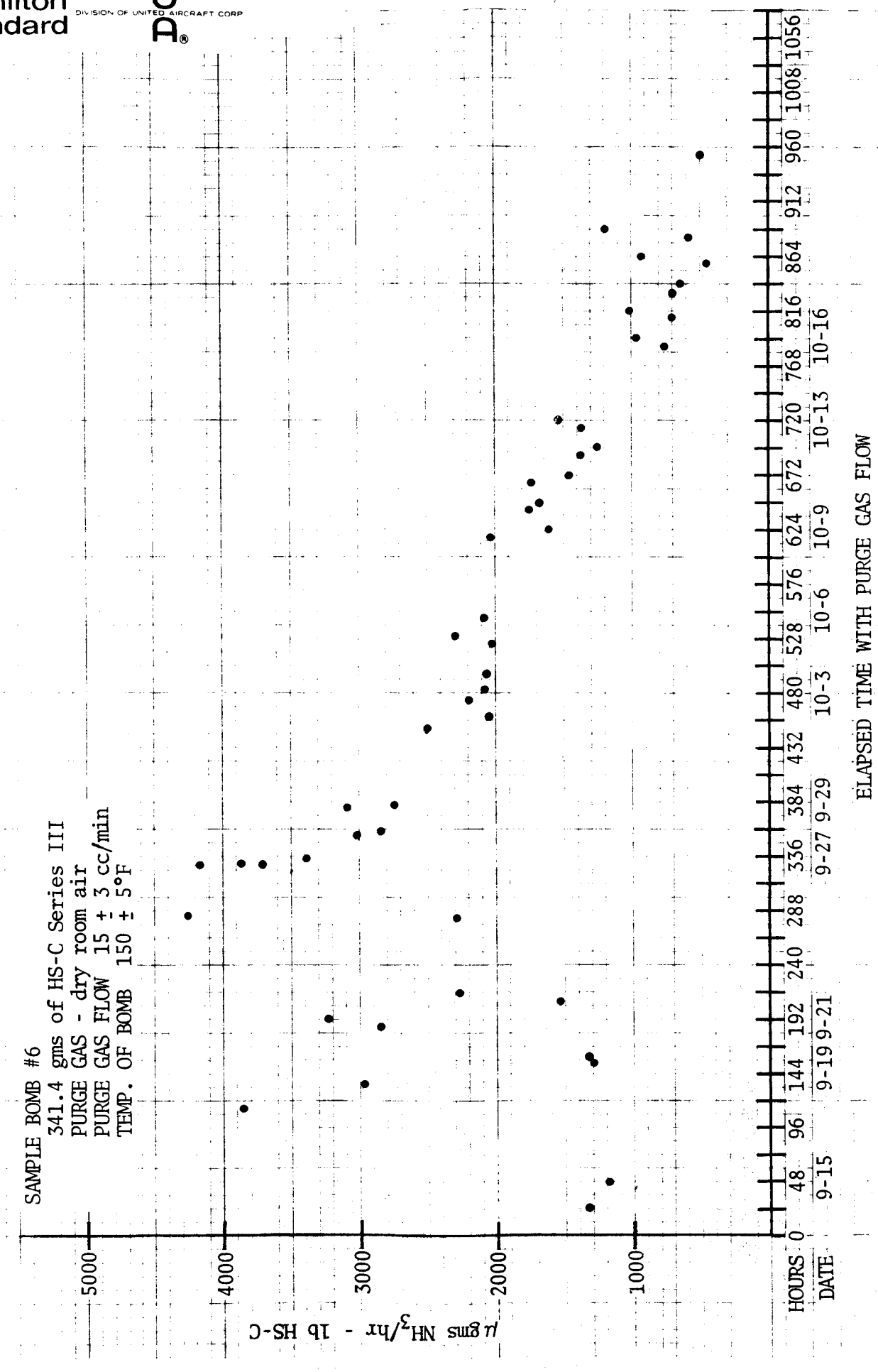
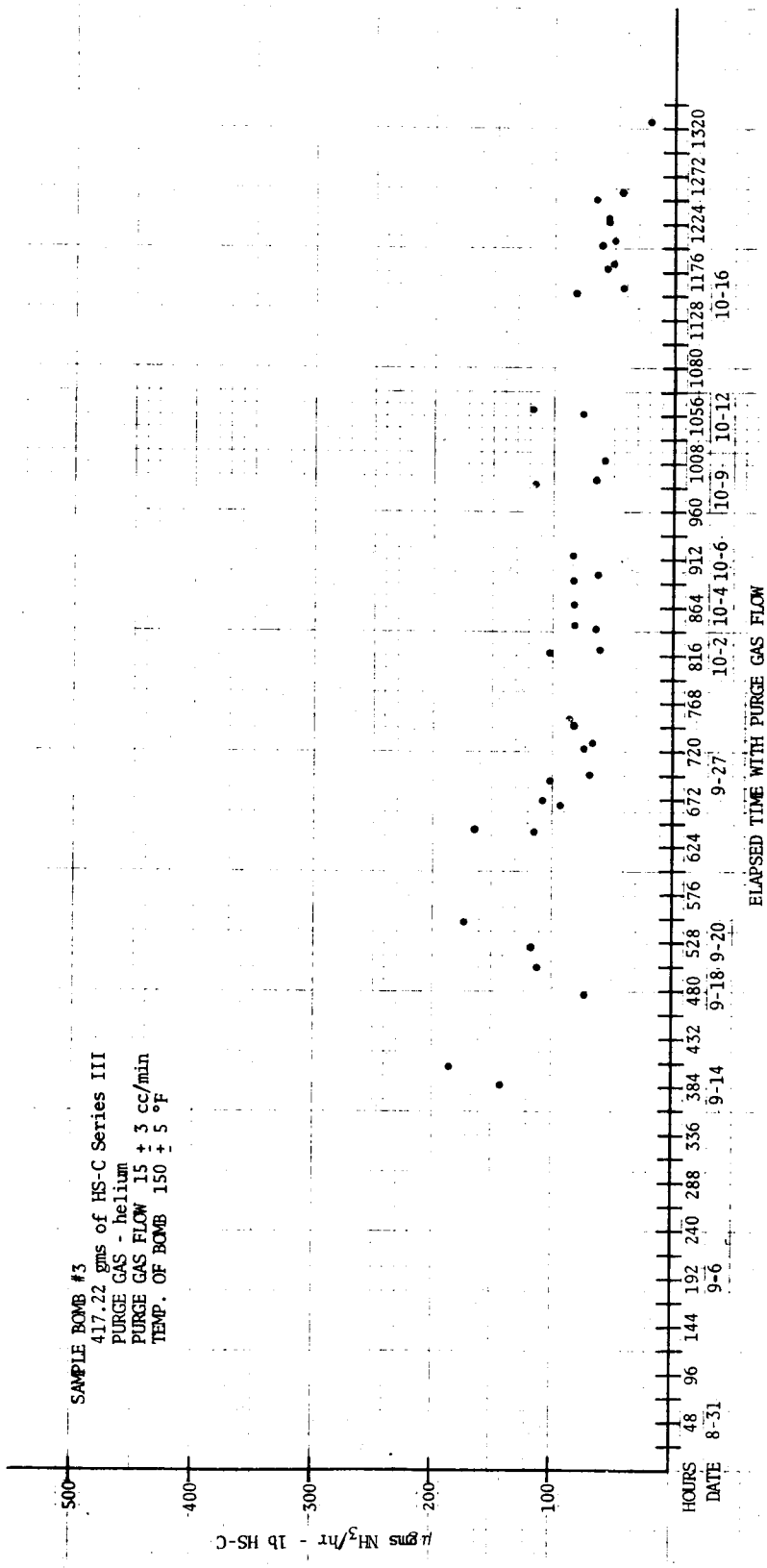


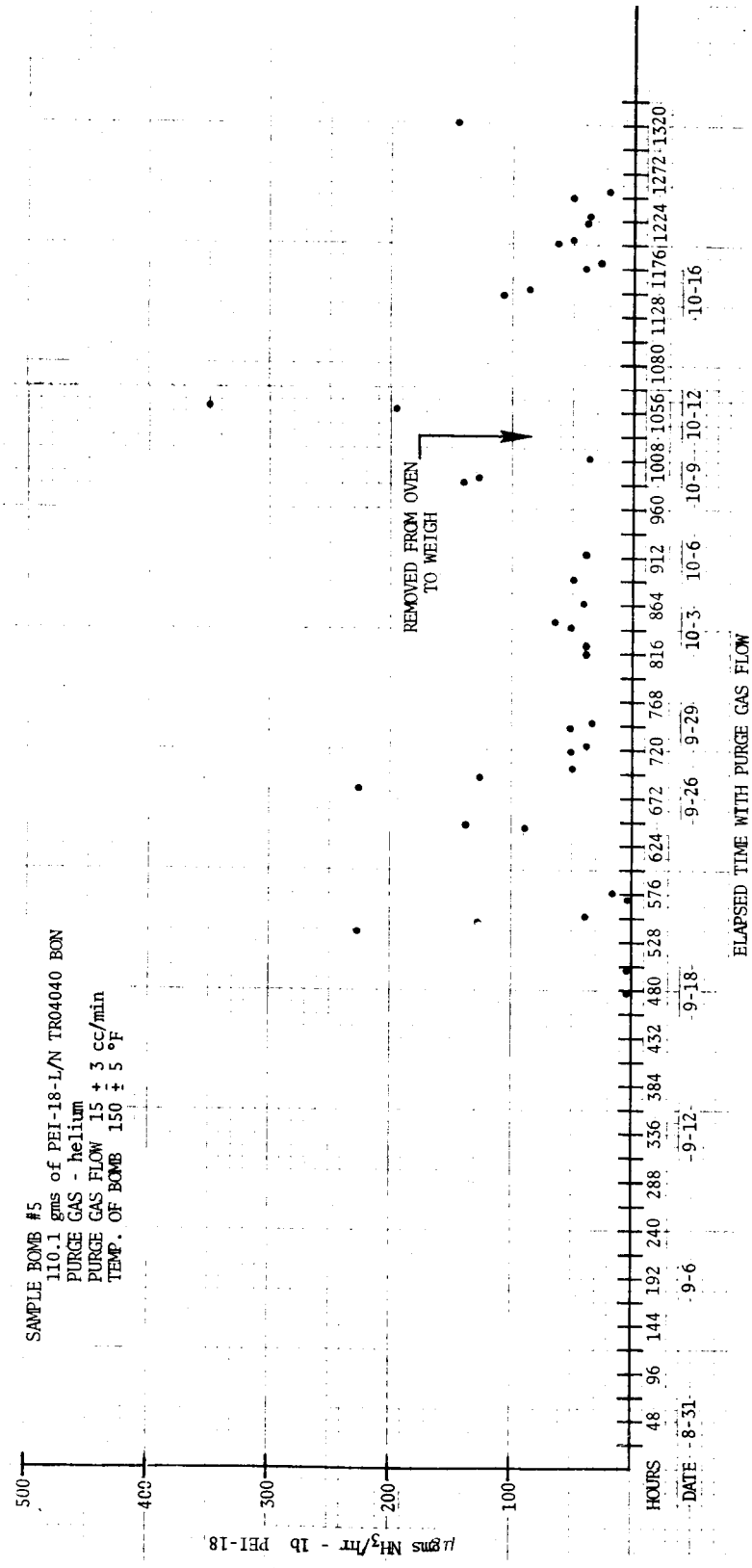
SAMPLE 6 OFF-GAS TEST DATA

FIGURE 6



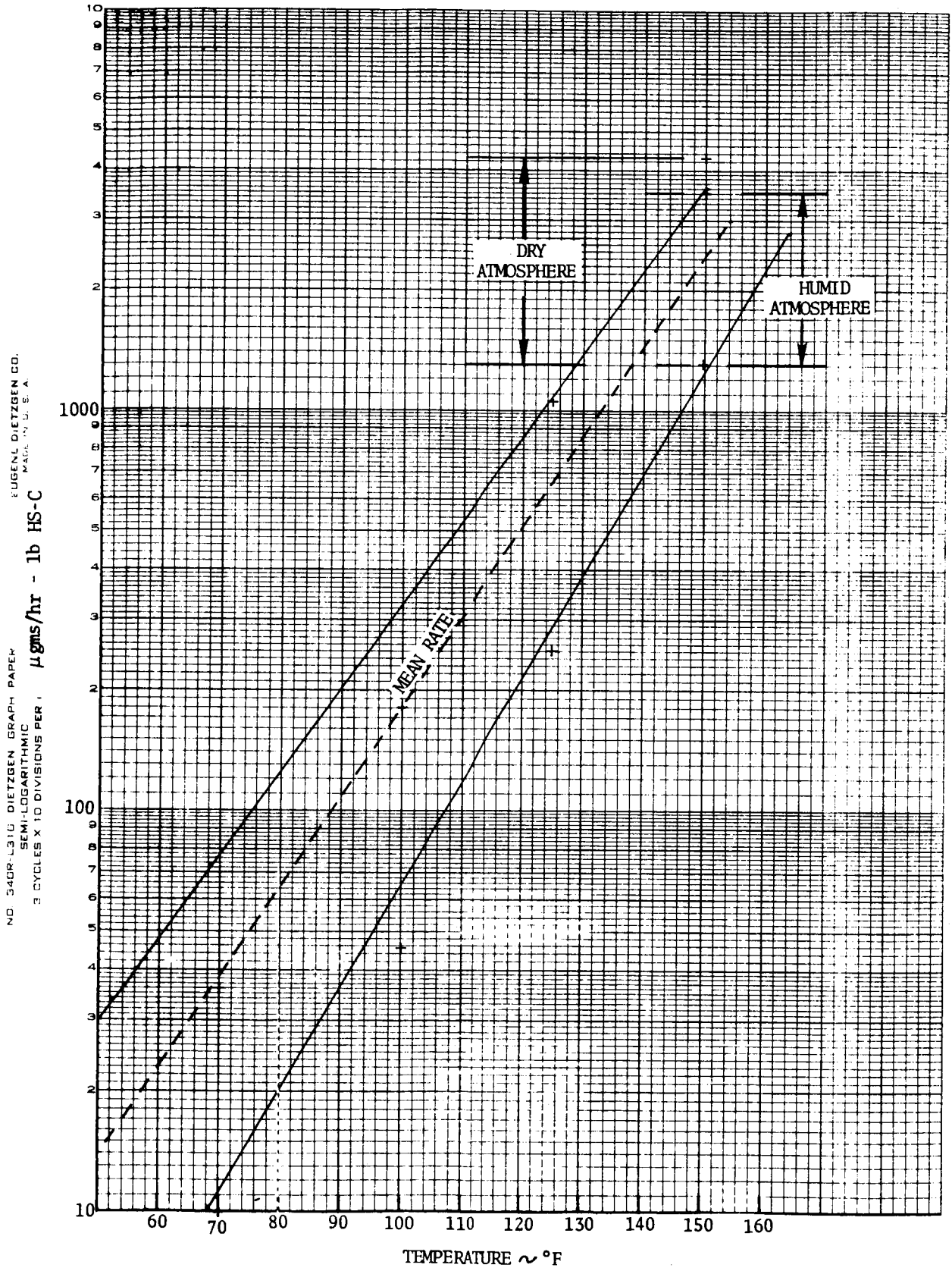
SAMPLE 3 OFF-GAS TEST DATA

FIGURE 7



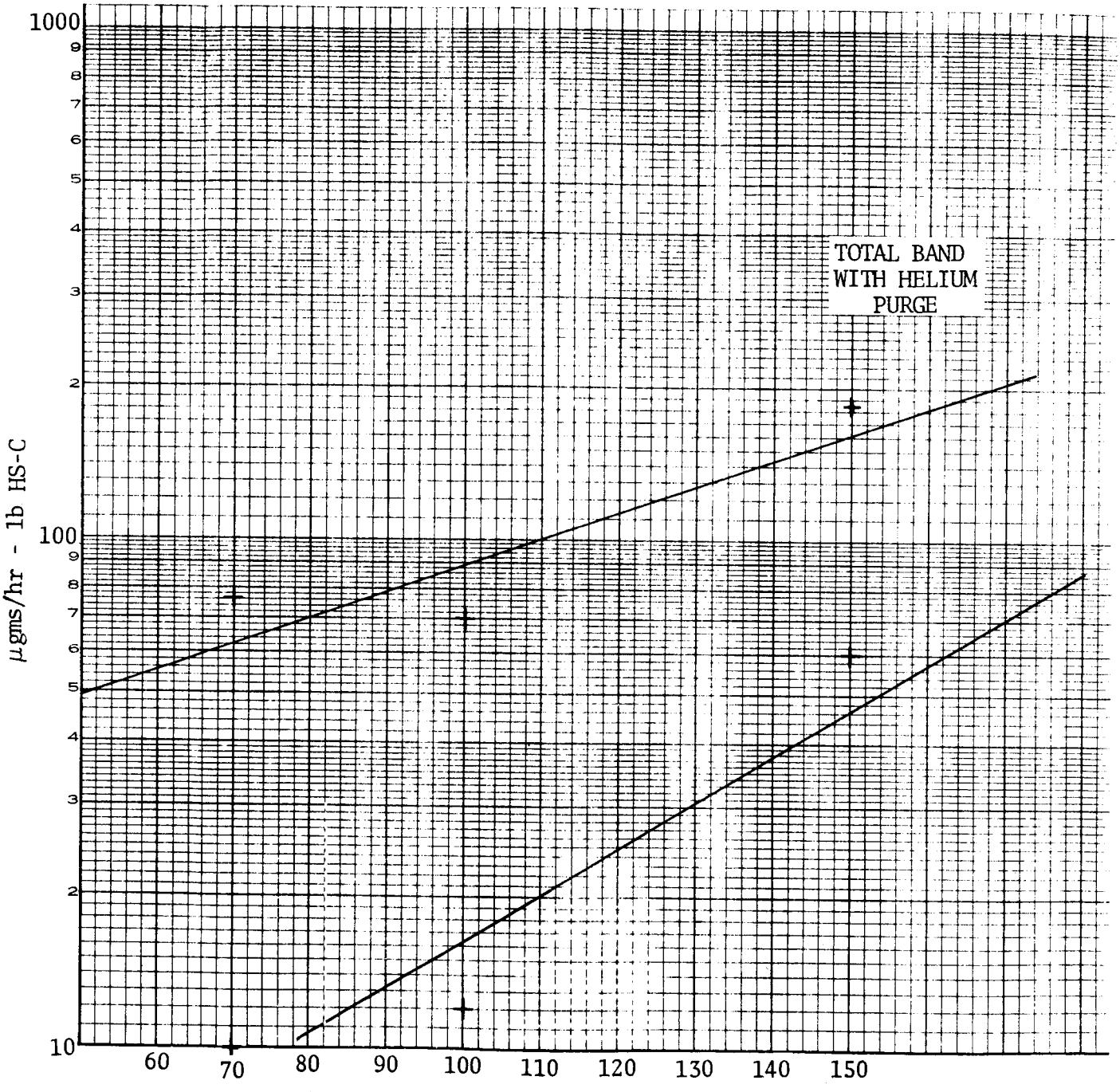
SAMPLE 5 OFF-GAS TEST DATA

FIGURE 8



AMMONIA GENERATION RATE - AIR ENVIRONMENT

FIGURE 9



AMMONIA GENERATION RATE - HELIUM ENVIRONMENT

FIGURE 10

A sample of PEI, sample six, also was tested. The amount of PEI in the container was the amount used as a coating for the other samples, 21% by weight. The results, shown in figure 8, were approximately the same as for sample 3, indicating that the substrate had only a minor effect on reaction rate at these conditions.

A sample of HS-C was tested to determine whether it would support fungus growth. No growth was found. The laboratory report for this test is included as Appendix E.

MISSION SIMULATION

The objective of this task was to determine ammonia production rates under normal operating conditions and to determine degradation under worst case conditions.

DISCUSSION

An 8.5 pound quantity of HS-C (designated HS-C Series IV) was prepared for this task. The test canister was packed with 6.65 pounds of dry HS-C and installed in a multi-purpose test rig. Parametric tests were run first, to obtain a performance baseline. The unit then was run through eight four-day mission simulations. At the start of each mission the canister was heated to 120°F and held at that temperature for four hours. After completion of the mission simulations the canister was subject to an extreme temperature at 150°F and also to a representative acid gas to accelerate any degradation.

Daily ammonia level measurements were taken from the recirculating atmosphere loop and from the condensate portion of the test rig. Wet chemistry (Nessler's Method) was used for ammonia analysis. Carbon dioxide removal performance and water removal performance were monitored throughout the test in order to detect possible degradation. Measurements were made at a standardized condition to allow comparison. Parametric performance tests also were run in order to map water removal efficiency for the improved heat exchanger design.

The test canister used for series II and III testing was modified for use in this test. Improvements were made to prevent channeling and to minimize the amount of material not in contact with a heat transfer surface. The configuration and nominal conditions used for testing were a three inch thick bed operating with 30 minute adsorb and 30 minute desorb times.

Conclusions

The modifications made to the test canister improved performance, most probably by improving heat transfer. The improvement appeared as a decrease in desorption time required for optimum performance. The reduction in desorption time was a decrease from 45 minutes to 30 minutes.

Ammonia production rates were approximately the same as those measured in the off-gassing tests. Very little ammonia was found in the circulating gas stream. The ammonia released from the canister was scrubbed from the air stream by a humidifier and by a condensing heat exchanger, both part of the test apparatus.

Material Description

HS-C is a proprietary sorbent made from commercially available raw materials. It consists of small (1/2 mm) spheres of polymeric macroreticular substrate which is coated with a thick, polymeric, liquid sorbent made from low molecular weight amines.

The substrate is Rohm & Haas XAD-7 sorbent. It is processed at Hamilton Standard by sieving, by washing with deionized distilled water and analytical grade methyl alcohol, and then coated with the liquid sorbent, Dow PEI-18, and dried. Ultra-pure water is needed for the washing procedure since traces of copper adversely affect adsorptive performance.

XAD-7 is a polymeric acrylic ester (a relative of Plexiglas and other acrylic plastics) in the form of small spheres (typically 1/2 mm and smaller) which have many microscopic fissures making them very porous. They are white in color, and crush with moderate difficulty using the flat side of a knife. They swell to twice dry volume when wet with water or alcohol.

The coating is Dow PEI-18, a polyethyleimine (PEI) of the chemical form:

$$\left\{ \begin{array}{l} -CH_2-CH_2-NH_2 \quad (25\%) \\ -CH_2-CH_2-NH- \quad (50\%) \\ -CH_2-CH_2-N \quad\quad (25\%) \end{array} \right\}_n$$

It is thick and viscous (like cold molasses) with an average molecular weight of 1800 (hence PEI-18).

Selected HS-C Formula - Series IV

The HS-C formula selected for the Series IV tests is presented below.

Substrate Mesh Size	30-40 mesh
Coating Agent	PEI-18
Coating Weight	21%
Density (coated)	0.350 ±10% gm/cc.

Evaluation

Prepared HS-C was evaluated in a small scale apparatus using a set cycle. These nominal conditions were:

Sample Size	5 ml
P_{CO_2}	3 mmHg
Air Flow	500 ml/min
Air Dew Point	52°F
Bed Temperature	75°F
Desorb Pressure	50 microns or better at end of desorption
Cycle Times	45 minutes adsorption, 45 minutes desorption.

Capacity was checked against a reference sample of Series III material to minimize any effects of rig fluctuations. Table II summarizes these results.

Note that CO_2 capacity was on the average about 14% greater than the Series III reference. Better sifting techniques using a new vibrating sifter might be responsible for the increase in CO_2 capacity.

Test Canister

An exploded view of the test canister is shown in Figure 11. The HS-C bed itself is a modified fin-tube heat exchanger. The depth of the bed is 3 inches (airflow path of 3 inches). The face area is 14 inches by 14.5 inches.

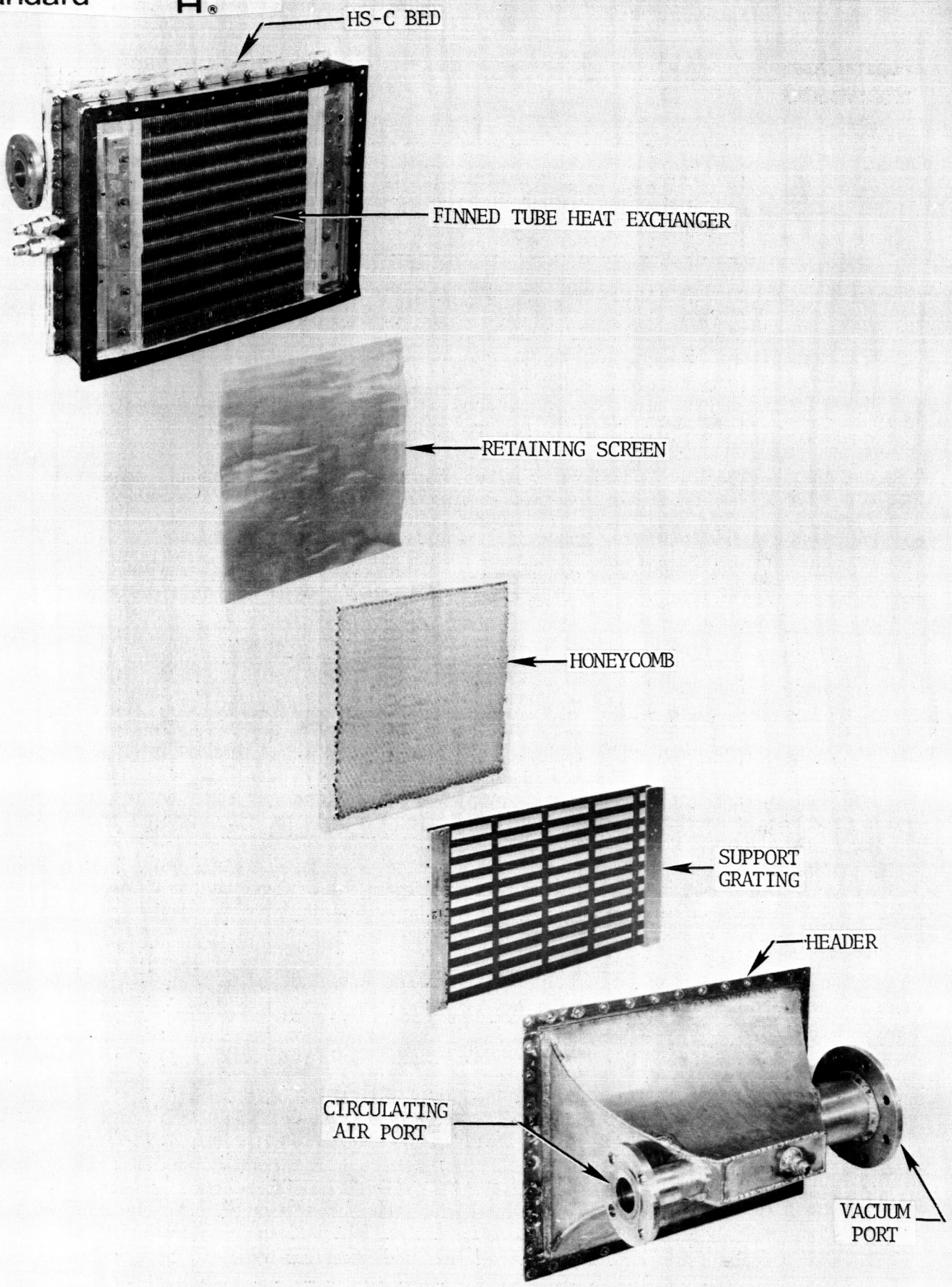
A fifty mesh screen is placed over the heat exchanger face to retain the HS-C granules. An aluminum honeycomb is used to provide rigidity to the screen.

By experimentation it was determined that a support grating was necessary to prevent the honeycomb and screen from bulging away from the heat exchanger face. The addition of the grating was an improvement over previous canister test configurations.

The header for the unit has a circulating air duct of 2 inches diameter and a vacuum port 5 inches in diameter.

Test Equipment

Hamilton Standard test rig #88 was used for this test program as illustrated by Figure 12. It provides a stream of conditioned air to the HS-C materials under test with automatically controlled pressure, flow rate, CO_2 partial pressure, dew point, and temperature. The conditioned air flows through the canister for the selected adsorption time while the canister is cooled by a constant temperature water heat transport supply. At the end of the adsorb cycle, desorption begins automatically with the isolation of the test canister from the conditioned air and the application of a high vacuum to the HS-C in its canister. The water transport flow is maintained and provides heat for desorption. The entire cycle is repeated for the required mission duration.



SS 10763-8

TEST CANISTER

FIGURE 11

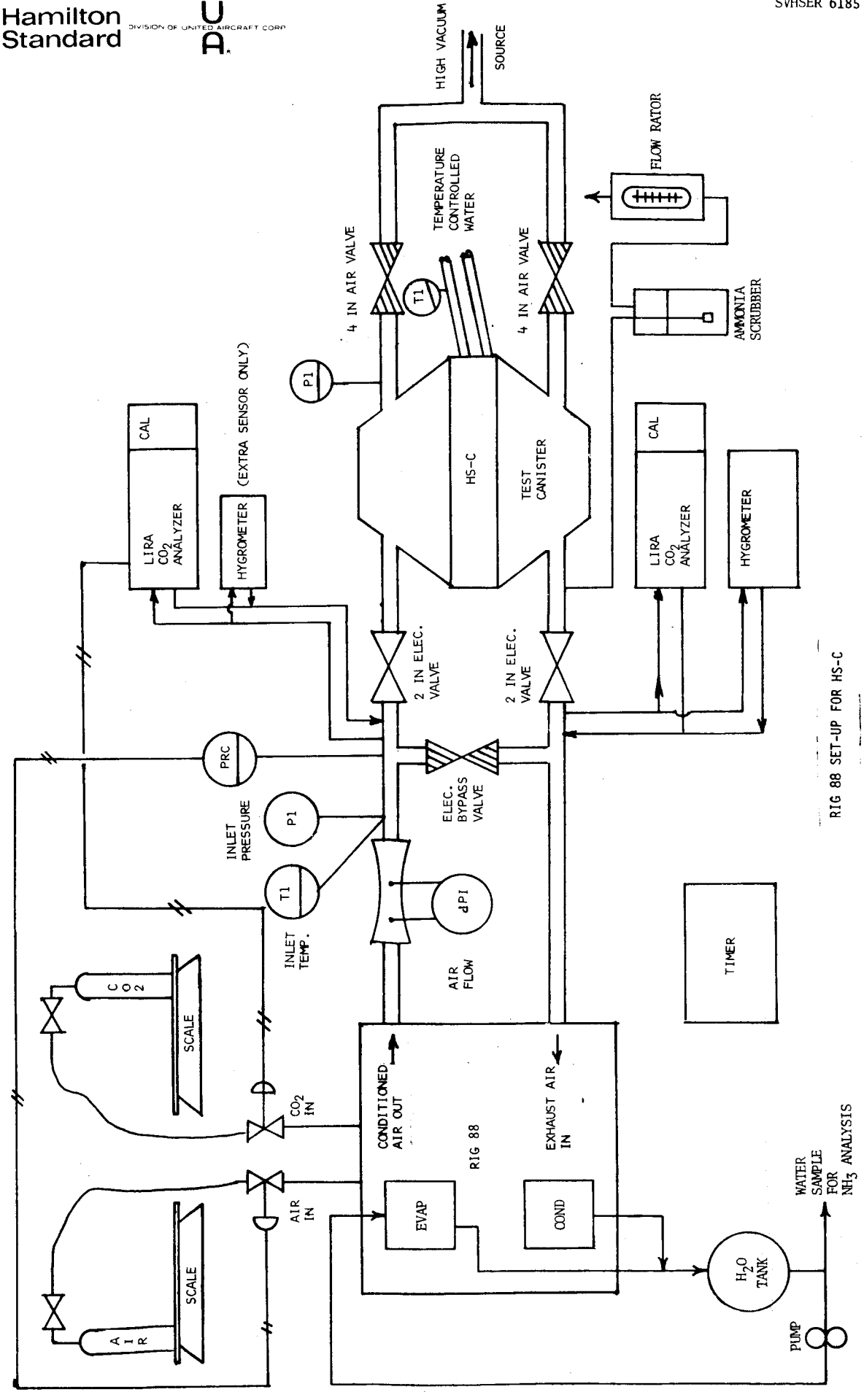
TABLE II

LARGE SCALE HS-C PREPARATION

PREP. NUMBER	CO_2 CAPACITY % by WEIGHT	CO_2 REFERENCE* CAPACITY % by WEIGHT	% INCREASE OVER REFERENCE	H_2O CAPACITY % by WEIGHT	DENSITY g/ml	DATE PREPARED	WEIGHT PREPARED, POUNDS
P-IV-1	2.20	1.90	16.7	5.02	0.360	11-30-72	0.56
P-IV-2	2.47	2.27	8.8	5.02	0.366	12-07-72	1.15
P-IV-3	2.16	1.78	21.3	5.00	0.364	12-07-72	1.14
P-IV-4	2.36	2.15	9.8	4.69	0.374	12-07-72	1.15
P-IV-5	2.42	2.15	12.6	4.78	0.344	12-14-72	1.16
P-IV-6	2.48	2.30	7.8	4.82	0.362	12-14-72	0.88
P-IV-7	2.82	2.53	12.6	5.04	0.320	12-18-72	1.14
P-IV-8	2.39	1.96	22.0	4.64	0.324	12-18-72	1.18

* Sample from Series III tests, (P-9130-II-B), CR-115568.

NOTE: Average % Increase in CO_2 Capacity Over Reference = 14.0%.
Total Weight Prepared = 8.36 lbs.



RIG 88 SET-UP FOR HS-C

FIGURE 12

Both CO_2 and air usage are determined by measuring the weight change of the bottles used to supply these gases. This method is extremely accurate when used to integrate the usage for a large number of cycles.

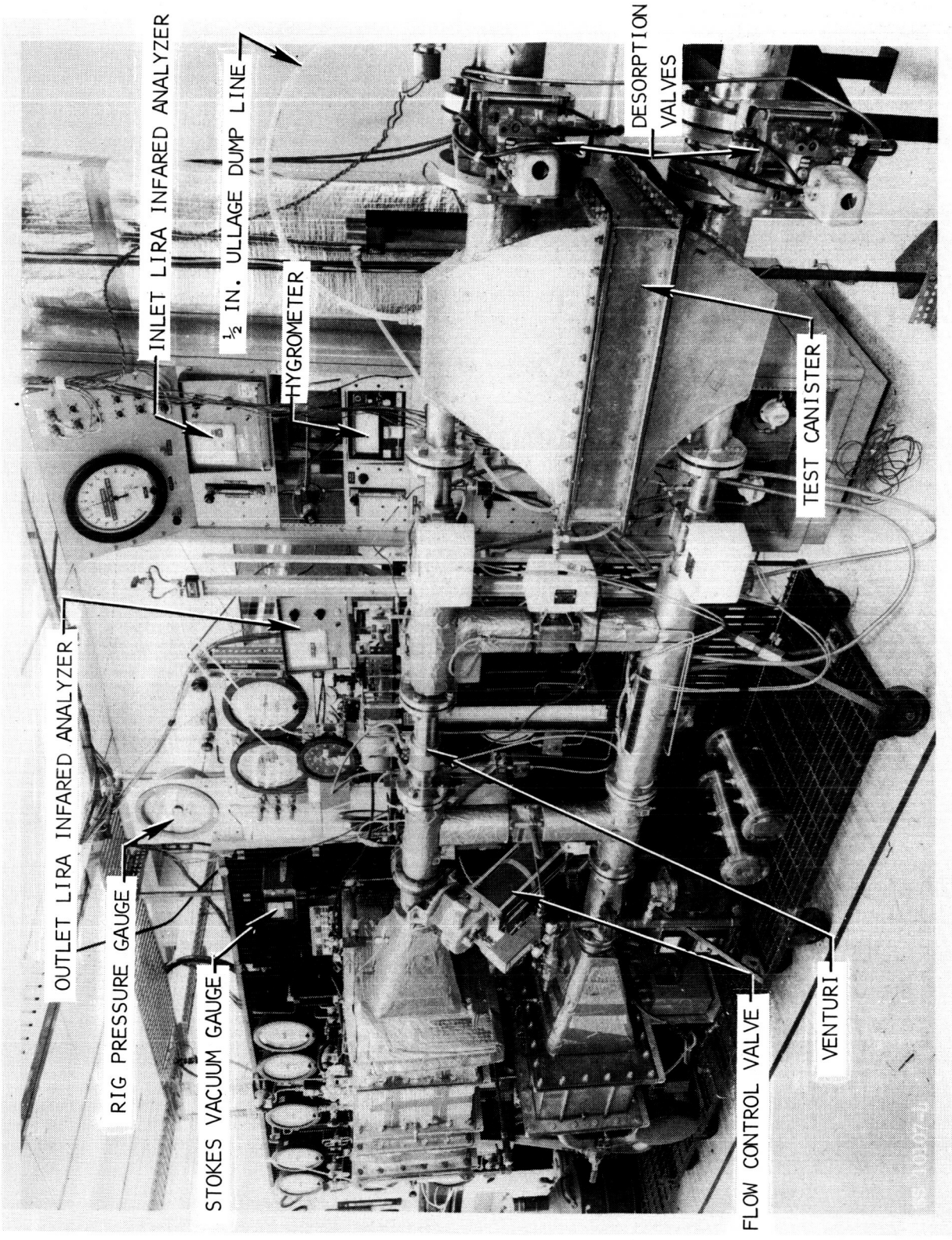
Water capacity can be determined by two methods. The method for measuring capacity of an individual cycle is by integrating inlet and outlet dew point and air flow. For a large number of cycles, water addition to the water tank can be measured. The tank has a capacity of 8000 cc which is approximately a three day supply under nominal test conditions.

The HS-C canister was set up on Rig #88 as shown in Figure 13. Measurements were as shown in Table III.

TABLE III

LARGE SCALE TEST INSTRUMENTATION REQUIREMENTS

Parameter	Units	Accuracy
Cycle Time	minutes	1% of interval
Air Flow Rate	in H_2O reported in cfm	10% of flow
Inlet Temperature	°F	2°F
Inlet Pressure	psia	0.2 psia
Hygrometer (dew point)	°F	2°F
Water Temperature	°F	2°F
Inlet and Outlet CO_2	volts reported as mmHg	2% of full scale (full scale = 5 mm)
Weight CO_2 Added	lbs	0.02 lbs
Weight Air Added	lbs	0.02 lbs
Desorption Vacuum	microns	5% of non-linear scale of Hastings gauge, as calibrated for air
Ammonia Concentration	ppm	0.1 ppm in water 10 ppm in air



LARGE SCALE TEST APPARATUS

FIGURE 13

Actual Test Conditions

The test plan for the large scale testing is Appendix F of this report. Table IV shows the actual conditions of test for the test duration of 1116 cycles. In addition to the planned tests, a parametric series was run during the sixth, seventh, and eight mission simulations. This was done to determine water capacity over a range of flows and dew points.

A number of cycles also were run with a dry loop to allow ammonia measurement in the air loop. With a wet humidifier, the ammonia was removed by the water.

TEST RESULTS

CO_2 Removal Capacity

The series IV material shows an improved CO_2 capacity over previous tests. This is attributed to two factors: improved control of material processing and an improved canister configuration.

Figure 14 shows CO_2 capacity as a function of airflow. This plot was constructed from data obtained both during the initial parametric series (Table V) and a parametric series run during the mission simulations. Capacity at 3 mmHg P_{CO_2} for the series IV material is the same for a 30 minute desorb time as was obtained from Series II tests with a 45 minute desorb time. Both test series utilized a 3 inch thick bed.

Table VI shows a summary of CO_2 removal performance during the eight mission simulations. CO_2 removal performance at the end of the series, was 0.121 lbs/cycle as compared to 0.126 lbs/cycle at the start of testing. Intermediate points ranged from 0.117 lbs/cycle to 0.129 lbs/cycle. This entire range is $\pm$ 5% which is the expected accuracy of the test apparatus. Any degradation in CO_2 capacity during this period is judged to be negligible.

Table VII shows CO_2 performance under conditions designed to promote degradation. The first extreme was to inject 500 cc of hydrogen sulfide into the recirculating air loop. This would simulate acid gases of the type possibly found in a cabin atmosphere at extreme levels. After eight hours of testing, no loss in performance was evident. The canister was then subjected to three 12-hour soaks at 150°F. CO_2 capacity remained constant at 0.12 lbs/cycle following these exposures.

TABLE IV

TEST CONDITIONS

TEST NO.	CYCLE NO.	FLOW cfm	AIR TEMP. °F	BED TEMP. °F	P_{CO_2} mm Hg	VAC μ	DEW PT. °F	REMARKS
PARAMETRIC								
1	1-16	40	75	85	3	37	52	Rig shutdown due to low pressure in loop.
	17-62	↓	↓	↓	↓	80	↓	
	63-66	↓	↓	↓	↓	-	↓	Malfunction in vacuum system.
2	67-79	40	120	120	5	58	52	
	80-81	↓	↓	↓	↓	-	↓	Malfunction of vacuum timer switch.
	82-89	↓	↓	↓	↓	65	↓	
3	90-98	40	75	85	5	-	52	
	99-111	↓	↓	↓	↓	-	↓	Shutdown, CO_2 not added to loop, malfunction of CO_2 control.
	112	↓	↓	↓	↓	-	↓	
	113-118	52	↓	↓	↓	28	↓	
4	119-132	40	75	83	5	27	52	
MISSION SIMULATION								
Heat Soak - 4 Hours at 120°F								
1	133-150	41	75	82	5	27	52	
	151	↓	↓	↓	↓	-	↓	Rig shutdown, vacuum valves cleaned.
	152-177	↓	↓	81	↓	27	↓	
	178-228	↓	↓	↓	↓	↓	-	Loop run dry.
	229-250	↓	↓	↓	↓	↓	52	
Heat Soak - 4 Hours at 120°F								
2	251-339	41	75	85	5	27	52	
	340-344	↓	↓	↓	↓	↓	57	Raised dew point in loop.
	345-351	↓	↓	↓	↓	-	52	Dew point restored.
	352	↓	↓	↓	↓	80	↓	Adsorb 30 min - desorb 15 min.
	353	↓	↓	↓	↓	84	↓	Adsorb 30 min - desorb 16 min.

TABLE IV (Continued)

TEST CONDITIONS

TEST NO.	CYCLE NO.	FLOW cfm	AIR TEMP. °F	BED TEMP. °F	P_{CO_2} mm Hg	VAC μ	DEW PT. °F	REMARKS
	354	41	75	85	5	88	52	Adsorb 30 min - desorb 16 min.
	355	↓	↓	↓	↓	78	↓	Adsorb 30 min - desorb 17 min.
	356-358	↓	↓	↓	↓	27	↓	Adsorb 30 min - desorb 30 min.
Heat Soak - 4 Hours at 120°F								
3	359-378	41	75	86	5	26	52	
	379-385	↓	↓	↓	↓	↓	-	Dry loop.
	386-408	↓	↓	↓	↓	↓	52	
Heat Soak - 4 Hours at 120°F								
4	409-426	41	75	80	5	26	-	Run dry.
	427-453	↓	↓	↓	↓	↓	52	
Heat Soak - 4 Hours at 120°F								
5	454-472	41	75	80	5	27	52	
	473-563	20	↓	↓	↓	↓	↓	
Heat Soak - 4 Hours at 120°F								
6	564-602	40	75	80	5	26	52	
	603-624	20	↓	↓	↓	↓	↓	Lowest possible flow with large venturi.
	625	15	↓	↓	↓	↓	60	
	626-627	20	↓	↓	↓	↓	↓	
	628-629	40	↓	↓	↓	↓	↓	
	630	20	↓	↓	↓	↓	52	
	631-717	↓	↓	↓	↓	↓	-	Dry loop.
	718	↓	↓	↓	↓	↓	52	Injected 100 cc NH_3 into loop.
	719-741	↓	↓	↓	↓	↓	↓	
Heat Soak - 4 Hours at 120°F								
7	742-804	20	75	80	5	26	52	
	805-807	↓	↓	↓	↓	↓	45	
	808-809	15	↓	↓	↓	↓	↓	
	810-813	10	↓	↓	↓	↓	52	
	814-894	20	↓	↓	↓	↓	↓	

TABLE IV (Concluded)

TEST CONDITIONS

TEST NO.	CYCLE NO.	FLOW cfm	AIR TEMP. °F	BED TEMP. °F	P_{CO_2} mm Hg	VAC μ	DEW PT. °F	REMARKS
Heat Soak - 4 Hours at 120°F								
8	895	10	75	80	5	26	52	
	896-918	20	↓	↓	↓	↓	↓	
	919-939	40	↓	↓	↓	↓	↓	
	940	↓	↓	↓	↓	↓	↓	Introduced 500 cc H_2S into loop.
ACID GAS TEST								
1	941-964	60	75	80	5	26	52	
	966-1031	40	↓	↓	↓	↓	↓	
	1032-1033	60	↓	↓	↓	↓	↓	
	1034	40	↓	↓	↓	↓	↓	
	1035-1042	60	↓	↓	↓	↓	↓	
EXTREME TEMPERATURE TESTS								
Heat Soak - 14 Hours at 150°F								
1	1043-1054	40	75	80	5	27	52	
Heat Soak - 12 Hours at 150°F								
2	1055-1076	40	75	80	5	27	52	
	1077-1081	60	↓	↓	↓	↓	↓	
	1082-1088	40	↓	↓	↓	↓	↓	
Heat Soak - 12 Hours at 150°F								
3	1089-1092	40	75	80	5	27	52	
	1093	20	↓	↓	↓	↓	↓	
	1094-1113	40	↓	↓	↓	26	↓	
	1114-1116	↓	↓	↓	↓	↓	53	

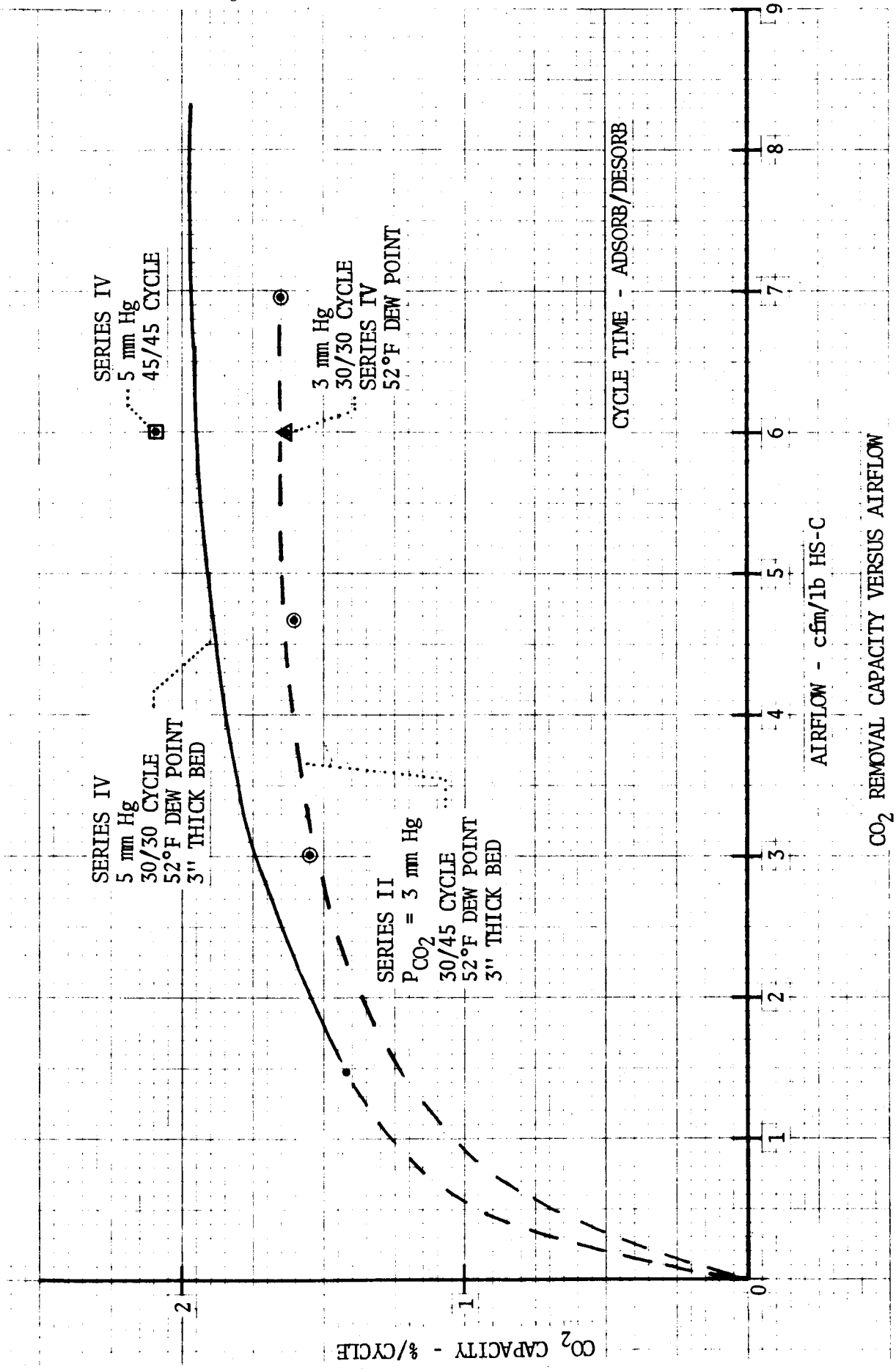

SERIES IV
5 mm Hg
45/45 CYCLE
3 mm Hg
30/30 CYCLE
SERIES IV
52°F DEW POINT
SERIES IV
5 mm Hg
30/30 CYCLE
52°F DEW POINT
3" THICK BED
SERIES II
P_{CO_2} = 3 mm Hg
30/45 CYCLE
52°F DEW POINT
3" THICK BED
CYCLE TIME - ADSORB/DESORB
AIRFLOW - cfm/lb HS-C
CO_2 CAPACITY - %/CYCLE
CO_2 REMOVAL CAPACITY VERSUS AIRFLOW

FIGURE 14

TABLE V

CO_2 REMOVAL CAPACITY
INITIAL PARAMETRIC SERIES

TEST NUMBER(1)		1	2	3	4
BED THICKNESS		3	3	3	3
CO_2 PARTIAL PRESSURE	mmHg	3	5	5	5
AIRFLOW	cfm	40	40	55	40
AIR INLET TEMP	°F	75	120	75	75
AIR INLET DEW POINT	°F	52	52	52	52
COOLANT INLET TEMP	°F	81	120	81	81
ADSORB TIME	min	30	30	30	45
DESORB TIME	min	30	30	30	45
CYCLE NO.'S		17-43	83-88	90-117	120-132
TOTAL CYCLES		27	6	28	13
TOTAL CO_2 REMOVED	lbs	2.93	.63	3.64	1.8
CO_2 CAPACITY	%/cycle	1.63	1.58	1.86	2.08

Notes:

(1) Series 1 parametric test from Master Test Plan (see Appendix F).

TABLE VI

CO_2 CAPACITY
MISSION SIMULATION

MISSION SIMULATION	Cycle	No Cycles	lbs CO_2 Removed	Air Flow cfm	CO_2 Capacity lbs/Cycle
1	120°F - 4 HRS				
	133 - 150	Poor Vacuum - No Data			
	151 - 179	29	3.65	41	0.126
	180 - 229	51	4.64	41	0.093(1)
	230 - 251	22	2.77	41	0.126
2	120°F - 4 HRS				
	252 - 339	88	11.315	41	0.129
	340 - 358	Experimented with Vacuum Level - No Data			
3	120°F - 4 HRS				
	359 - 408	50	6.42	41	0.128
4	120°F - 4 HRS				
	409 - 426	18	2.065	41	0.115(1)
	427 - 453	27	3.28	41	0.121
5	120°F - 4 HRS				
	454 - 471	18	2.3	41	0.128
	472 - 561	89	10.68	20	0.120
6	120°F - 4 HRS				
	563 - 602	40	4.87	40	0.122
	603 - 625	23	2.76	20	0.120
7	120°F - 4 HRS				
	742 - 780	39	4.51	20	0.116
	781 - 806	26	2.98	20	0.115
	874 - 894	21	1.87	10	0.089
8	120°F - 4 HRS				
	895 - 916	22	2.61	20	0.119
	919 - 939	21	2.46	40	0.117
	940 - 957	18	2.18	40	0.121

Notes:
(1) Air loop run dry to obtain NH_3 reading

TABLE VII

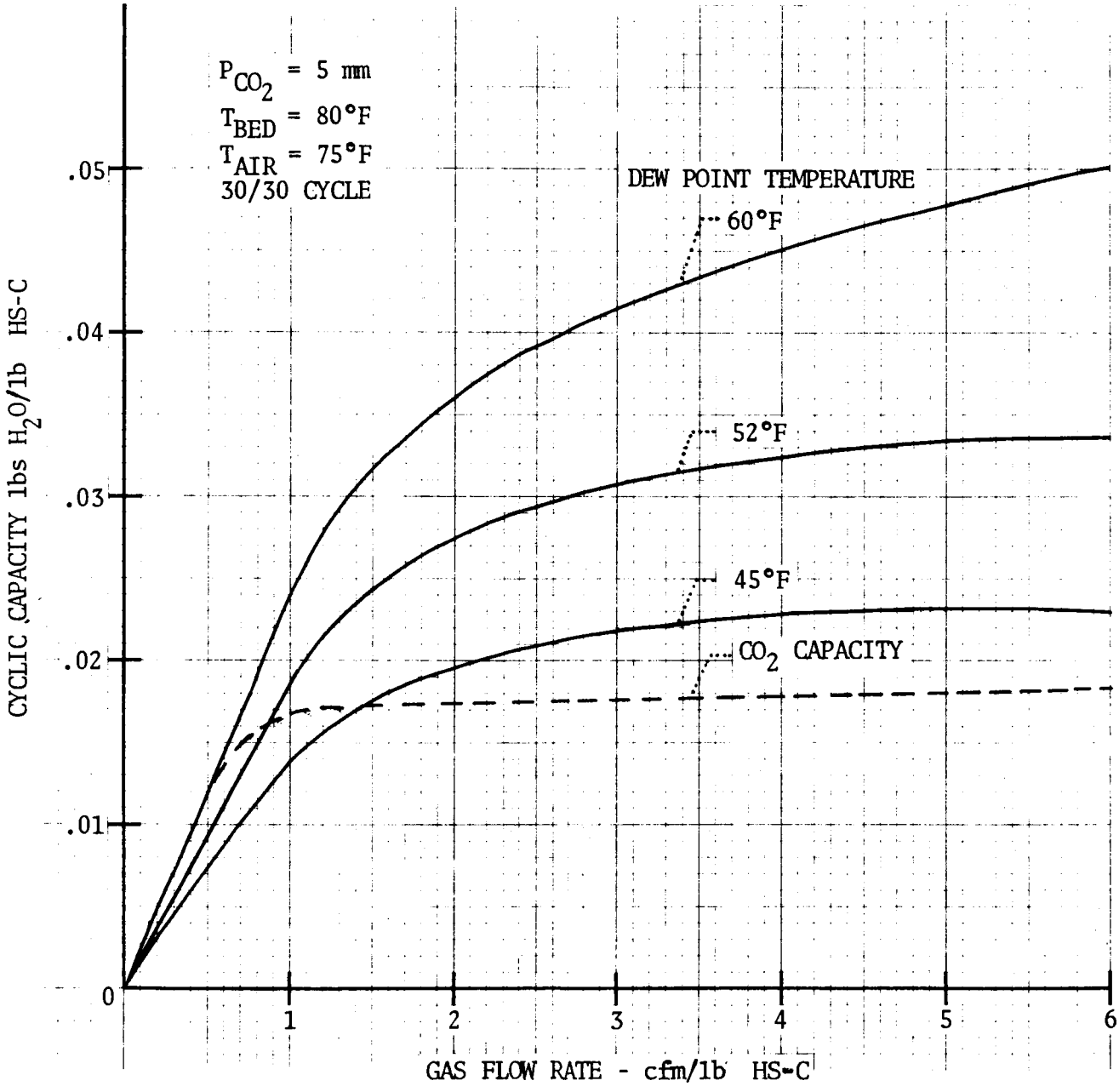
EXTREME CONDITION EXPOSURE
CO_2 PERFORMANCE

Cycle No.	Number of Cycles	lbs. CO_2 Removed	Air Flow cfm	CO_2 lbs/Cycle
---------- 500 cc H_2S Introduced into Loop----------				
1035 - 1042	8	0.99	60	0.124
----------Canister Heated to 150°F for 12 Hours----------				
1048 - 1054	7	0.84	40	0.12
----------Canister Heated to 150°F for 12 Hours----------				
1059 - 1076	17	2.04	40	0.12
----------Canister Heated to 150°F for 12 Hours----------				
1091 - 1092	2	0.24	40	0.12

Moisture Removal Capacity, Parametric Data

A map showing cyclic water capacity as a function of air flow and dew point is shown in figure 15. This data was obtained from parametric tests run during the mission simulations. From this graph it can be seen that an optimum air flow is about 2 cfm/lb of HS-C. Above this air flow only a small gain can be made in capacity at the expense of fan power. An alternate method of presenting this performance is shown in figure 16. This shows moisture capacity to be roughly proportional to water vapor partial pressure. Both of these plots appear consistent with expected performance.

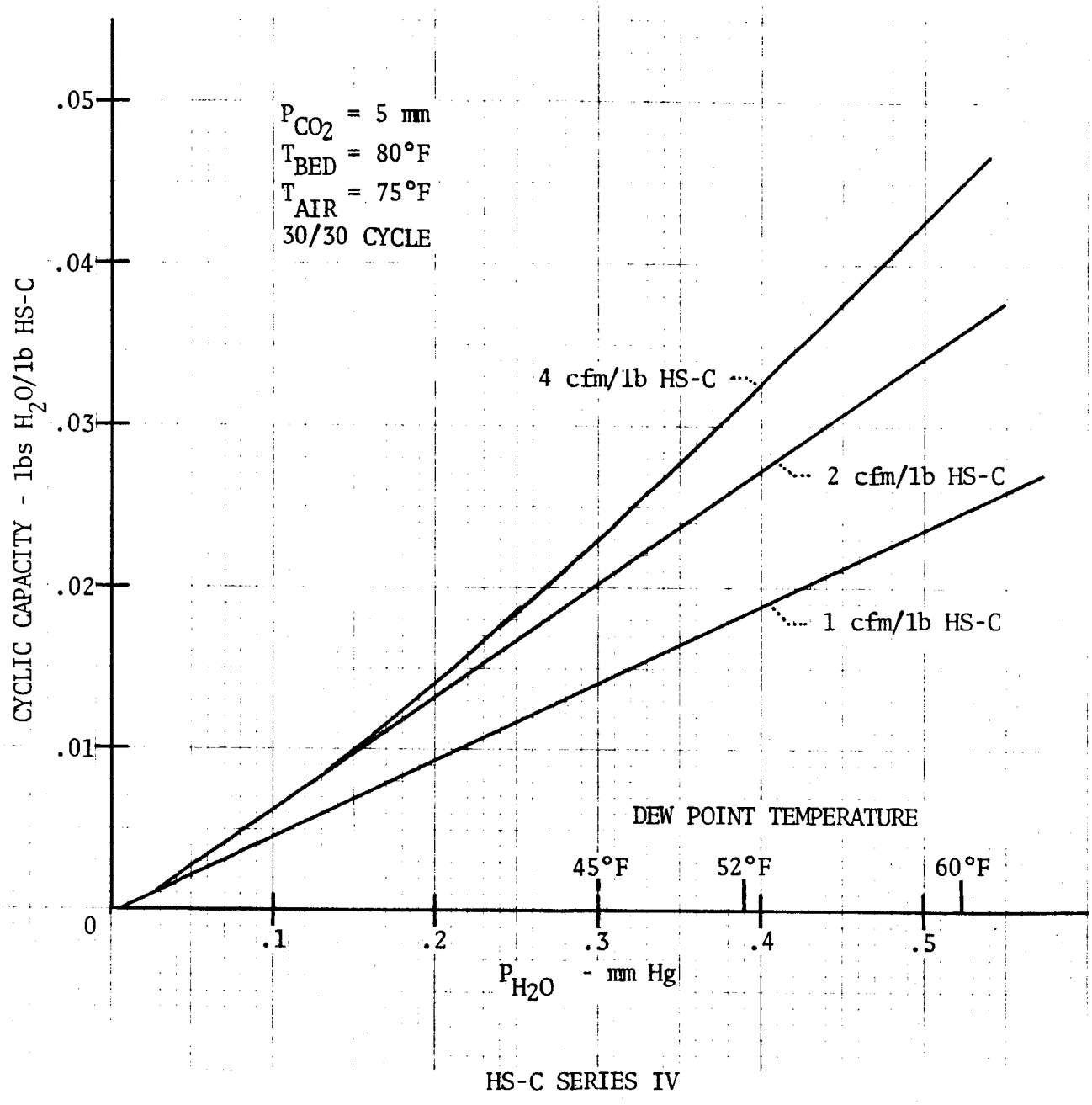
The method of measuring cyclic water removal capacity was to integrate the differential between inlet and outlet dew point measurements. This data is shown in figures 17 through 19. After any change in conditions, it was determined that equilibrium had been reached,(i.e., a minimum of two cycles showed the same results) before a data point was used.



HS-C SERIES IV

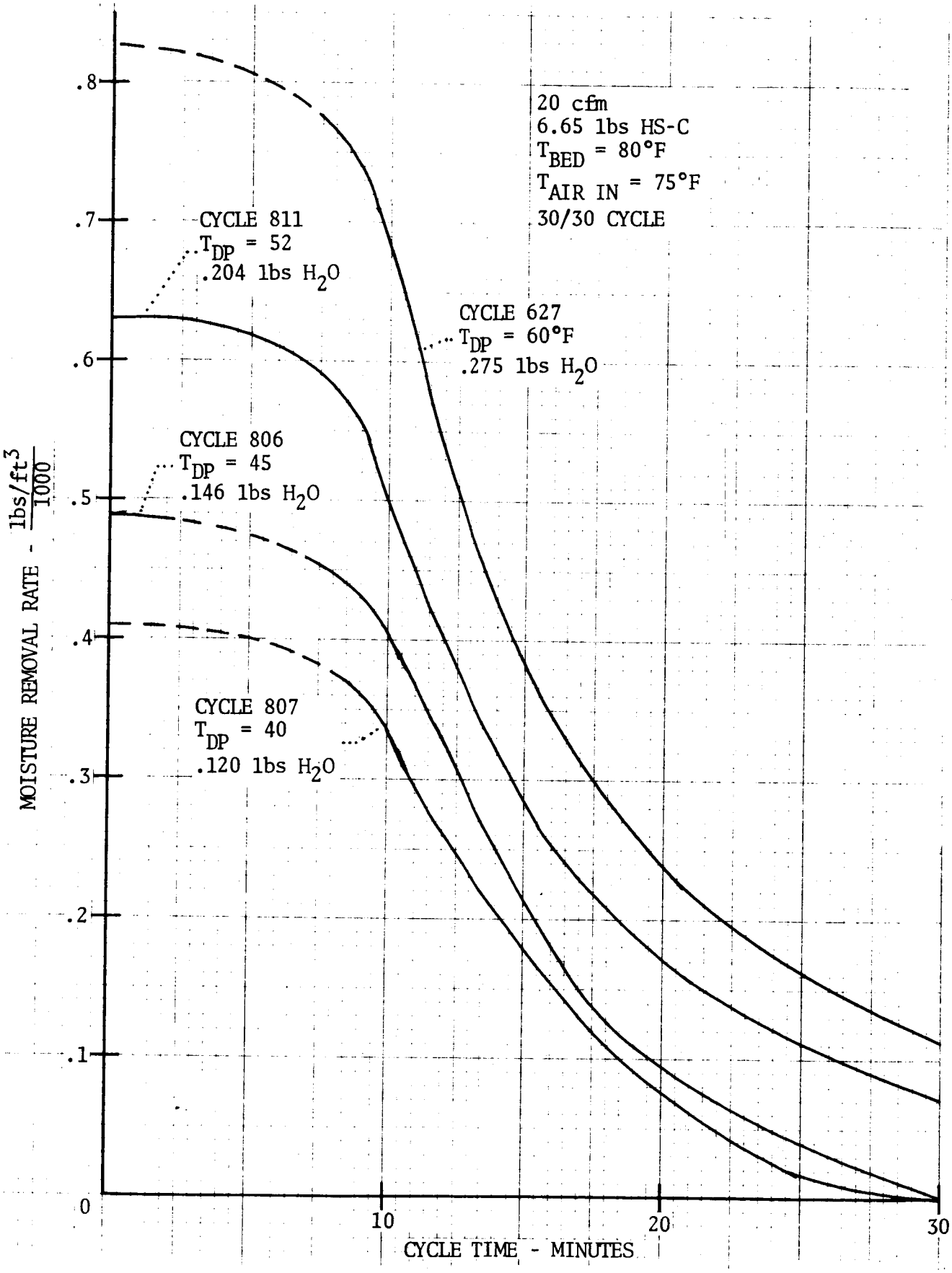
WATER REMOVAL CAPACITY VERSUS AIRFLOW RATE

FIGURE 15



WATER REMOVAL CAPACITY VERSUS WATER VAPOR PARTIAL PRESSURE

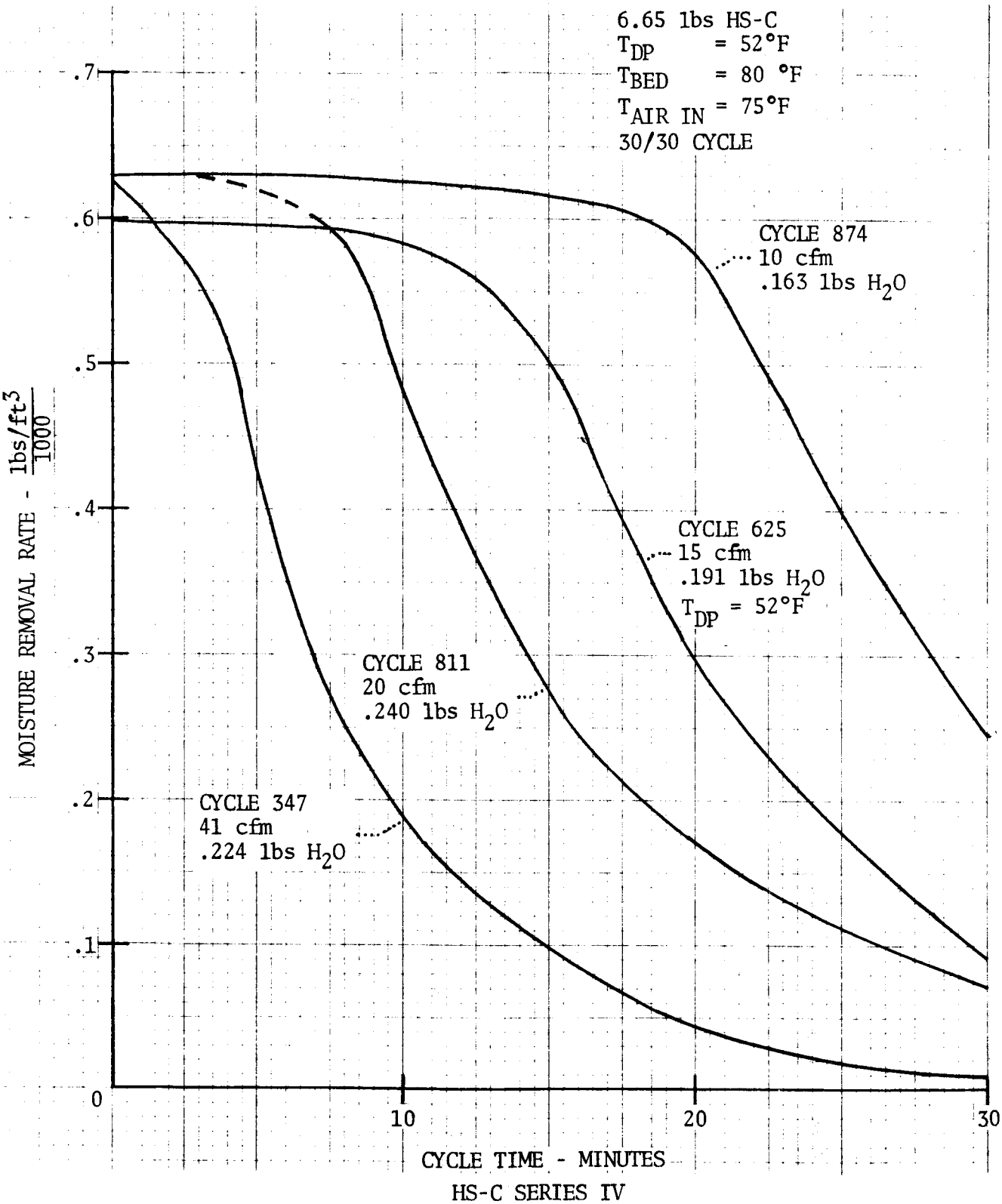
FIGURE 16



HS-C SERIES IV

MOISTURE ADSORPTION RATE VERSUS ADSORB TIME

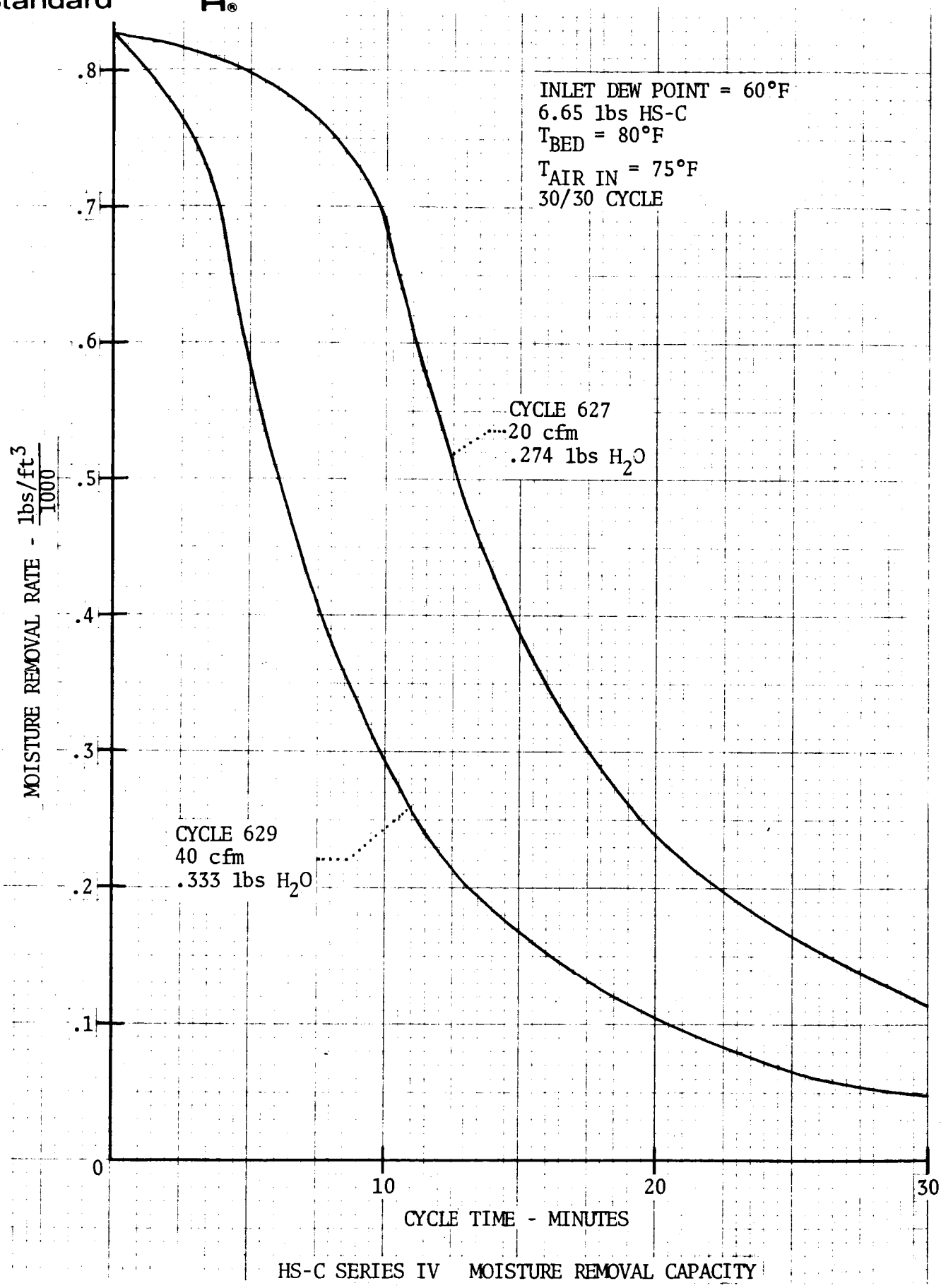
FIGURE 17



HS-C SERIES IV

MOISTURE ADSORPTION RATE VERSUS ADSORB TIME

FIGURE 18



HS-C SERIES IV MOISTURE REMOVAL CAPACITY

MOISTURE ADSORPTION RATE VERSUS ADSORB TIME
FIGURE 19

Water Capacity Change

Figure 20 shows the water usage rate as determined by a direct method. This consisted of draining the rig water reservoir and measuring the amount of water left. The reservoir had previously been filled with 8000 cc less 100 cc for an ammonia sample. By subtracting the amount left from 7900, the usage rate for that period was determined. The reservoir was then refilled and an ammonia sample taken. Test data points are shown in Table VIII.

The data points were adjusted by adding the average usage rate during the periods when the rig was run dry.

The graph shows that the rate of moisture removal remains constant for the test period and is unaffected by the 120°F heating periods.

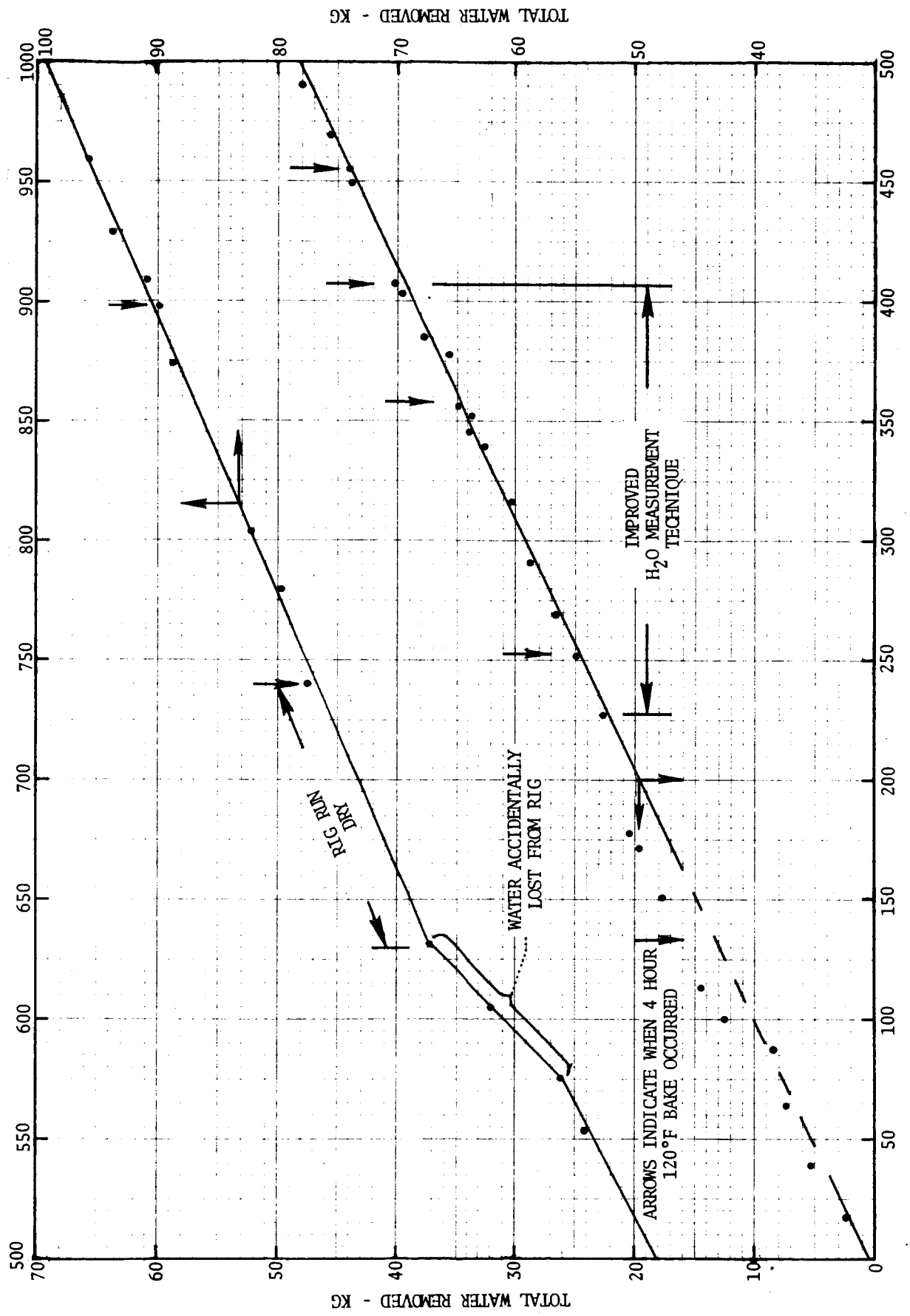
The average removal rate, as determined by the slope of the curve, is 0.032 pounds of water per cycle per pound HS-C. This is in good agreement with the integration technique described above, which showed a cyclic capacity of 3.35% or 3.35 pounds per cycle/pound HS-C, at nominal conditions.

Water capacity change also was evaluated by using outlet hygrometer readings for selected cycles throughout the test series. The hygrometer readings for these cycles are shown in Table IX. The first hygrometer reading is at five minutes because dew points prior to that time were off the scale of the hygrometer used. A hygrometer with an increased range was tried but found to have too slow a response time to obtain the required data. Using the integration method described earlier, the water capacities for these cycles were calculated and shown in Table IX. As can be seen, the total variation in water capacity is less than 10%, with no indication of degradation over the 1116 cycles.

Ammonia Measurement

The condensor and evaporator in the air loop were extremely effective in removing all ammonia from the air stream. The method of determining ammonia generation, therefore, was to measure the concentration of ammonia in the water reservoir which serviced both the condensor and evaporator. The accumulated ammonia generation rate is shown in figure 21. The test data from which this plot was constructed is shown in Table X. The average rate of ammonia generation is 36×10^{-6} grams per hour per pound of HS-C. This is close to the mean rate shown in figure 9 as determined by the off-gassing tests.

There was no correction applied for the time the material was exposed to 120°F and would, therefore, have a higher ammonia generation rate. It was assumed that the ammonia generated during the heat periods would be desorbed to vacuum prior to exposure to the air loop. This assumption was based on tests which show HS-C to have very little adsorption capacity for ammonia.



HS-C SERIES IV RIG WATER USAGE

FIGURE 20

TABLE VIII

WATER ADSORPTION - CUMULATIVE

START OF CYCLE	H_2O IN TANK cc	H_2O USED cc	CUMULATIVE H_2O USED cc
17	7950	2500	2500
39		2650	5150
44	8000	850	6000
64	8000	1250	7250
LOST 2 CYCLES			
86		(1000)	8250
100	7950	3900	12150
113	7930	2680	14830
151	7800	2900	17730
173	7900	2050	19780
179	7350	(900)	20680
229	6200	(1600)	22280
252	8000	-	-
270	7900	1100	26080
275	7030	-	-
293	7900	2200	28280
297	7416	-	-
300	7093	-	-
316	7900	1995	30275

TABLE VIII (Continued)

WATER ADSORPTION - CUMULATIVE

START OF CYCLE	H_2O IN TANK cc	H_2O USED cc	CUMULATIVE H_2O USED cc
339	7900	2090	32365
347	4000	800	33165
352	7900	500	33665
358	7900	832	34497
378	5500	2400	36897
RAN DRY			
386	7900	(800)	37697
403	7900	2150	39847
408	7900	300	40147
431	7900	1300	41447
451	7900	2000	43447
454	7900	300	43747
470	7900	1690	45437
471	7900	100	45537
492	7900	2150	47687
561	8000	6170	53857
581	7900	2700	56557
603	7900	5500	62057
629	7900	5700	67757
629 - 740 RAN DRY (adjust by adding 10,500)			78257

TABLE VIII (Concluded)

WATER ADSORPTION - CUMULATIVE

START OF CYCLE	H_2O IN TANK cc	H_2O USED cc	CUMULATIVE H_2O USED cc
742	7900	-	-
758	7900	1800	80057
781	7900	2150	82207
804	7900	2650	84857
873	7900	5050	89907
893	7900	1650	91557
912	7900	1660	93217
935	7900	2850	96067
958	7900	2000	98067
1031	7900	6500	104,567

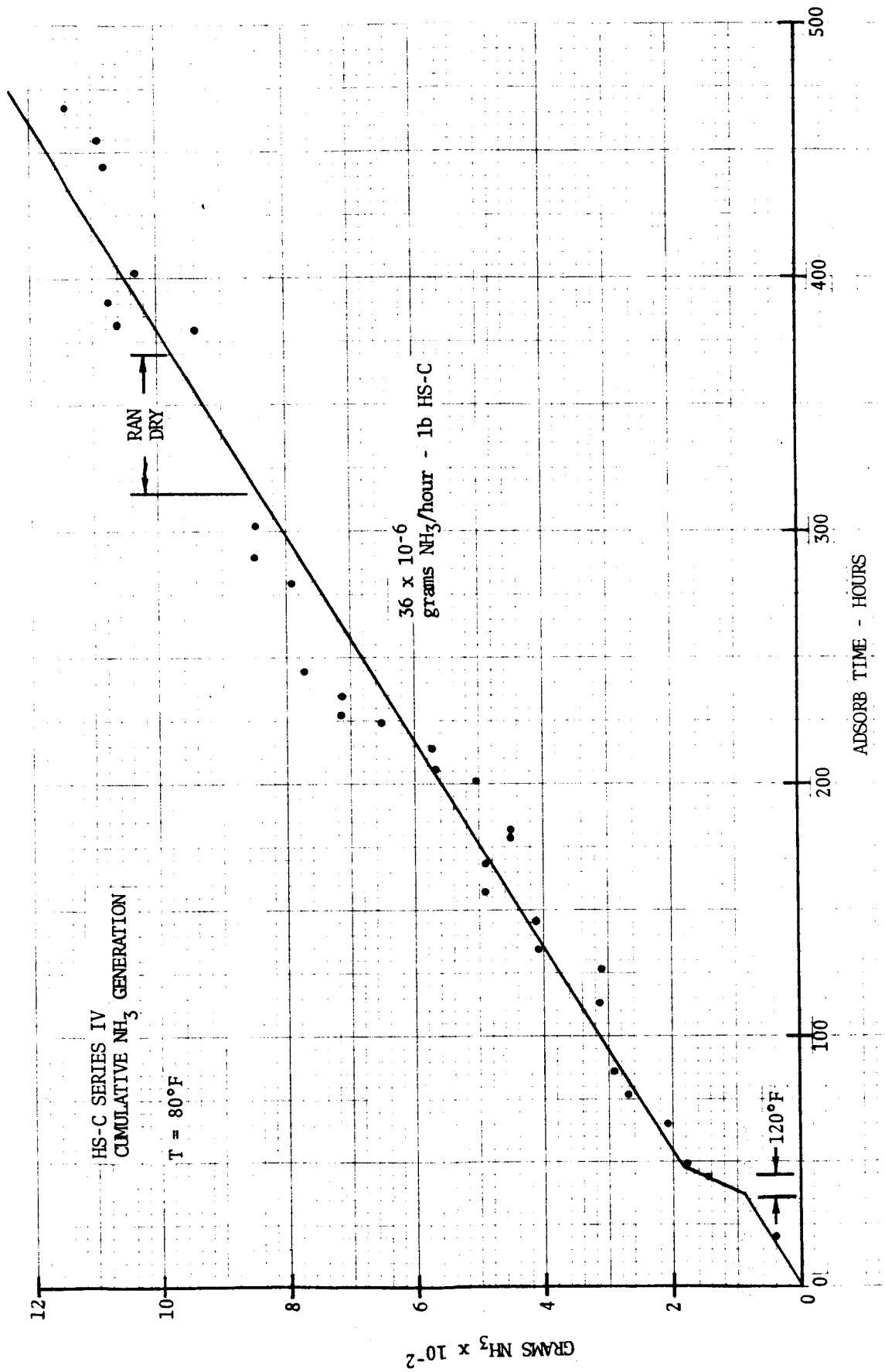
NOTE: Numbers in parentheses have been corrected to adjust for rig malfunctions.

TABLE IX

WATER REMOVAL CAPACITY COMPARISON

CYCLE NO.	179	293	347	408	433	452	472	585	602	935	1034	1045	1116
LBS H_2O/CYCLE	0.238	0.235	0.229	0.228	0.228	0.239	0.221	0.242	0.230	0.248	0.229	0.235	0.245
CYCLE TIME (MINUTES)			BED OUTLET DEW POINT TEMPERATURE ~ °F										
0	50.5	50.5	51.5	52.0	52.0	52.0	52.0	52.5	52.0	52.0	52.5	52.0	52.5
5	17.5	19.5	22.0	21.5	21.5	19.5	22.5	20.5	20.5	13.5	22.5	15.5	19.0
6	25.0	27.5	29.5	28.5	28.5	27.5	29.5	28.0	28.0	24.0	29.5	23.5	27.5
7	30.0	32.0	34.0	33.5	33.5	32.5	34.0	33.0	33.0	30.1	34.5	30.5	33.0
8	34.0	35.5	37.0	37.0	37.0	36.0	37.5	36.5	36.5	34.0	37.5	34.5	36.5
9	36.5	38.0	39.5	39.5	39.5	39.0	40.0	39.5	39.5	37.5	40.0	38.0	39.5
10	38.5	39.5	41.5	41.5	41.5	41.0	42.0	41.5	41.5	39.5	42.0	40.5	41.5
12	41.5	43.0	44.0	44.0	44.5	43.5	44.5	44.5	44.5	43.0	45.0	44.0	44.5
15	44.5	45.5	46.5	47.0	47.0	46.5	47.5	47.0	47.0	46.0	47.5	47.5	47.0
20	46.5	47.5	49.5	49.5	49.5	49.0	49.5	49.5	49.5	49.0	50.0	50.0	49.5
25	47.5	49.0	50.5	50.5	50.5	50.5	50.5	51.0	51.0	50.5	51.0	51.5	50.5
30	48.0	49.5	51.0	51.5	51.5	51.5	51.5	51.5	51.5	51.5	52.0	52.0	51.0

NOMINAL CONDITIONS: FLOW = 40 cfm
T_{DP} = 52°F
30/30 CYCLE TIMES



CUMULATIVE AMMONIA VERSUS TIME

FIGURE 21

TABLE X

AMMONIA GENERATION MEASUREMENTS

WATER SAMPLE NO.	CYCLE NO.	NH_3 CONC. ppm IN H_2O	WATER QUANTITY IN SYSTEM cubic centimeters	TOTAL NH_3 IN SYSTEM grams x 10^{-2}	CUMULATIVE NH_3 grams x 10^{-2}	TOTAL HOURS ADSORB TIME
0	-	-	-	0.53	0	0
1	43	1.198	7950	0.95	0.42	22.5
2	90	3.27	6050	1.98	1.45	45
3	99	4.79	4800	2.30	1.77	49.5
4	Baseline	.38	8800	0.334	-	-
6	132	.84	7600	0.64	2.08	66
7	151	1.46	8450	1.23	2.67	75.5
8	174	1.63	8700	1.42	2.86	87
9	228	2.40	7050	1.69	3.13	114
10	251	1.86	8800	1.63	3.07	125.5
11	269	2.93	8800	2.58	4.02	134.5
12	292	3.03	8800	2.66	4.10	146
13	315	3.84	8800	3.48	4.92	157.5
14	338	3.78	8800	3.42	4.86	169
15	358	3.43	8800	3.02	4.46	179
16	361	3.81	8150	3.10	4.54	180.5
18	402	4.10	8800	3.60	5.04	201
19	408	4.85	8800	4.26	5.70	204
20	430	4.90	8800	4.31	5.75	215

100%

TABLE X (Concluded)

AMMONIA GENERATION MEASUREMENTS

WATER SAMPLE NO.	CYCLE NO.	NH_3 CONC. ppm IN H_2O	WATER QUANTITY IN SYSTEM cubic centimeters	TOTAL NH_3 IN SYSTEM grams x 10^{-2}	CUMULATIVE NH_3 grams x 10^{-2}	TOTAL HOURS ADSORB TIME
21	450	5.71	8800	5.02	6.46	225
22	453	6.51	8800	5.72	7.16	226.5
23	469	6.46	8800	5.69	7.13	234.5
24	471	1.35	8800	1.19	-	235.5
25	491	2.00	8800	1.76	7.70	245.5
27	561	2.21	8800	1.94	7.88	280.5
28	580	2.82	8800	2.48	8.48	290
30	603	.62	8800	0.545	-	301.5
31	630	1.67	3000	0.502	-	315
32	742	.62	8800	0.545	-	371
33	758	2.15	6900	1.48	9.35	379
34	759	1.92	8800	1.69	10.56	379.5
35	781	2.79	6550	1.83	10.70	390.5
37	805	4.02	6150	2.47	10.37	402.5
40	893	4.03	7150	2.88	10.78	446.5
42	912	4.22	7140	3.01	10.91	456
44	935	5.88	5950	3.50	11.40	467.5

NOTE: Samples 5, 17, 26, 29, 36, 38, 39, 41 and 43 were omitted because they were part of calibrations or were taken before proper mixing time had elapsed.

Atmosphere Ammonia Measurements

The ammonia measurements in the gas stream ranged from 0-10 ppm. Since the accuracy of the detection method was approximately 10 ppm, these measurements were not assumed to have significance.

Ammonia Adsorption Capacity of HS-C

It was theorized that HS-C may be a potential regenerable ammonia sorbent. To test this theory the loop was run dry and 100 cc of ammonia gas was injected into the loop. The ammonia level then was measured in the loop air for six cycles. The results of this test are shown in Table XI.

The free volume of the HS-C canister was determined to be 0.21 that of the total air loop. This rate was used to calculated ammonia decrease as a function of ullage only, the rate of decrease being 1/1.2 per cycle.

TABLE XI

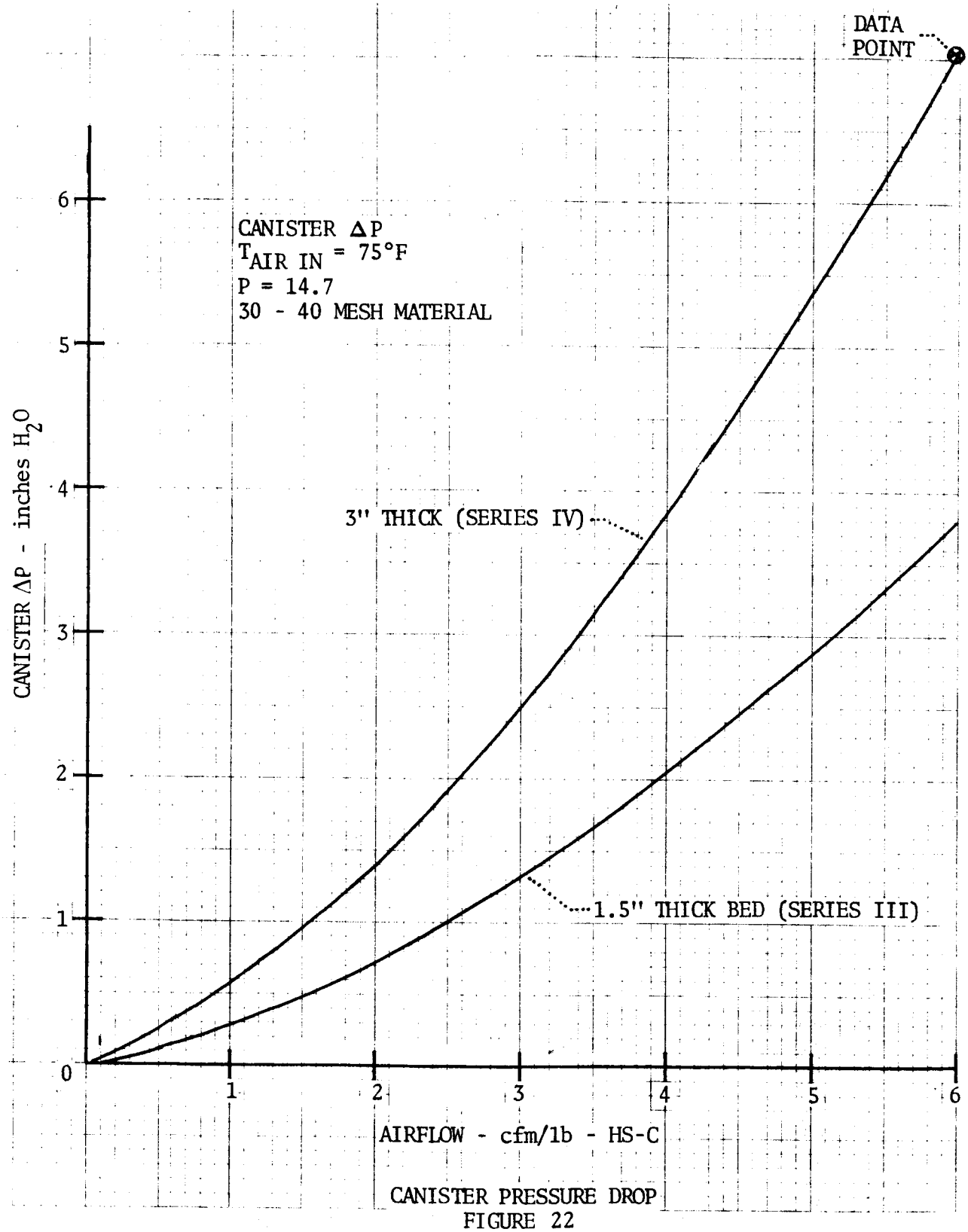
AMMONIA ADSORPTION EVALUATION

Cycle	ppm Meas.	ppm Reduction Calculated from Ullage Only		
1	1053	1053	-	
2	388	875	-	
3	138	725	138	calculated decrease assuming 138 ppm at cycle 3
4	-	599	114	
5	-	495	94	
6	79	409	78	

From Table XI it can be seen that the initial ammonia level reduction in the test loop is greater than could be accounted for by ullage. After a level of 138 ppm is reached, ullage can account for all of the reduction indicating that adsorption has no significant role at this level. From this data, it is concluded that HS-C has little or no capacity to remove ammonia at the level of interest, which is 10 ppm.

Canister Pressure Drop

Figure 22 shows the canister pressure drop for 30-40 mesh material. The pressure drop includes the two 50 mesh screens and the canister headers. Test data is available from two bed thicknesses and can be used to predict pressure drop for alternate designs.



CANISTER PRESSURE DROP
FIGURE 22

FLIGHT CONCEPT DEFINITION

A flight system was sized to meet the present Shuttle requirements of ten men and a normal cabin CO_2 partial pressure of 5 mmHg. The system was concepted to meet the fail operational, fail safe Shuttle design criteria.

The proposed system is shown schematically in figure 23. The system contains three HS-C canisters, two operating and one redundant. A LiOH canister is provided to meet the requirement to fail safe after a second failure. The LiOH also would be used for atmospheric flight, where vacuum for desorption is not available.

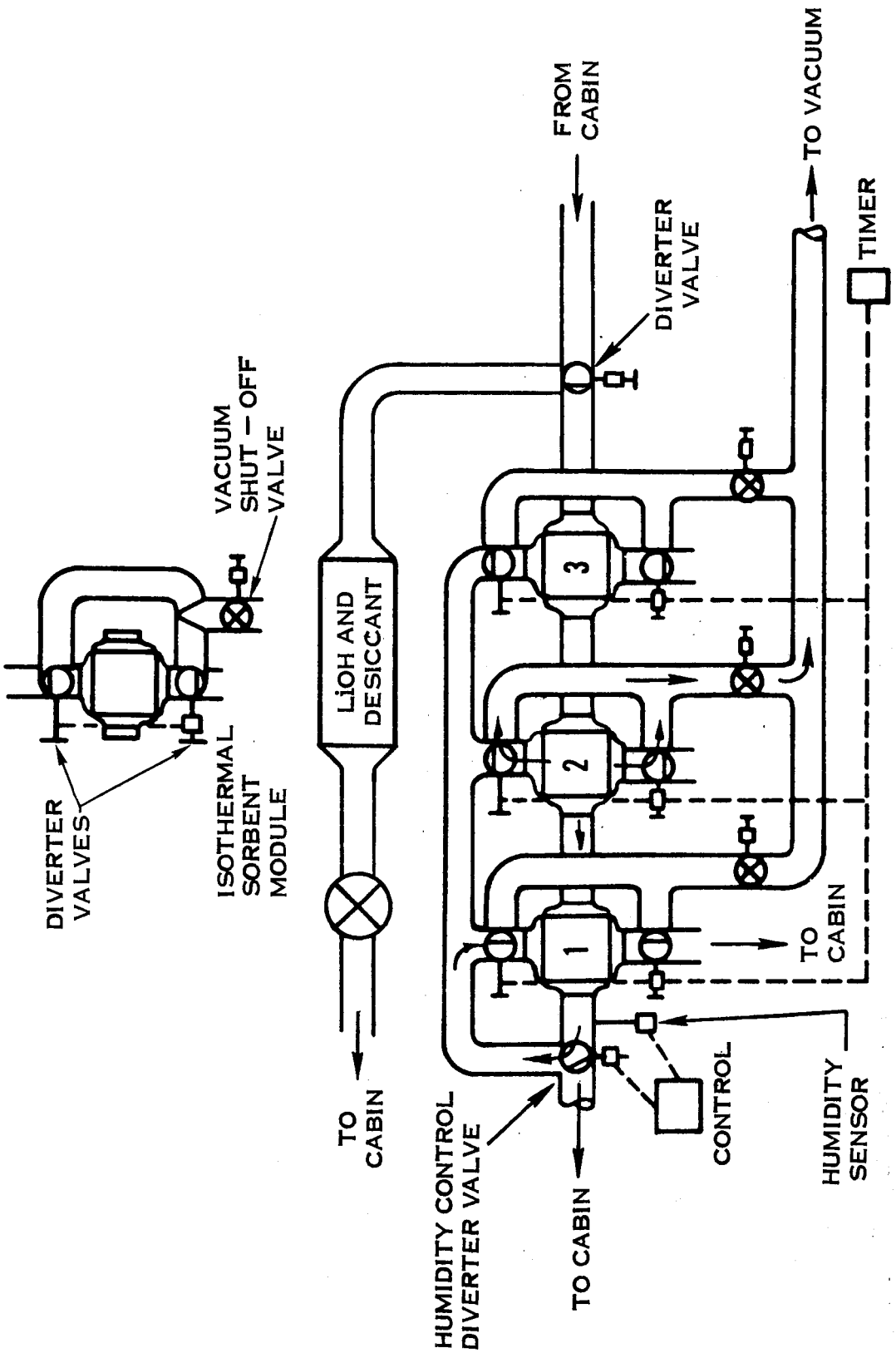
Each canister is a crossflow heat exchanger, one side of which is packed with HS-C and the other side designed to provide sufficient heat transfer for the desorption cycle.

System airflow first passes in series through the heat transfer passages of the three canisters. In the process the airflow is cooled by the desorbing canister. The flow then is ducted to the active adsorbing bed, where its moisture and CO_2 are removed.

TEN-MAN HS-C CANISTER

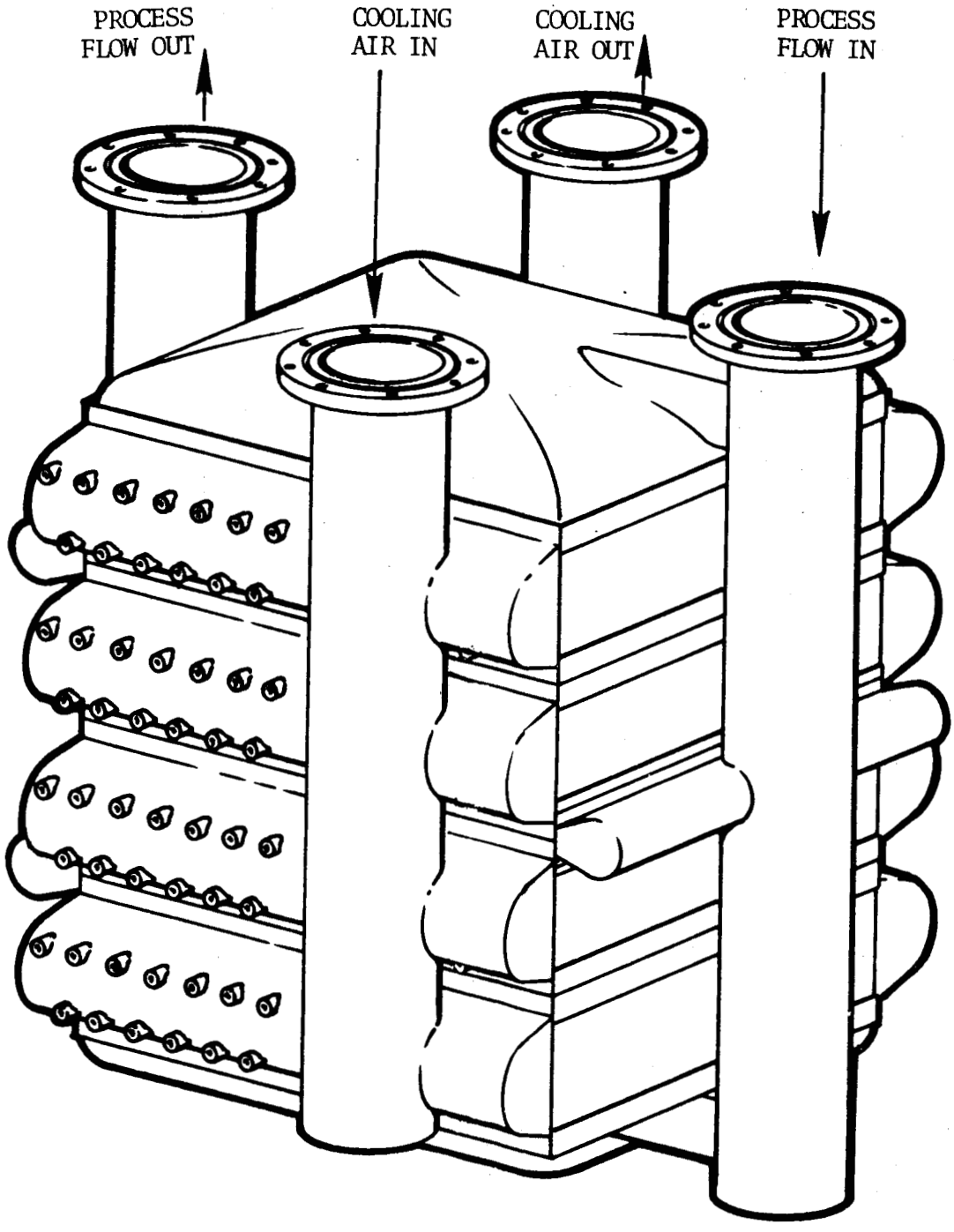
The ten-man HS-C canister, figure 24, was conceptually designed with a four segment desiccant bed configuration to produce a unit that is nearly cubic in shape. Each HS-C bed segment, which is four inches thick and measures 17.80 inches wide by 16.50 inches deep, is composed of alternate layers of herringbone fin cooling passages. The cooling passages, 26 in number and 1/4 inch in thickness, allow cooling air to flow from front to back; the HS-C containing passages, 25 in number and 3/8 inch in thickness, allow process air to flow from bottom to top. Fine mesh screens, supported by backup strips and securely welded or riveted to the cooling passage closure bars, provide for top and bottom containment of the HS-C material within the HS-C passages. The HS-C is loaded into - or removed from - the bed through filling tubes located in the HS-C passage closure bars. The fin perforations allow cross-flow of the HS-C particles during the loading process. The canister assembly consists of the four HS-C beds stacked in layer form with a one inch separation between the beds.

As illustrated in figure 25 process flow is directed into the top,bottom, and center headers which are ported together through a four inch vertical line located on the side. Process flow then is removed from the alternate headers, which are also ported together through a four inch vertical line located on the other side. During vacuum desorption of the HS-C beds both the inlet and outlet process flow lines are vented to vacuum, thereby allowing desorption from both sides of each HS-C bed.



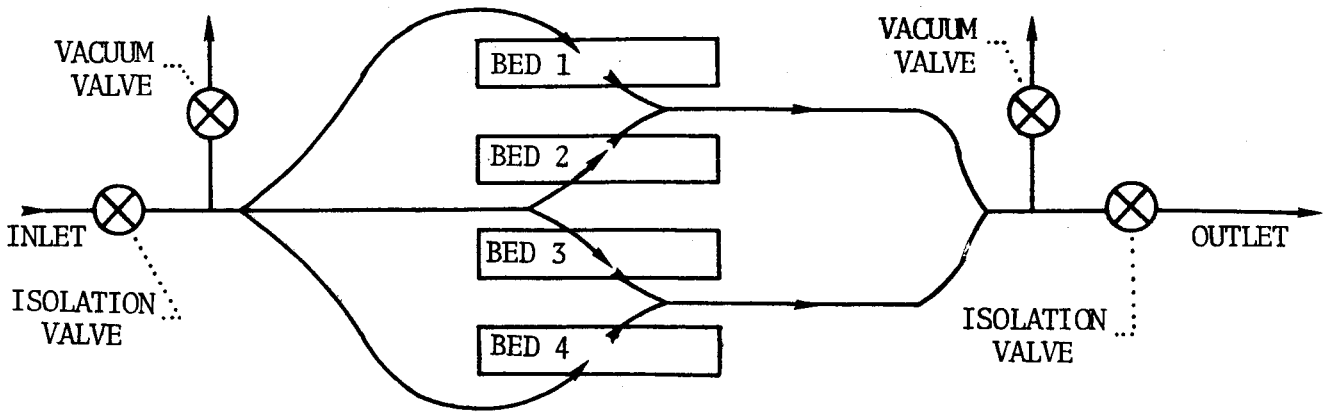
CO_2 AND HUMIDITY CONTROL SYSTEM

FIGURE 23



HEAT EXCHANGER FOR BREADBOARD REGENERABLE CO_2
AND HUMIDITY CONTROL SYSTEM

FIGURE 24



CANISTER FLOW ARRANGEMENT

FIGURE 25

The cooling flow enters a four inch vertical line located in front, passes into each of the four front cooling flow headers, flows through the cooling passages of each of the four HS-C beds, flows into the four rear cooling flow headers, and passes out through a rear mounted four inch vertical line. The entire unit is mounted in the vehicle or in the test section by means of attachment flanges located on each of the four vertical four inch lines.

The performance requirements used to size the flight concept unit are the requirements presently being considered for Shuttle.

These requirements are

number of men.....10

CO_2 production rate.....21.1 lbs/day

moisture production rate.....43.2 lbs/day

design CO_2 partial pressure.....5 mm Hg

design dew point..... 61°F

The approximate method for sizing the HS-C canisters is given below. This size is based on 30 minute adsorb and 30 minute desorb times. An actual design will require the optimization of all parameters affecting performance.

Canister Sizing

CO_2 Removal

The required CO_2 removal rate is 21.1 pounds/day, which equals

$$\frac{21.1}{24} = 0.88 \text{ lbs/hour.}$$

For the selected 30 minute adsorb/30 minute desorb cycle there are two adsorb periods per hour. Thus the required capacity per cycle is

$$\frac{0.88 \text{ lbs/hr}}{2 \text{ cycles/hr}} = 0.44 \text{ lbs/cycle.}$$

From figure 14, CO_2 removal capacity at an assumed flow of 2 cfm/lb, which is the knee of the capacity curve, is 1.5% (0.015 lbs/cycle - lb HS-C). Therefore, the amount of HS-C required per canister is

$$\frac{0.44 \text{ lbs/cycle}}{0.015 \text{ lbs/cycle - lb HS-C}} = 29.3 \text{ lbs HS-C.}$$

Water Removal

The required water removal capacity is 43.2 lbs/day. Therefore, the required water removal capacity per cycle is

$$\frac{43.2}{24 \times 2} = 0.90 \text{ lbs/cycle.}$$

For a 29.3 pound canister this gives a water capacity of

$$\frac{0.90 \text{ lbs/cycle}}{29.3 \text{ lbs}} = 0.0307, \text{ or } 3.07\%.$$

From figure 15, the airflow required to obtain a 3.07% water capacity is 1.5 cfm/lb. Since this is less than the 2 cfm/lb required for CO_2 removal, it is apparent that CO_2 capacity is the sizing factor.

Airflow

The above discussion on CO_2 Removal derives that 29.3 pounds of HS-C are required for each canister and that this relates to a flow of 2 cfm per pound of HS-C. Therefore, the required airflow is

$$29.3 \text{ lbs HS-C} \times 2.0 \frac{\text{cfm}}{\text{lb HS-C}} = 58.6 \text{ cfm .}$$

System Pressure Drop and Power

From figure 22, the canister pressure drop for a three inch thick bed is

$$\Delta P = 1.4 \text{ inches of } H_2O .$$

For a four inch thick bed, $\Delta P = 1.4 \times \frac{4}{3} = 1.87$ inches of H_2O .

The airflow goes through three canisters in series each with a pressure drop of 0.50 inches of H_2O.

The total ΔP pressure drop then is

adsorbing canister	1.87
heat exchange passages	1.50
valves and ducts	1.00
Total	4.37 inches of H_2O

The power required is

$$\text{Power} = \frac{\text{cfm} \times \Delta P}{3.5} = \frac{58.5 \times 4.37}{3.5} = 73 \text{ watts}$$

The 3.5 conversion factor in the above equation includes an assumed overall fan efficiency of 41%.

Ammonia Generation

From the large scale testing it was determined that HS-C produces 36×10^{-6} grams of ammonia per hour of adsorb time, per pound of HS-C. For the proposed design the lb - hours/day are

$$29.3 \text{ lbs HS-C} \times 24 \frac{\text{hours}}{\text{day}} = 704 \frac{\text{lbs HS-C - hours}}{\text{day}} .$$

The resulting ammonia generation is calculated as

$$704 \frac{\text{lbs HS-C - hours}}{\text{day}} \times 36 \times 10^{-6} \frac{\text{grams } NH_3}{\text{lbs HS-C - hours}} = 0.0254 \frac{\text{grams } NH_3}{\text{day}}$$

This is a negligible amount compared to the predicted metabolic rate of 3 grams/day for 10 men in the Shuttle.

Using the above generation rate and assuming a zero leakage cabin having a volume at 2000 cubic feet, the ammonia concentration would increase as follows:

$$NH_3 \text{ concentration} = \frac{\text{gen. rate x ft}^3\text{/meter}^3}{\text{cabin volume - ft}^3} = \text{gms/meter}^3\text{/day}$$

$$= \frac{0.0254 \times 35.4}{2000} = 0.45 \times 10^{-3} \text{ gms/meter}^3\text{/day}$$

The allowable concentration is 3.5×10^{-3} gms/meter^3/day. It would be reached only after 7.8 days and then only if there were no leakage in the cabin and if there were no ammonia removal equipment aboard.

APPENDIX A

NESSLER'S METHOD

NITROGEN, AMMONIUM

Nessler's Method
Standard Methods, 12th Ed., page 193

Two methods are given by the **APHA Standard Methods** for carrying out this test: one is a distillation method for the separation of the ammonia from the water, and the other is the direct Nesslerization method. The distillation method permits the concentration of trace amounts of ammonia. Only the direct Nesslerization procedure is given below, though the same calibration table can be used with both procedures provided any change in volume of the sample due to distillation is taken into account.

Procedure

1. Measure a 25 ml water sample by filling a clean 25 ml graduated cylinder to the 25 ml mark. Pour the sample into a clean 50 ml flask. *See Notes A and B.*

2. Measure a 25 ml sample of demineralized water by filling another clean 25 ml graduated cylinder to the 25 ml mark. Pour it into a clean 50 ml flask.

3. Add to each sample 1.0 ml of Nessler's Reagent. Swirl to mix. If ammonium nitrogen is present, a yellow color will develop. Allow ten minutes for full color development.

4. Use the prepared sample of demineralized water for standardizing the instrument. Measure the color of the prepared water sample and find the ppm ammonium nitrogen (N) from the table.

Notes

A. The temperature of the sample should be 20°C. If the sample temperature is above 20°C, the results of the test will be high; if below, the results will be low.

B. If the hardness of the water sample is above 100 ppm (about 6 grains) a positive interference may result due to the precipitation of magnesium hydroxide. To eliminate this interference, add one drop Rochelle Salt Solution to the demineralized water sample and to the water sample before adding the Nessler's Reagent in Step 3.

C. In addition to calcium and magnesium, iron and sulfide may interfere by causing the formation of turbidity with the Nessler's Reagent. Pretreatment with zinc sulfate and alkali may be used to eliminate interference from these sources. *See Standard Methods for details.*

D. There are a number of rarely encountered compounds (mostly organics) which may interfere. Some of these are hydrazine, glycine, various aliphatic and aromatic amines,

organic chloramines, acetone, aldehydes and alcohols. Some symptoms may be a yellowish or greenish off-color or a turbidity. If these compounds are present, it may be necessary to distill the sample before the test is performed. *See Standard Methods for details.*

E. For dilution of samples, *see Sample Dilution Techniques.*

F. The results of this test are given in terms of ppm ammonium nitrogen (N). To express as ppm ammonia (NH_3), multiply the N value by 1.21. To express as ppm ammonium (NH_4^+), multiply the N value by 1.29.

B & L SPECTRONIC 20 CALIBRATIONS

Nessler's Method

425 nm - ½ inch test tube

	0	1	2	3	4	5	6	7	8	9
30							2.52	2.46	2.43	2.35
40	2.29	2.23	2.18	2.13	2.07	2.02	1.97	1.93	1.89	1.84
50	1.80	1.75	1.70	1.66	1.62	1.58	1.54	1.50	1.46	1.43
60	1.39	1.35	1.31	1.28	1.25	1.21	1.17	1.15	1.11	1.07
70	1.04	1.01	0.98	0.95	0.92	0.89	0.86	0.83	0.80	0.77
80	0.75	0.72	0.69	0.66	0.64	0.61	0.58	0.56	0.53	0.50
90	0.48	0.45	0.43	0.40	0.37	0.35	0.30	0.25	0.21	0.15

Replacement Chemicals

Cat. No.			
151-11	Nessler's Reagent	pint	$4.00
1725-33	Rochelle Salt Solution	1 oz DB*	1.40
1725-14	Rochelle Salt Solution	4 oz	2.10
	*Dropping Bottle		

APPENDIX B

DISTILLATION METHOD

B. Distillation Method

1. General Discussion

1.1. *Principle:* Free ammonia nitrogen can be quantitatively recovered by distillation when the distillation mixture is maintained at about pH 7.4. The distillate may be collected in a volumetric flask for nesslerization or the sample may be distilled into boric acid or standard sulfuric acid and the ammonia determined by titration.

1.2. *Interference:* Ammonia recovery will be low on samples containing more than 250 mg/l calcium unless sufficient phosphate buffer is added. The calcium and phosphate of the buffer react to precipitate calcium phosphate, releasing hydrogen ions and lowering the pH. A number of aliphatic and aromatic amines, organic chloramines, acetone, aldehydes, and alcohols, among other undefined organic compounds, yield a yellowish or greenish off color or a turbidity following the addition of nessler reagent to distillates collected from dechlorinated samples. Sulfide has also been reported to cause turbidity following nesslerization, a condition which may be avoided by adding lead carbonate to the flask prior to distillation. Volatile substances, such as formaldehyde, can be removed by boiling at low pH, after which the sample can be distilled and nesslerized in the normal way.

The titration procedure is also subject to amine interference because the standard acid can react with such alkaline substances. The titration process is free of interference from neutral organic compounds.

2. Apparatus

2.1. *Distillation apparatus:* A glass flask, 800 ml, with a condenser and adapter so arranged that the distillate can be collected either for nesslerization or in standard H_2SO_4 or H_3BO_3 solution for titration.

2.2. *Colorimetric equipment:* The same colorimetric equipment is required as for Method A.

3. Reagents

3.1. *Ammonia-free water:* Prepare as directed in Method A, Sec. 3.1.

3.2. *Phosphate buffer solution,* 0.5*M*. Dissolve 14.3 g anhydrous potassium dihydrogen phosphate, KH_2PO_4, and 68.8 g anhydrous dipotassium hydrogen phosphate, K_2HPO_4, in ammonia-free water and dilute to 1 liter.

3.3. *Standard sulfuric acid titrant,* 0.02*N*. Prepare as directed in Part I, Alkalinity, Sec. 3.2; 1.00 ml = 0.28 mg N. Other strengths of standard acid may be used.

3.4. *Indicating boric acid solution:* Prepare as directed under Nitrogen (Organic), Sec. 3.8.

3.5. *Standard ammonium chloride solution:* Prepare as directed in Method A, Sec. 3.5.

3.6. *Nessler reagent:* Prepare as directed in Method A, Sec. 3.6.

4. Procedure

4.1. *Distillation:* Steam out the still until free from ammonia. Place 100–400 ml of sample in an 800-ml kjeldahl flask. Neutralize to pH 7 if the sample is acid or alkaline. Add 25 ml phosphate buffer solution, which should keep the pH of the distillation mixture at 7.4 during the distillation. For samples containing more than 250 mg/l calcium, add up to 40 ml of buffer solution first and then adjust the pH to 7.4 with acid or base. Dilute to 400 ml with ammonia-free water and distill 200 ml into a 200-ml graduated flask for nesslerization or into standard H_2SO_4 or H_3BO_3 solution for titration as described in Nitrogen (Organic), Sec. 4.

4.2. *Nesslerization:* Dilute an aliquot of the distillate with ammonia-free water, nesslerize, and compare colors as directed in Method A, Sec. 4.5.

4.3. *Titration:* If the concentration of ammonia nitrogen is greater than 5 mg/l, collect the distillate in 50 ml indicating boric acid solution, and back-titrate with standard H_2SO_4 titrant as in Nitrogen (Organic), Sec. 4.3 and 4.4.

5. Calculation

For nesslerization:

$$\text{mg/l ammonia N} = \frac{R \times 2{,}000}{Sd}$$

where R = ml standard solution, S = ml sample, and d = distillate nesslerized.

For titration:

$$\text{mg/l ammonia N} = \frac{\text{ml } H_2SO_4 \text{ titration} \times 0.28 \times 1{,}000}{\text{ml sample}}$$

6. Precision and Accuracy

The distillation and titration procedure is more accurate than the direct nesslerization method. The recoveries are 99 to 100 per cent and the precision, over a range from 5 to 50 mg/l, may be expressed as a standard deviation of 0.18 ml H_2SO_4, or 0.5 mg/l when a 100-ml sample is used ($n = 3$; 5×5).

The distillation and nesslerization method is more precise for concentrations of 1 to 5 mg/l. Using a 100-ml sample and a 25-ml aliquot from the 200-ml distillate, the standard deviation was 0.0019 mg ammonia nitrogen or 0.15 mg/l ($n = 1$; 11×10).

Bibliography

1: PHELPS, E. B. A Critical Study of the Methods in Current Use for the Determination of Free and Albuminoid Ammonia. *APHA Public Health Papers & Repts.* 29:354 (1903); *J. Infectious Diseases* 1:327 (1904).

APPENDIX C

PROCEDURE FOR CALIBRATION

OF THE COLEMAN SPECTROPHOTOMETER 295

Procedure for Calibration of the Coleman Spectrophotometer 295

Five samples of known ppm (by weight) of NH_4Cl in distilled water were prepared for the calibration curve namely 0.0, 0.5, 1.0, 1.5, 2.0. The procedure is as follows:

1. Measure out 25 ml of each known sample into a clean 50 ml flask.

2. Add to each sample 1.0 ml of Nessler's Reagent. Swirl to mix. Allow 10 minutes for full color development. A detailed description of Nessler's Method is provided in Appendix A of this report.

3. From each flask pour sample into 12 mm test tubes. Set the wave length at 425 on the spectrophotometer. Insert the 0.0 ppm tube first and set meter to 80 with gain control, then place each of the four known samples in the spectrophotometer and record results.

4. From the data taken in step 3,a calibration curve can be made on Coleman #14-322 chart paper.

APPENDIX D

PROCEDURE FOR GAS SCRUBBING IN COLLECTION BOTTLE

Procedure for Gas Scrubbing in Collection Bottle

The fritted tube remains on the sample bomb outlet immersed in distilled water at all times to prevent flow variations, which cause the reading to fluctuate. The procedure is as follows:

1. Measure out 100 ml of .02 normal H_2SO_4 in graduate and put in sample bottle.
2. Remove fritted tube from water and rinse with distilled water. Place tube into sample bottle and record the time.
3. Place the tygon tube from the flowmeter on the sample bottle outlet and record flow.
4. Remove after 15 minutes for high ppm (>1000) sample bombs and 60 minutes for low ppm (< 1000).
5. Place the fritted tube back into distilled water.
6. Measure out 25 ml. into 50 ml flask from sample bottle.
7. Measure out 25 ml. into 50 ml from .02 normal H_2SO_4.
8. Add 1 ml to each flask, allow 10 minutes for full color development.
9. From each flask pour sample into 12 mm test tube and insert the 0.02 normal H_2SO_4 sample into the spectrophotometer and set dial to 80 using the gain control. Then insert the unknown sample into spectrophotometer and record dial reading.
10. Use the following calculations to obtain μgms/hr-(lb HS-C or PEI). Take dial reading and obtain curve value in ppm.

$$\left(\text{curve value}\ \frac{\mu\text{gm/ml}}{}\right) \times \frac{\text{molecular wt ammonia}}{\text{molecular wt nitrogen}} \times \left(\text{sample size}\ \frac{\text{total ml}}{}\right)$$

$$\times \text{ dilution factor} \times \frac{60\text{min/hr}}{\text{sample time (min)}} \times \frac{454\ \text{gm/lb}}{\text{sample wt. (gms)}} = \mu\text{gms/hr-lb HS-C or PEI}$$

11. Plot μgm/hr-lb HS-C or PEI versus elapsed time with gas flow.

12. If reading falls below 35 on dial, dilute sample to bring reading up to 40 - 60 range.

Error Analysis

An error analysis of the test method was conducted as described in this section.

sample time	60 min ± .5
	15 min ± .25
sample size	100 ml. ± 1 ml.
spectrophotometer reading	± 1 division

(reading error Taken from figure D-1) + (sample size error) + (sample time error) = Total Error

If a reading of 60 is obtained on a sample that ran for 15 minutes the error would be as follows:

4.7% + 1% + 1.7% = Total Error

7.4% = Total Error

An increase in readings due to flow increases has been noted, but after extended time (>15 hrs) the reading drops to a value corresponding to measurements with lower flows.

Figure D-1 presents the percent error on the Coleman Spectrophotometer 295 with a ± 1 division accuracy.

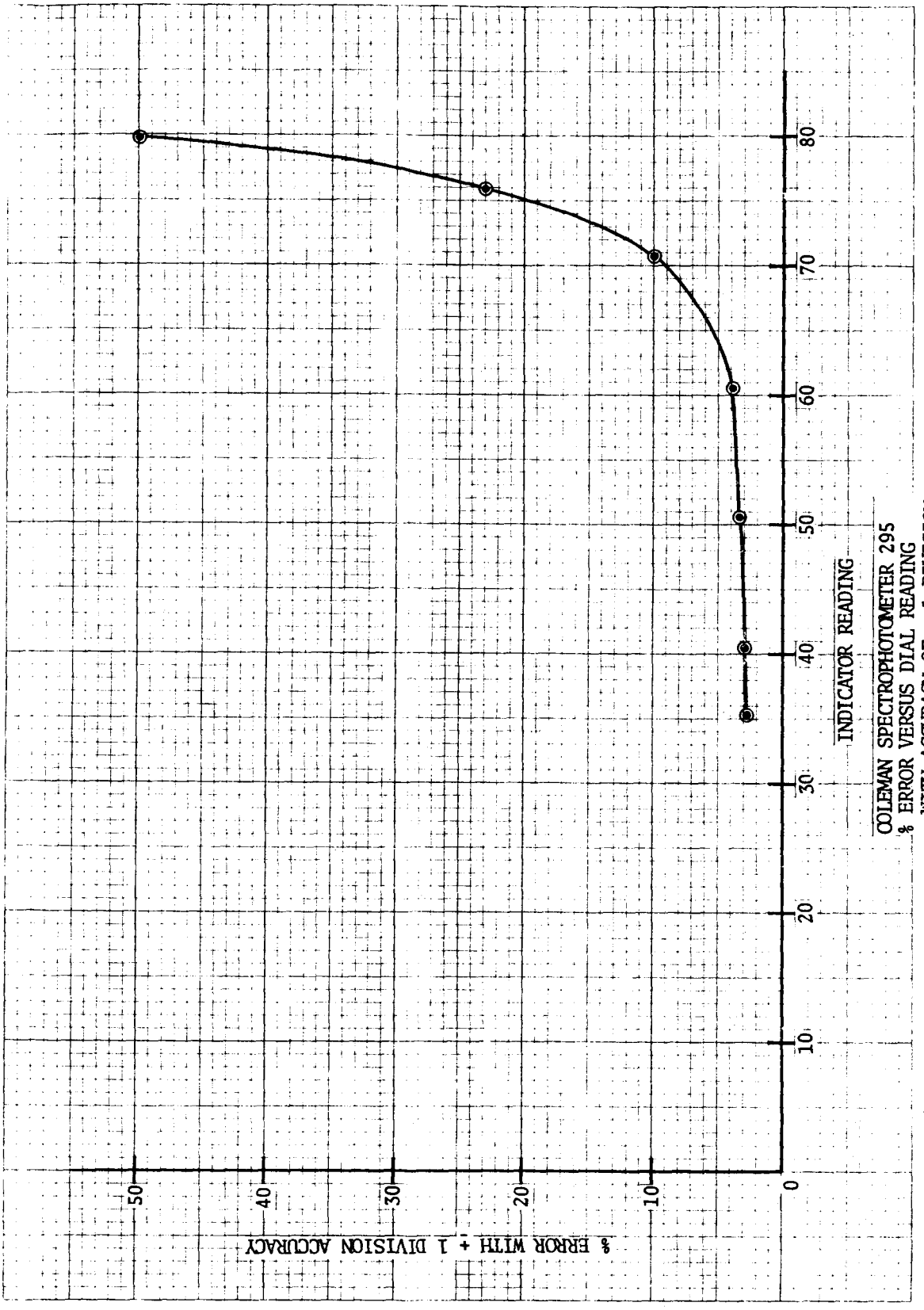

% ERROR WITH ± 1 DIVISION ACCURACY
50
40
30
20
10
0
10
20
30
40
50
60
70
80
INDICATOR READING
COLEMAN SPECTROPHOTOMETER 295
% ERROR VERSUS DIAL READING
WITH ACCURACY OF ± 1 DIVISION

FIGURE D-1

APPENDIX E

REPORT OF HS-C FUNGUS RESISTANCE TEST

Test Report No. 9559 No. of Pages 2

Report of Test on

TEST SAMPLES
for
HAMILTON STANDARD
under
PURCHASE ORDER NO. 040859

ENVIRONMENTAL TESTING CORPORATION
ACTON

Date September 12, 1972

	Prepared	Checked	Approved
By	A.Dentino	W.Schreiner	M.L.Tolf
Signed	A. Dentino	W. Schreiner	M.L. Tolf
Date	9/13/72	9/13/72	9/13/72

MLT:AD/hmf

Administrative Data

1.0 Purpose of Test: To determine if the test samples will satisfactorily meet the requirements of the fungus test as specified in MIL-STD-810B.

2.0 Manufacturer: HAMILTON STANDARD

3.0 Manufacturer's Type or Model No: Series 3 HSC
Series 3 Substrate
PEI 18

4.0 Drawing, Specification or Exhibit: MIL-STD-810B

5.0 Quantity of Items Tested: One (1) each of the above

6.0 Security Classification of Items: NONE

7.0 Date Test Completed: September 5, 1972

8.0 Test Conducted By: A.C.Dentino

9.0 Disposition of Specimens: The samples were returned to Hamilton Standard

10.0 Abstract: Refer to RESULT section herein.

Report No. 9559 Page 1

ACTON ENVIRONMENTAL TESTING CORPORATION

1.0 REQUIREMENTS

The test samples shall be exposed to the fungus test as specified in MIL-STD-810B.

Following the test, the samples shall be visually examined to determine if there is any evidence of fungus growth.

2.0 PROCEDURES

The test samples were suspended in a Tenney Engineering Fungus Chamber, Model TH16. The samples were then inoculated with each of the required fungus spores. The chamber temperature was 86°F. These conditions were maintained for a period of 28 days.

At the end of 14 days, the chamber was opened and the control sample inspected for an abundant fungus growth.

At the end of the 28-day period, the samples were removed from the chamber and visually examined for any evidence of fungus.

3.0 RESULTS

After 14 days, the control item[1] showed an abundant fungus growth.

After 28 days of test, the samples showed no evidence of fungus growth.

The test samples were returned to Hamilton Standard for further evaluation.

Note:

(1) The control item is a known fungus nutrient, not HS-C.

Report No. 9559

APPENDIX F

MASTER TEST PLAN

SOLID AMINE IMPROVEMENT PROGRAM

MASTER TEST PLAN

PREPARED UNDER CONTRACT NAS 9-12957

by

HAMILTON STANDARD

DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONNECTICUT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

AUGUST 1972

Prepared by: J. S. Lovell
J. S. Lovell
Program Engineer

Approved by: F. H. Greenwood
F. H. Greenwood
Program Manager

DRL ITEM 3

MASTER TEST PLAN

It is the purpose of this document to supplement the Program Operating Plan in order to provide additional instruction to the test engineer.

HS F-927 6/56

TEST NO. _____ HAMILTON STANDARD PAGE 1 OF _____

PLAN OF TEST Task 1.1

JOB: NAS 9-12957 PLAN PREPARED BY: J. Lovell

PROJECT & ORDER: _____ APPROVED BY: _____

INSTRUCTION: _____ TEST ENGINEER: _____

TIME PERIOD: August 14, 1972 TO October 7, 1972

1. WHAT IS ITEM BEING TESTED?

2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?

3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.

4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.

5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.

6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1. HS-C adsorbent material from NAS 9-11971 series III full scale test.

2. To determine NH_3 off-gassing characteristics.

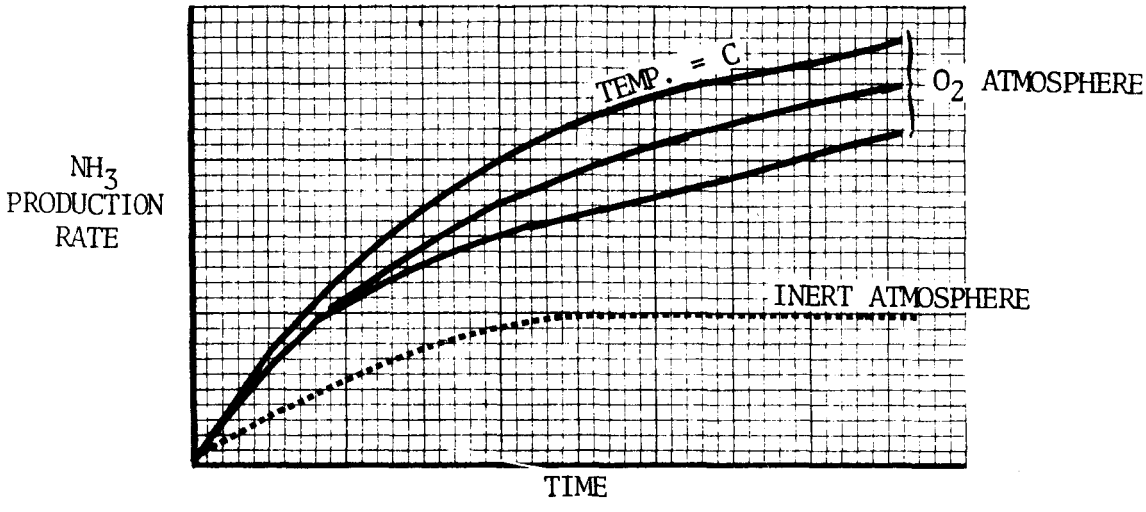
3. No special test setup is required. Vacuum ovens will be used for sample preparation and a 10 CM cell IR spectrophotometer will be used for analysis. The following existing equipment will be available for this program.

   a. (3) Vacuum ovens.
   b. (3) Vacuum pumps.
   c. (1) Small scale sorbent performance test rig (1/4/73 - 2/15/73).
   d. (1) IR gas analyses with (2) 10 CM cells.

In addition, the following will be purchased under this contract.

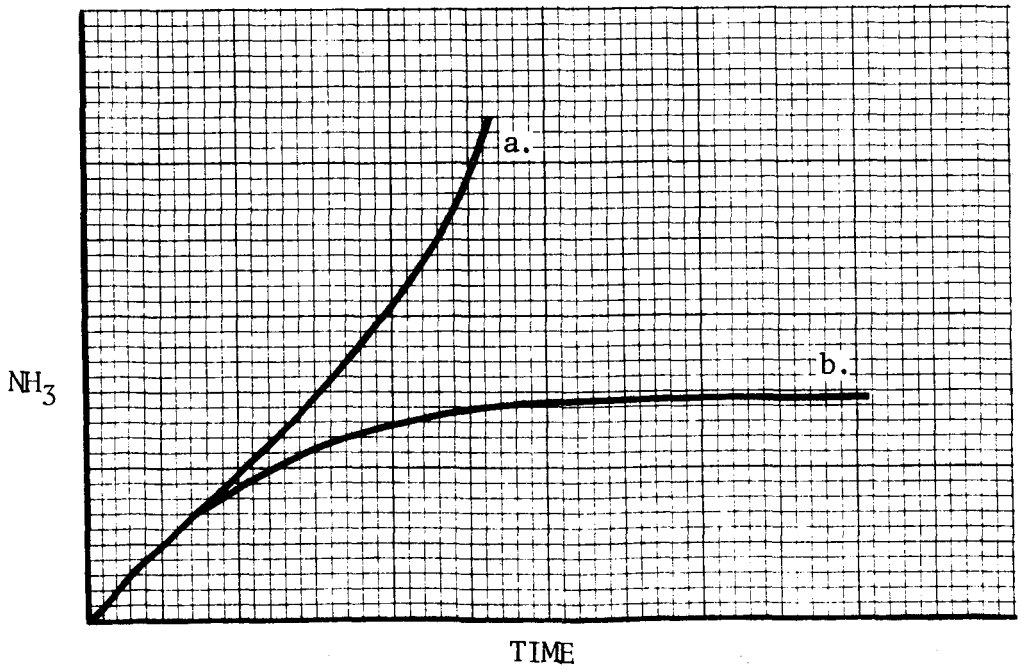
   a. Twenty sample bottles with shut-off valves and quick disconnects.
   b. Calibration gasses and miscellaneous chemicals.

4. Test runs as defined in paragraph 3.2.1.1 of the program operating plan. Temperature, time and vacuum levels will be recorded.
5. Prior to each new test series the sample bottles will be cleaned and checked for residual ammonia. The IR will be calibrated prior to each use and after every fourth sample.
6. The following data is expected from this test program.



This data will quantify the ammonia production rate over a range of operating conditions. It will also indicate the most probable cause of off-gassing as explained below.

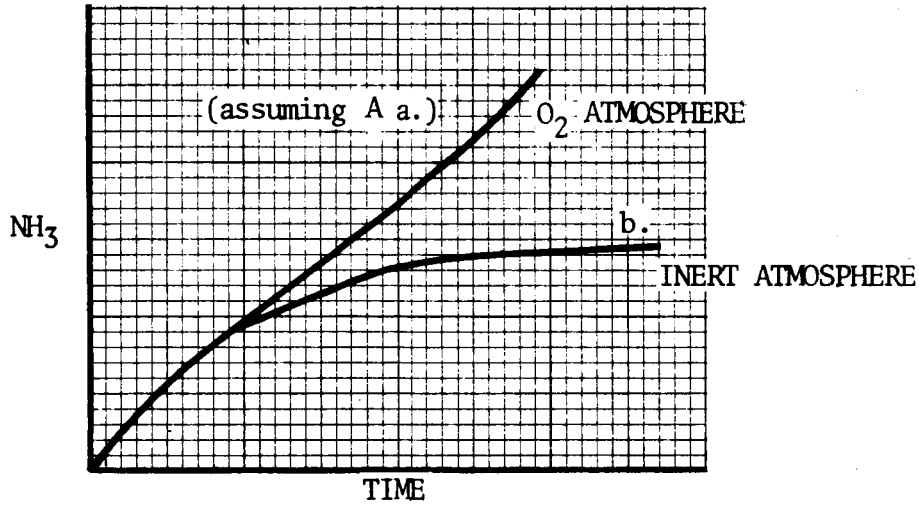
A.



a. Ammonia production is a result of primary amine group, will increase with time.

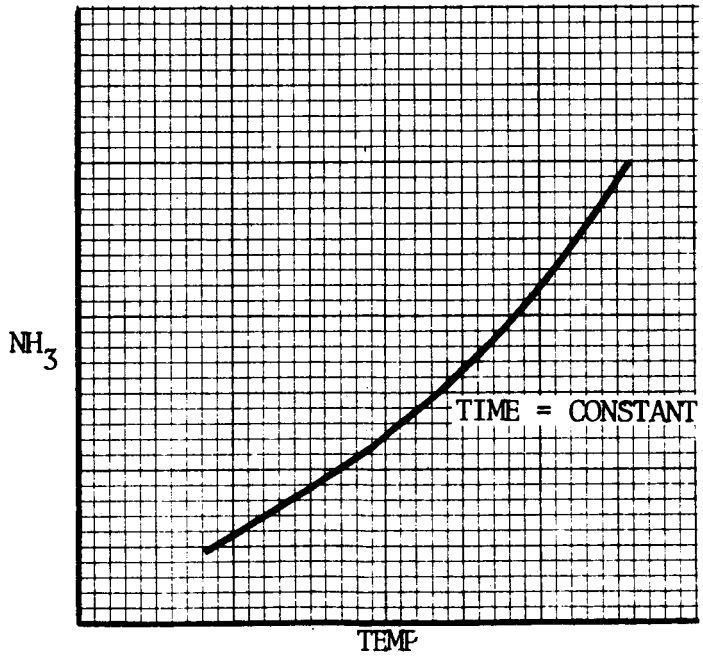
b. Ammonia is a result of a contaminant and will eventually disappear.

B.



Amine breakdown results from oxidation of primary amine group.

C.



A characteristic as shown above would indicate that thermal decomposition is the primary cause of ammonia production.

HS F-927 6/56

TEST NO. _____ HAMILTON STANDARD PAGE 1 OF __

PLAN OF TEST Task 1.2

JOB: NAS 9-12957 PLAN PREPARED BY: J. Lovell

PROJECT & ORDER: August 14, 1972 APPROVED BY: December 31, 197

INSTRUCTION: _____ TEST ENGINEER: _____

TIME PERIOD: _____ TO _____

1. WHAT IS ITEM BEING TESTED?

2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?

3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.

4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.

5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.

6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1. Improved HS-C.

2. Determine effect of methods of reducing or eliminating ammonium from PEI.

3. See Attachment 1.

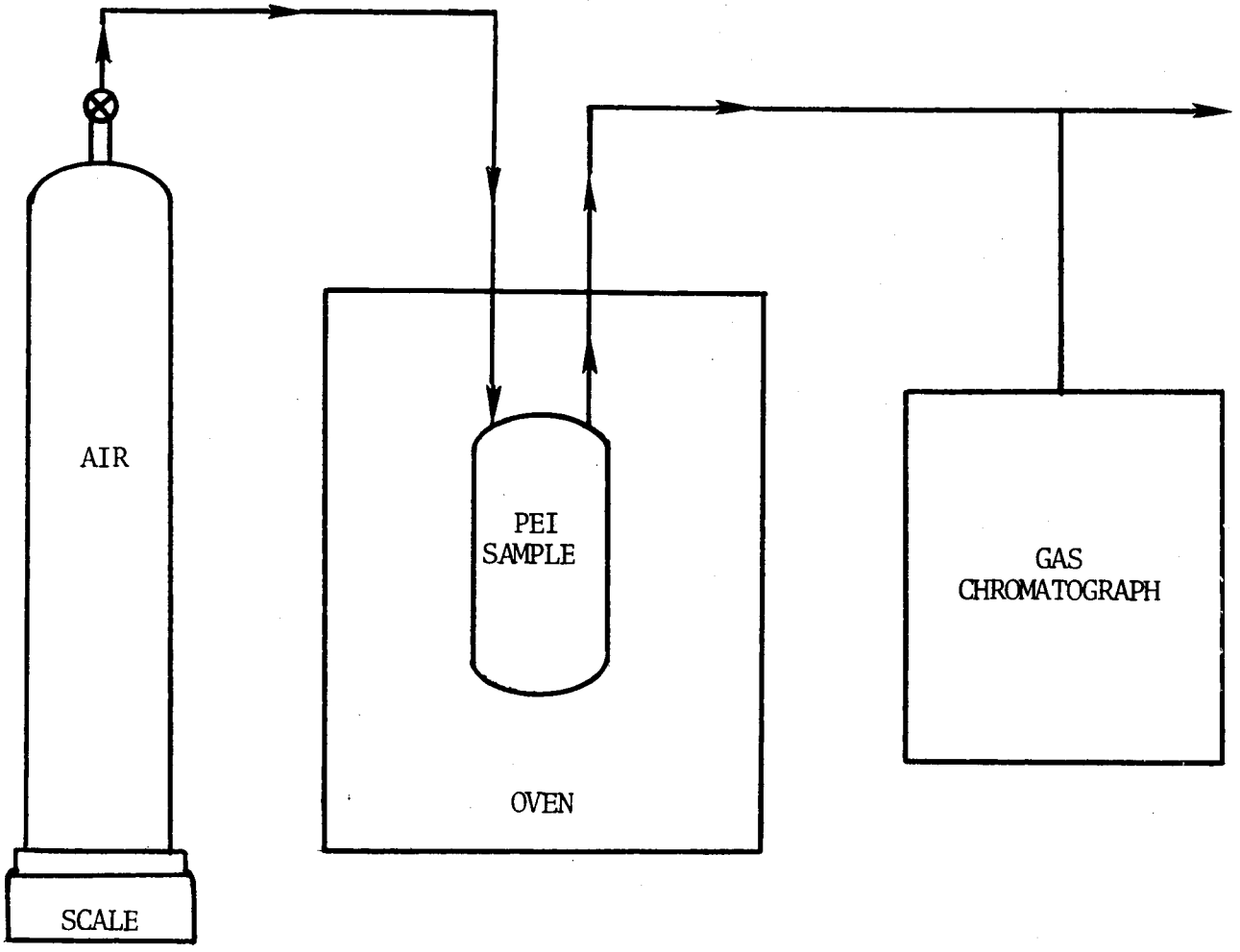
4. Samples of improved PEI will be tested for up to 200 hours to determine degree of improvement. A gas chromatograph will be used to determine ammonia production rate. The nominal temperature will be 150°F, however, temperature may be varied to accelerate testing if necessary.

5. None.

6. None.

Task 1.2

TEST APPARATUS



PLAN OF TEST

JOB: SOLID AMINE DEVELOPMENT PROGRAM PLAN PREPARED BY: F. Kester

PROJECT & ORDER: _____ APPROVED BY: J. Lovell

INSTRUCTION: Large Scale HS-C TEST ENGINEER: W. Conway

TIME PERIOD: Dec. 1972 TO March 1973

1. WHAT IS ITEM BEING TESTED?
2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?
3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.
4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.
5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.
6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1. 10 pounds HS-C prepared in-house.

2. To demonstrate feasibility of HS-C material for use on Shuttle for desiccant and CO_2 control in a full scale test.
   The objectives of the test program are:
   a. Material degradation under worst case mission profiles.
   b. Ammonia production rates under mission simulation.
   c. Ammonia scrubbing capability of HS-C.
   d. Nitrogen purging operating parameters for ground operation.
   e. Investigation of other toxicants (e.g., ethylene imine).

3. The conditioned air to the canister is run in a closed loop, i.e. air, effluent from the canister is reconditioned and becomes incoming air by the addition of water and CO_2. The CO_2 added is weighed and reported for each cycle.

   Air must be added to the loop once each cycle to compensate for the ullage lost during desorption; this air is weighed and reported.

   During the adsorption cycle the control valves will be as shown and air flow directed through the test canister. The CO_2 partial pressure at the canister inlet will be maintained constant by adding CO_2 under closed loop control. The CO_2 cylinder will be weighed [illegible]

Test Requirements

A. Test Equipment Requirements

Hamilton Standard test rig #88 will be used for this test program (see figure 1). It will provide a stream of conditioned air to the HS-C materials under test with automatically controlled pressure, flow rate, CO_2 partial pressure, dew point, and temperature. The conditioned air shall be maintained for the selected adsorption time while the canister is cooled by a constant temperature water coolant. At the expiration of this time desorption begins automatically with the isolation of the test canister from the conditioned air and the application of a high vacuum to the HS-C in its canister. The water coolant is maintained, and and heats the canister during desorption. The entire cycle is repeated until the results repeat, when the system is said to be in "cyclic equilibrium".

B. Reliability

The reliability of the test equipment must be such that the initial and final test runs are reproduced within the run tolerance (see item E below).

C. Loads

Not applicable.

D. Predicted Environments

Not applicable.

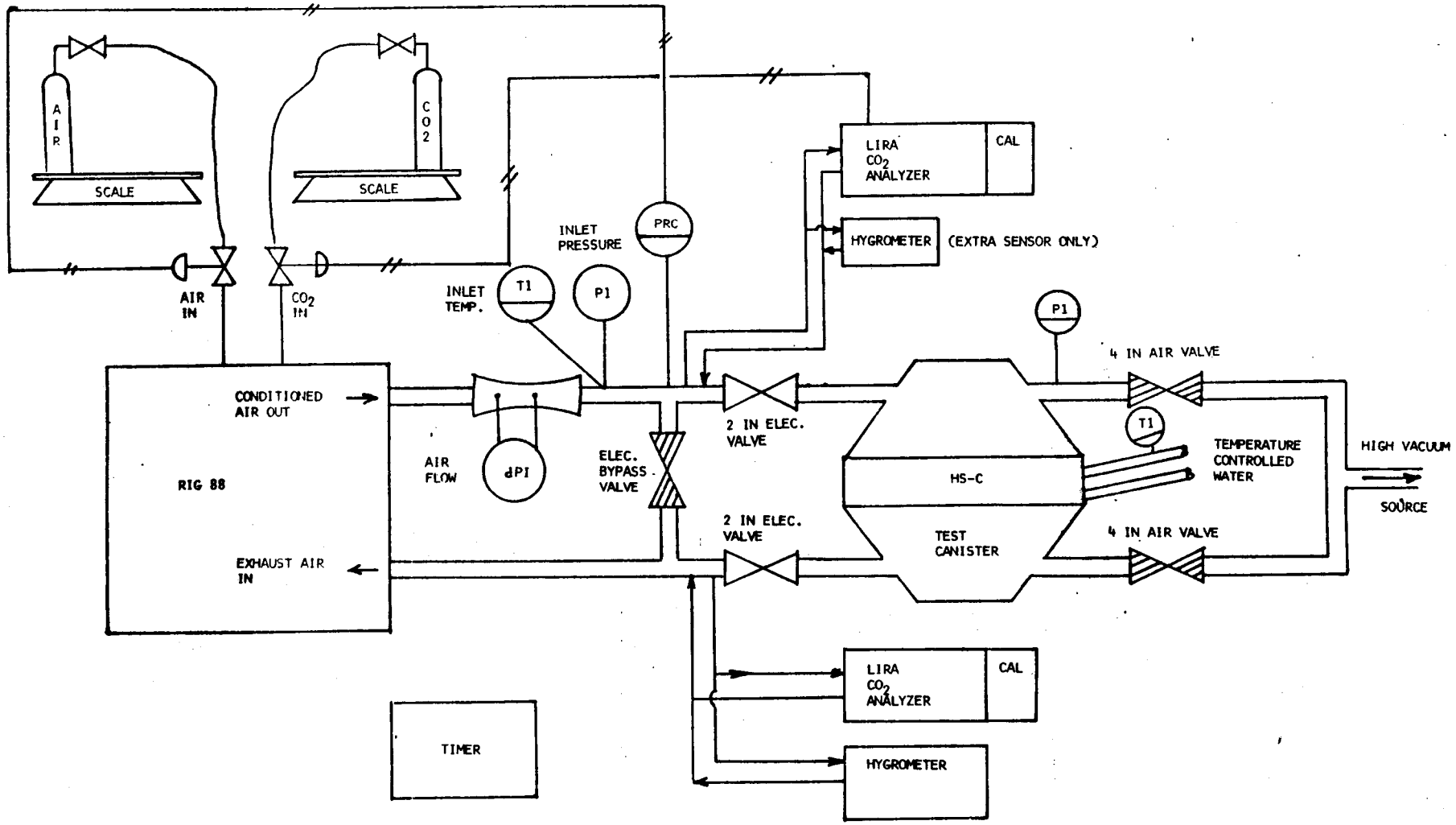
E. Allowable Tolerances

Each run shall be repeatable to the "run tolerance", defined as ± 10% on CO_2 and H_2O capacity.

F. Applicable Standards

None.

Dew point, pressure,inlet gas temperature, bed temperature and cycle times will be automatically controlled to test values by Rig #88. Desorption vacuum will depend on rig capacity.



RIG 88 SET-UP FOR HS-C

FIGURE 1

4. The HS-C canister is to be set up on Rig #88 as shown in figure 1. Rig #88 will be adjusted to give the desired experimental conditions during cyclic operation.

Required measurements are as follows:

	Units	
Cycle Time	Minutes	± 1% of Interval
Air Flow Rate	in H_2O Reported in CFM	± 10% of Flow
Inlet Temperature	°F	± 2°F
Inlet Pressure	psia	± 0.2 psia
Hygrometer (dew point)	°F	± 2°F
Water Temperature	°F	± 2°F
Inlet and Outlet CO_2	volts Reported as mm Hg	± 2% of full scale (full scale = 5 mm)
Weight CO_2 Added	lbs	± .02 lbs
Weight Air Added	lbs	± .02 lbs
Desorption Vacuum	Microns	± 5% of non-linear scale of Hastings gauge as calibrated for air
Ammonia Concentration	ppm	± 1 ppm

SERIES 1. PARAMETRIC PERFORMANCE TEST

Objective: A. To determine baseline performance to be used for comparative purposes.

B. To determine whether an ammonia sorbent is required as part of the HS-C subsystem.

Test Number	1	2	3	4	5
Bed Thickness	3"	3"	3"	3"	3"
Cycle Time - ad.	30	30	30	45	45
des.	30	30	30	45	Variable
Flow - cfm	40	40	60	40	40
Air Temperature °F	75	120	75	75	75
Bed Temperature °F	80	120	80	80	Variable
P_{CO_2} - mm Hg	3.0	5.0	5.0	5.0	5.0
Pressure - psia	14.7	14.7	14.7	14.7	14.7
Vacuum level - microns	20	20	20	20	20
Test duration - hours	48	24	24	24	48
Type of purge	vac	vac	vac	vac	N_2
Air dew point - °F	52	52	52	52	52

Special Measurements: Ammonia level in loop air and in humidifier to be measured daily.

If the ammonia level in the atmosphere leaving the HS-C canister exceeds 10 ppm during test number 2 an ammonia sorbent will be added to the system prior to further testing.

SERIES 2. MISSION SIMULATION

Objective: To determine effect of extreme mission temperature conditions on material performance.

Nominal Performance Conditions

Bed Thickness	3"
Cycle Time - ads.	30 min
des.	30 min
Flow	40 cfm
Bed Temperature	80°F
P_{CO_2}	5.0 mm Hg
Temperature dew point	52°F
Air Temperature	75°F

Procedure

Heat canister to 120°F for four hours. Return to nominal test conditions and run for three days.

Repeat above cycle seven times.

During the first and fourth simulations obtain sample of chamber atmosphere for trace contaminant analysis.

Continue to sample ammonia on a daily basis.

SERIES 3. EXTREME TEMPERATURE DEGRADATION TESTS

Objective: To measure performance degradation resulting from exposure to an extreme temperature.

Heat sealed canister to 150°F for twelve hours.

Test performance at nominal test conditions for twenty-four hours.

Repeat above cycle twice.

Obtain ammonia sample from canister just prior to cooling.

Obtain atmosphere sample for trace gas analysis.

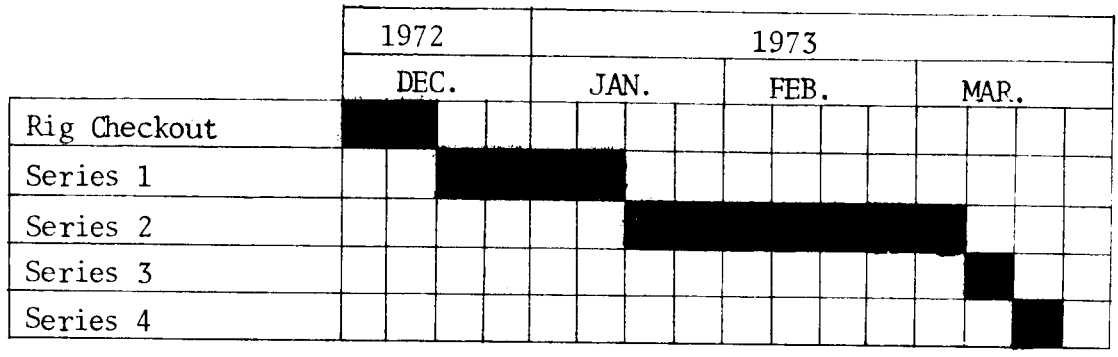
ACID GAS TESTS

SERIES 4.

Objective: To determine HS-C degradation resulting from trace contaminants.

Procedure

Trace quantities of hydrogen sulfide will be introduced into the system and testing continued under nominal conditions for four days.


1972
1973
DEC.
JAN.
FEB.
MAR.
Rig Checkout
Series 1
Series 2
Series 3
Series 4

SCHEDULE

APPENDIX G

DATA LOG SHEETS

FOR LARGE SCALE TEST

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 1 OF ___
DATE 1-19-73
ENGINEER WC
OPERATORS ___

RIG NO. 88
TYPE OF TEST Series II Material Series I Test
W.P.I. NO. ___

PLAN OF TEST NO. ECS-2131-L-011
SERIAL NO. Rev A
PART NO. ___

1-73	TIME	Begin of Cycle	FT Left on Roll	HRS On Test	lbs Wt CO2 Begin Ads	lbs ΔWt H2O End Ads	lbs Air Begin Ads	lbs Air End Ads	Min Time on Absorb	Min Time Desorb	μ End Des	°F Air Inlet	°F D.P. Inlet	°F Coolant Inlet	°F Coolant Outlet	mV ΔT Coolant	% Coolant Flow	"H2O Can ΔP	PSIA Ads Pres.	cfm Ads Flow	mm Hg PPCO2 Inlet	lbs CO2 Removed	% CO2 Capacity	% H2O Removed	lbs H2O Removed	% H2O Capacity
19	1200	*47	56	47.5	177.53	.10	143.63	.18	30.			75	52	81	82	-.133	16	3.60	14.70	40.	3.0					
19	1300	—		48.5	177.43		143.45		Shot down & Removed Bed From Rig. Found Beads Leaking From Bed																	
						Lost Approx 1.8 lbs of Beads.																				
			REPACKED BED & RESTARTED TEST																							
			Bed Size = 6.65 lbs.							HS-C SERIES IV																
29	1535	1	52	0	177.26		139.95		29.9	30	37	75	52	81	85	-.085	16	6.90	14.73	40	3.0					
	1615		—		177.08		139.58				—			80	VAR 70-85	—		—								
			—		—		—				—					—		—								
			—		—		—				—					—		—								
			—		—		—				—					—		—								
		↓	—	↓	—		—		↓	↓	—	↓	↓	↓	↓	—	↓	—		↓	↓					
		16	—	15	—		—				58															
		Rig Shot down — cause - low Pressure in loop - [illegible]																								
30	1030	17	45	16	175.24	.12				29.8	80	75	52.5	79	85	-.144	15.0	7.10	14.85	40	3.0					
30	1130	18	44	17	175.12	.105	135.12	.17	29.8	29.9	80	75	52.0	81	87	-.090	15.0	7.20	14.85	40	3.0					
30	1230	19	44	18	175.015	.105	134.95	.15	29.9	30.0	79	75	52	80	85	-.085	15.0	7.20	14.85	40	3.0					
30	1330	20	43	19	174.91	.11	134.80	—	30.0	30	79	75	52	80	87	-.023	15.0	7.25	14.65	40	3.0					
30	1430	Δ21	43	20	—	.11	—	—	30.0	30.0	74	75	52	80	86	-.065	24.0	7.25	14.85	40	3.0					
30	1530	*22	42	21	174.69	.11	134.48	.15	30.0		—	75	52	81	85	-.047	24.0	7.20	14.85	40	3.0					
30	1640	23	—	22	174.58	—	134.33 / 139.87	—			—			80		—										
			—	—	—	—	—	—		↓	—					—										
		38	—	37	—	.107 AVG	—	—	↓	30	82	↓	↓	↓	↓	—	↓	↓	↓	↓	↓					
31	0907	39*	35	38	172.86	.11	137.35	.16	30.2	30	82	75	52	80	85	-.020	24.0	7.30	14.85	40	3.0					
31	1008	40*	[illegible]	39	172.75	.11	137.19	.16	30.1	30	82	75	52	80	85	-.055	24.0	7.30	14.90	40	3.0					

REMARKS: * Ammonia Sample Taken on This cycle
Δ CO Sample Taken on This Cycle

PAGE NO. ___

REPORT NO. SVHSER 6185

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 2 OF ___
DATE 1-31-73
ENGINEER W.C.
OPERATORS ___

RIG NO. 52
TYPE OF TEST Series IV Material Series I Test
W.P.I. NO. ___

PLAN OF TEST NO. ECS-2131-L-011
SERIAL NO. Rev A
PART NO. ___

Date	UNITS →		FT	Hrs	Lbs	Lbs	Lbs	Lbs	MIN	MIN	μ	°F	°F	°F	°F	MV	%	H_2O	PSIA	CFM	mm Hg	Lbs	%	%	lbs	%
	TIME	Cycle No	Left on Roll	On Test	Wt CO_2 Begin Ads	Δ Wt CO_2 End Ads	Wt Air Begin Ads	Δ Wt Air End Ads	Time on Adsorb	Time on Desorb	Vac End Des	Air Inlet	Dew Point In	Coolant Inlet	Coolant Outlet	ΔT Coolant	Coolant Flow	Can ΔP	Ads. Press	Ads. Flow	$PPCO_2$ Inlet	CO_2 Removed	CO_2 CAR	H_2O Removed	H_2O Removed	H_2O CAP.
31	1109	41	34	40	172.64	–	132.03		30.1	30	82	75	52	82	84	-.025	24.0	7.25	14.[illegible]	40	[illegible]					
	–	–	–	–	–	–	–		↓	↓	–	↓	↓	↓	↓	–	↓	–	↓	↓	↓					
							136.56									–		–								
	1435	44	–	43	172.31	.115	136.00				–					–		–								
	1537	45	–	44		.115 Avg	–				–															
			–	–	172.08		–																			
			–	–																						
			–	–																						
			–	–																						
			–	–																						
			–	–					↓	↓	85															
1	0805	62	–	61	170.45				30	30		76	52	80	86	-.038	24	7.35	14.85	40	3					
			–	–	Correcting Vac Problem																					
					Changed to Test 6 Cond.					29.8	58															
1	1550	67	22	66	169.92	.10	132.17	.15	30.0			120	52	120	122	-.020	24	7.4	14.90	40	5					
			–	–	169.82		132.02																			
			–	–																						
			–	–																						
			–	–	Cycles 80 & 81 DID NOT HAVE A DESORB Time – PROBLEM with Rig 52 Timer on the VAC System was the cause																					
			–	–	APPROX. Time was 0530 2-2-73 Problem Corrected @0930																					
2	0823	83	15	82	168.45	.105	–	–	30.0	29.8	66	119	52	117	120	-.024	24	7.45	14.85	40	5					
2	0925	84	15	83	168.345	.105	129.67	.16	30.1	30.1	65	119	52	120	122	-.028	24	7.45	14.90	40	5					
2	1025	85	14	84	168.24	–	129.51	–	29.9	30	65	119	52	120	122	-.025	24	7.45	14.85	40	5					
2	1125	86 Δ	14	85	–	–	–	–	30.0	30.1	65	120	52	121	123	-.028	24	7.45	14.87	40	5					
2	1230	87 Δ	13	86	–	–	–	–	30.1	30.1	65	120	52	120	119	+.045	24	7.45	14.90	40	5					

REMARKS: Δ Ammonia Samples Taken on These Cycles

PAGE NO. ___
REPORT NO.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 3 OF ___
DATE 2-2-13
ENGINEER WC
OPERATORS ___

RIG NO. 58
TYPE OF TEST Series II Material Series I Test
W.P.I. NO. ___
PLAN OF TEST NO. ECS-2131-2-011
SERIAL NO. R-VA PART NO. ___

Cycle No.	Time	Cycle No.	Hrs Left on Roll	Hrs on Test	lbs Air CO_2 Begin Ads	lbs Δ Wt CO_2 End Ads	lbs Air Begin Ads	lbs Air End Ads	Min Time on Adsorb	Min Time on Desorb	in VAC End Des	°F Air Inlet	°F Dew Pt.	°F Coolant Inlet	°F Coolant Outlet	MV ΔT Coolant	% Coolant Flow	"H_2O Can ΔP	PSIA Ads Press	CFM Ads Flow	mm Hg $PPCO_2$ Inlet	lbs CO_2 Removed	% CO_2 CAP	% H_2O Removed	lb H_2O Removed	% H_2O CAP
2	1330	88 Δ	13	87	167.92	.105	128.02	.16	30.1	30.1	65	120	52	120	119	.036	24	7.45	14.90	40	5.0					
2	1430	89 Δ	13	88	167.815	.105	128.86	.15	30	30	6.5	120	52	121	122	+.035	24	7.50	14.90	40	5.0					
				Changing		Conditions To		Test #9																		
	1535	90	~	89	167.71	.16	128.71	.17	30.1	30	~	77	53	86	92	-.028	24	11.80	14.90	40	5.0					
		91	~	90	166.55	~	128.54 / 128.57	~	30.1	30	~	77	53	81	85	~	24	~	14.90	40	5.0					
4	9:30 am				166.49		146.66	CO_2 not being added								SHUT DOWN		RIG	REMOVED		40	cc	H_2O			
3		99		98	Shut down after cycle 99																					
5		Replaced Canister Gasket Drained Condenser and added 3950 ml 8000 ml H_2O - Removed 5000 H_2O																								
5	1615	100	~	99	166.33		145.92					75							14.85		5			For Sample prior to cycle 100		
		101	~	100	166.21		~					~							~		~					
		Line Failure on cycle 112 @ 0500 2-6-13 caused Rig To overpressurize and Rig shut down.																								
	0945	Removed 70 cc H_2O																								
6	1015	114 Δ	61	113	164.25		143.24	.16	30	30	28	75	52	81	85	-.002	27	~	14.90	52	5.0					
6	1127	115 Δ	61	114	164.05	.39	143.08	~	30	30	28	74	52	82	85	+.055	27	~	14.90	52	5.0	1.95	3 cycles			
6	1243	~	~	~	~		~	Avg .13	30	30	28	74	52	82	85	+.048	27	~	14.95	52	5.0					
6	1374	117 Δ	~	116	163.95		142.82	~	30	30	28	75	52	81	87	+.050	27	~	14.95	52	5.0					
		Changed To Test 4 Cans AFRA Cycle #118																								
1	1526	119	59	118	~		~	~	45	45	~	76	52	82	82	+.021	27	~	14.95	40	5.0					
		120	59	119.5	163.45		142.37	Avg .14	45	45	~	76	52	82	85	~	27	~	14.95	40	5.0	2.08	10 cycles			
7	1635	130 Δ	52	134.5	162.07	1.38	140.98	~	44.8	45.2	18	75	52	79	85	-.024	27	~	14.95	40	5.0	100 cc H_2O Sample Taken This Cycle				

REMARKS: Δ Ammonia Sample Taken ON These Cycles

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REPORT NO. STATSER 6185

LOG OF TEST
ENGINEERING LABORATORIES

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SHEET 4 OF ___
DATE 2-7-73
ENGINEER WC
OPERATORS ___

RIG NO. 88
TYPE OF TEST Series IV Material Series I Test (END) / Series II Test (START)
W.P.I. NO. ___
PLAN OF TEST NO. ECS 2131 2-011
SERIAL NO. Ser. 8
PART NO. ___

Day	TIME	CYCLE NO	FT Left on Roll	HRS on Test	lbs Wt CO2 Begin Ads	Lbs ΔWt CO2 End Ads	Lbs Wt Air Begin Ads	Lbs ΔWt Air End Ads	Min Time on Ads	Min Time on Des	μ Vac End Des	°F Air Inlet	°F Dew Pt	°F Coolant Inlet	°F Coolant Outlet	mV ΔT Coolant	% Coolant Flow	"H2O Can ΔP	PSIA Ads Press	CFM Ads Flow	mmHg PPCO2 Inlet	lbs CO2 Removed	% CO2 Cap	% H2O Removed	% H2O Removed	% H2O Cap
7		131	–	135.5	–	–	–	–	45	45	–	76	52	80	82	–	27		14.95	40	5.0		2.1	3 cycles		
7	1130	132	50	136.5	–	.14 AVG 3 cycles	–	–	45	45	–	76	52	80	82	–	27	–	14.95	40	5.0	100 cc H2O Sample Taken End of Cycle				
		132 END			161.65		140.57																			
		Isolate Can coolant @ 120°F For 4 hrs Start ... START of Series II Test 1st Temp Soak																								
	1830	132	–	139	161.53		139.57	–	–	–	–	–	–	–	–											
8	0800	151	–		159.40		136.70		VAC. Valve Did Not Close – Rig Shut down cause – Low Pressure.																	
					Removed Valve cleaned Replaced Started on Desorb @ 1040																					
									29.7	22																
8	1110	151	41	153	159.26		136.63		24	30	21	75	52	82	83	-.059	28		14.78	40	5.0	100 cc H2O Sample Taken End of Cycle				
8	1205	152	–	154	159.13		–		30	30	26	75	52	80	84	.000	28		14.75	40	5.0					
8	1307	153	–	155	158.99	.66	–	AVG .15 4 cycles	30.3	30	26	75	52	80	83	-.035	28		14.75	40	5.0		1.98			
	1408	154	–	156	–		–		30.3	30	26	75	52	80	83	-.028	28		14.75	40	5.0					
8	1510	155	39	157	158.73		136.02 / 135.87	.15	30.1	30	26	75	52	80	85	-.035	28		14.75	40	5.0					
8	1612	156	–	158	158.60		130.39	–	30	30	26	75	52	80	84	-.020	28		14.75	40	5.0					
																							1.9			
		171			.126 AVG 16 cycles	2.01 – 16 cycles	.59 AVG 16 cycles		30	30	26	75	52	80	84	–	28		14.75	40	5.0					
9	0837	172	31	174	156.59		126.25									–							1.88			
																						Added 2150 cc H2O End of Cycle				
		173	–	175	–	.5 (.125 AVG 4 cycles)	–									–						100 cc H2O Sample Taken End of Cycle				
		174	–	176	–											–										
		175 END	–	177	156.09		–																			

REMARKS:

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SVHSER 6185
REPORT NO.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 5 OF ___
DATE 2-9-7[illegible]
ENGINEER WC
OPERATORS ___

RIG NO. 88
TYPE OF TEST Series II Material Series II Test
W.P.I. NO. ___
PLAN OF TEST NO. [illegible]
SERIAL NO. Kent
PART NO. ___

UNITS → / TIME	Cycle No	[illegible]	Test	lbs WT CO_2 Begin ADS	lbs ΔWT CO_2 End ADS	lbs WT Air Begin ADS	lbs Cur Air End ADS	min Time on Absorb	min Time on Desorb	VAC End Ads	Air Inlet Temp	Dew Pt	Coolant In	Coolant Out	Coolant ΔT	% Coolant Flow	H_2O Can ΔP	PSIA ADS Press	ADS Flow	mmHg PP CO_2 Inlet	lbs CO_2 Removed	CO_2 ΔP	% H_2O Removed	lbs H_2O Removed	[illegible]
	176	-	178	156.09	↑	-		30	30	-	75	52	80	81	-	28	-	14.75	40	5.0		↑			
	177	-	179	-	.40 (12 AVG 4 CYCLES)			30	30	28	75	52	80	81	-.004	28	-	↓	↓	↓		1.81			
1445	178	-	180	155.85		125.35		↓	↓	-	↓	↓	↓	↓	-	↓	-	↓	↓	↓	Added	350 cc	on this cycle		
1547	179	-	181	-	↓	-		↓	↓	-	↓	↓	↓	↓	-	↓	-	↓	↓	↓		↓			
	180	-	182	155.61 / 181.54		141.05		↓	↓	-	↓	↓	↓	↓	-	↓	-	↓	↓	↓	H_2O = 7350				
930	228 *	-	230	177.01		137.84															TOTAL H_2O [illegible]		= 6250 ml		
	230	-	232	176.91	↑																	↑			
					2.77	* FOR 22	CYCLES =	.126 #/CYCLE =	1.9% CO_2 CAP													1.9			
12 0830	251 B	-	253	174.25		134.61	-	30	30	-	75	52	80	81	-	28	-	14.75	40	5.0	TOTAL H_2O Added 5000 ml		3000 ml Took 100 ml Sample		[illegible]
	251 E	New R[illegible]	254	174.13	↓		1 hr	120°F Soak			CAN	IN ISOLATE		2nd Temp Soak								↓			47.7%
12 1330		99				START UP	ON DESORB		30																
12 1400	252	-	254	-		-	-	30	30	-	75	52	86	87	-	28	-	14.75	40	5.0					
12	253	98	255	173.95		134.02		↓	↓	-	↓	↓	85	86	-	↓	-	↓	↓	↓					
12	254	-	-	173.85		-		↓	↓	-	↓	↓	79	81	-	↓	-	↓	↓	↓	added		400 ml H_2O		
13	270	-	-	171.81		-		↓	↓	-	↓	↓	80	80	-	↓	-	↓	↓	↓	added to bring		1200 ml H_2O total to 8000		
				CO_2 CAP		CYCLES		254 - 269 =		2.015# = 1.89%			H_2O CAP =		1200/454 x 6.65 x 16 =					2.48%			100 cc Sample Taken Before 270		
13	273	-	275	-		130.72 / 127.89																			
								30	30	25	75	52	81	80		28		14.8	40	5					cycle 277
13 1600	278	-	280	170.79		CO_2 CAP 270-278 = 1.02# = 1.91%							H_2O Cap	270-278						3.6%					
[illegible]	293	80	295	[illegible]				30	30	26	[illegible]	[illegible]				[illegible]		[illegible]	40	[illegible]	Added 2300 ml H_2O (5700 ACT) To bring total to 8000 ml				
				CO_2 CAP	[illegible]			[illegible]		1.77		97%			cycles 278-293		[illegible]			[illegible]	Took [illegible] sample before 293				

Right margin: 7900 / 8000 / ~~8000~~ / 7900 / 7030 / 7900

REMARKS:

* H_2O pump not operative for cycles 180 through 227

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Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 6 OF ___
DATE 2/14/73
ENGINEER [illegible]
OPERATORS ___

RIG NO. [illegible]
TYPE OF TEST [illegible] Material [illegible] II Test
W.P.I. NO. ___
PLAN OF TEST NO. ECS-2/31-L-011
SERIAL NO. [illegible]
PART NO. ___

Day	Time	[illegible]	[illegible]	[illegible]	lbs CO2 Begin Ads	lbs Out CO2 End Ads	lbs Wt Air Begin Ads	lbs Wt Air End Ads	Min Adsorb	Min Desorb	M Vac End Des.	°F Air Inlet	°F Dew Pt	°F Coolant Inlet	°F Coolant Outlet	MV Coolant ΔT	Flow	H2O ΔP	PSIA Ads Press	CFM Ads Flow	mm Hg pCO2 Inlet	Notes	
										30									14.9	40			
14	1305	297	-	299	168.32	↑	120.88	-	30				52	81	80		28	4.07%	[illegible]	40	5.0	Drained out 7416 ml of H2O Replaced into DP System	7416
						.38 = .126 AVG FOR 3 CYCLES = 1.9% CO2 CAP																	
						↓																Drained out 7093 ml Replaced into DP Loop	7093
14	1615	300	77	302	167.94	↑	120.32	-	30	30	-	75	52	80	80		28	-	14.9	40	5.0		
						2.0 = .125 AVG FOR 16 CYCLES = 1.88%																	
						↓							52		cc H2O							Drained 5905 ml [illegible] Added 2095 To make 8000 Took 100cc Sample	7900
15	0845	316	-	318	165.94	↑	130.54		30	30	-	[illegible]	316		74/cycle		28	-	14.9	40	5.0	Add Flow meter To H2O Line To	
						.95 = .135 avg for 7 cycles = 2.04%																Evaporator - 11.5% [illegible]	
						↓							52		cc H2O							Drained 7163 ml From DP Loop Replaced into DP Loop	7163
15	1600	323	-	325	164.99	↑	-		30	30		[illegible] - 323			113/cycle		28	-	14.8	40	5.0		
						2.05 = .128 AVG FOR 16 CYCLES = 1.93%																	
						↓							52									Drained 5810 ml from DP Loop Added 2190 to make 8000 ml Took 100cc Sample	7900
16	0805	339	-	341	162.94	↑	122.92		30	30		323-339			84/cycle		28	-	14.9	40	5.0		
						.125	= 1.88%																
						↓																Drained 7850 ml From DP Loop Replaced	7850
16	0905	340	-	342	162.815		-		30	30		Increase DP To 57°F					50 cc/cycle						
		345	-	347		at End of 345 DP Changed To 52°F																	
16	1625	346	-	348	161.94				30	30			52	81	80		28	-	14.9	40	5.0		
																						Replaced with 8000 ml.	
19	1100	347	-	349	160.43		119.01		30	30		76	52	81	80		28	-	14.9	40	5.0	Drained 100 CC	
		348	-	350	160.13	.25	118.64	.37	30	30	-	76	52	81	80		28	-	14.8	40	5.0		
		349	-	351	160.03	.15	118.47	.17	30	30	-	↓	↓	81	80		↓		↓	↓	↓		
		350	-	352	159.92	.11	-	-	30	30				82	81							Drained 3350 ml After Cycle 351	
20	0900	352	-	354	-	-		-	30	15	80			81	81							Added 4850 ml Took 100 cc Sample	7980

REMARKS:

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Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 7 OF
DATE 2-20-73
ENGINEER WC
OPERATORS

RIG NO. 6
TYPE OF TEST Seaco Material Series II Test
W.P.I. NO.

PLAN OF TEST NO. ECS-2131-L-011
SERIAL NO. Rev A
PART NO.

Feb 73	TIME	Cycle No	Ft Left on Unit	Hrs on Test	lbs Wt CO2 Beg Ads	lbs ΔWt CO2 End Ads	oz Wt Air Beg Ads	lbs ΔWt Air End Ads	min Ads	min Des	VAC End Des	Air Inlet	Dew Pt Inlet	°F Coolant Inlet	°F Coolant Outlet	MV ΔT Coolant	% Coolant Flow	"H2O Can ΔP	psia Ads Press	cfm Ads Flow	mmHg PPCO2 Inlet	lbs CO2 Removed	% CO2 Cap	% H2O Removed	lbs H2O Removed	% H2O Cap
20	1645	353	47	354	159.335	↓	-	-	30	16	84	76	52	81	81	-	28		14.9	40	5.0					
		354		355	-		-		30	16	88	↓	↓	↓	↓	-	↓		↓	↓	↓					
		355		356	-	.715 = .119 Avg 6 cycles = 1.79%			30	17	78					-										
		356		357			-	-	30	30	27					-										
20	1415	357		358	158.885		129.17	-	30	30	27	76	52	82	80	1.022	28	-	15.1	40	5.0					
20	1515	358 B		359	158.75		-	-	30	30	26	75.5	52	80	85	-	28	-				Drained 7068 ml From DP Added 932 ml To make 8000 ml				
		358 E		360	158.61	↓	-	-	-	-	-	-	-	cycle 352 - 358			139 cc/cycle					100 cc Sample Taken				
						Isolate Can		Coolant @ 120° for 4 hrs Start @ 0830									3rd Temp Soak									
						Start with 30 min Desorb after Temp Soak																				
21	1300	359	43	360	158.585		-	-	30	30	-	75	52													
		361			158.29	.148 2 cycles	-	-	30	30	-	75	52									another 100 cc Sample Taken				
22	0830	378	30	379	156.12	.127 Avg 17 cycles	-	-	30	30		75	52									Drained 5500 ml from DP				
		379			155.91		-	-	30	30		75	cycle 359 - 378		2300 ml/20 cycles = 115 cc/cycle							No addition (run dry)				
									[illegible] with [illegible] in DP Loop					cycles 378-385				Took gas sample on cycles 383, 384, 385					Filled DP Loop after 385				7900
22	1635	386			155.165		-	-	30	30		75	52	80	80	-	28	-	14.95	40	5.0					
23	1005	403	23	404	153.[illegible]	.127 Avg 17 cycles	-	-	30	30	-	75	52	80	80	-	28		14.95	40	5.0	Drained 575[illegible] ml From DP Added 2250 ml Took 100 cc Sample				7900
23	1515	408 B	21	409	152.36		-	-	30	30	-	75	52	80	80	-	28		14.95	40	5.0	Drained 7660 ml From DP Added [illegible] Took 100 cc [illegible]				7900
		408 E																								
					Isolate Can		Coolant @ 120°F For 4 hrs					Start @ 1020				4th Temp Soak										

REMARKS:

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REPORT NO.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 8 OF ___
DATE 2-26-73
ENGINEER CWC
OPERATORS ___

RIG NO. 88
TYPE OF TEST Series IV Material Series II Test
W.P.I. NO. ___
PLAN OF TEST NO. ECS 2131-L-011
SERIAL NO. Rev A
PART NO. ___

Feb 73	TIME	Cycle #	FT Left on Roll	HR on Test	lbs CO_2 Begin ADS	lbs ΔW CO_2 End ADS	lbs W Air Begin ADS	lbs ΔW Air End ADS	MIN ADS	MIN DES	μ VAC End DES	°F Air Inlet	°F Dew Pt.	°F Coolant Inlet	°F Coolant Outlet	MV ΔT Coolant	% Coolant Flow	"H_2O Can ΔP	PSIA ADS Pres	CFM ADS Flow	mmHg $ppCO_2$ Inlet	lbs CO_2 Removed	% CO_2 Cap	% H_2O Removed	lbs H_2O Removed	% H_2O Cap	Notes
26	1440	409		410	152.165				30	30	-	75.5	52	80	80		28	-	14.95	40	5.0		D.P. H_2O Pump off From cycle 409-427				
27		427		428	150.10				30	30	26	75	52	80	80		28		15.0	40	5.0	After cycle 430	(Drained 6630 ml from DP, Added 1400 ml Took 100cc sample				7900
27		433*		434	149.39	.118 AVG 6 cycles			30	30	26	75	52	80	80		28		15.0	40	5.0						
28		451		452	147.19	.120 AVG 18 cycles			30	30	-	75	52	80	80		28		15.0	40	5.0		After cycle #450 Drained 5900 ml from DP loop Added 2160 ml Took 100cc sample				7900
																	(100 cc/cycle avg on 20 cycles)										
	1800	453 F		453	146.82	.123 AVG 3 cycles																					
							Isolate	Can	Coolant @ 120°F		For 4 Hrs		Start @ 1955				5th	Temp	Soak								
		454		453	146.73				30	30	-	74	52	80	80		28		15.0	40	5.0		After cycle 453 Drained 1600 ml from DP Added 400 ml Took 100cc sample				7900
	0815	468		469	144.93	.128 AVG 14 cycles			30	30		74	52	80	80		28		15.0	40	5.0		After cycle 469 Drained 6270 from DP loop Added 1790 ml Took 100cc sample				7900
																	1.5 cc/cycle avg 16 cycles.										
		470		471	-	-	-	-	30	30		74	52	80	80		28		15.0	40	After cycle 470		Drained Dew PT loop Replaced with 5000 ml clean H_2O - circulated H_2O 15 min Took 100 cc sample				7900
	[illegible]	471		472	-				30	30		75	52	80	80		28		15.0		5.0						
	[illegible]	472	51	473	144.43																						
		473Δ	794 Rd	474	-				↓	↓		75	52	80	80		28		15.0	20	5						
		474Δ		475	-				↓	↓				↓	↓		↓		↓	↓	↓						
		475Δ		476	-	-	-		↓	↓				↓	↓		↓		↓	↓	↓						
		[illegible]		477	142.24				30	30		75	52	↓	↓				15	20	5						

REMARKS: * Gas Sample for Trace Contaminant Analysis [illegible]
Δ Gas Sample for [illegible]

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PAGE NO.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 9 OF ___
DATE 3-2-73
ENGINEER [illegible]
OPERATORS ___

RIG NO. 88
TYPE OF TEST Series II Material Series II Test
W.P.I. NO. ___
PLAN OF TEST NO. ECS 2131-L-011
SERIAL NO. Rev A
PART NO. #5

DAY	TIME	CYCLE #	FT LEFT ON BOTT	HR ON TEST	lbs WT CO2 Begin ADS	lbs ΔW CO2 End ADS	lbs WT AIR Beg. ADS	lbs CUT AIR End ADS	MIN ADS.	MIN DES.	μ VAC End DES	°F (7) AIR INLET	°F DEW PT	°F (4) COOLANT INLET	°F COOLANT OUTLET	MV COOLANT ΔT	% COOLANT FLOW	"H2O ΔP CAN	PSIA ADS PRES	CFM ADS FLOW	mmHg PP CO2 INLET	lbs H_2O Removed	% CO2 CAP	% H_2O Removed	lbs H_2O Removal	% H_2O CAP
2		492	98	493	192.04	.119 avg/cycles	—	—	30	30		75	50.5	80			29	—	15.0	20	5	Drained 5250 ml from DP loop End of cycle 491 Added 2250 ml Took 100cc sample 7900				
2		493*	-	494	-	-	-	-	↓	↓		↓	↓	↓			↓	102 cc/cycle avg 21 cycles	↓	↓						
2		494*	-	495	-	-	-	-																		
2		496*	-	497	-	-	-	-																		
2	1517	498	-	499	141.31	.121 avg 6 cycles			30	30		75	52	80			28		15	20	5.					
3	2045	526E	–	528	137.78	-			↓	↓		↓	↓	↓			↓		↓	20		Drained 1730 from DP loop END OF CYCLE 520				
3	2050	527	–	528	183.65	- New bottle of CO_2														20						
5	0810	561	–	562	179.57	.120 avg/13 cy			30	30		75	52	80			28 (99.5 ml/cycle avg 13 cy)					Added 8000 ml of NEW DIST WATER				
	1420	563	–	563	179.29	-			6th Temp soak			Baked 4 hrs @ 120°F						drained		1000 ml and replaced with H_2O						
6	1000	581	–	582	177.10	.122 avg/18 cy											142 ml/cycle			40 avg. 19 cy		drained 5360 ml from DP loop added 2700 ml took 100 ml sample 7900				
																				40						
7	850	603	–	604	174.42	.122 avg/22 cy.								(204 ml/cycle avg. 22 cy)						20		drained 2450 ml replaced with 3000 ml [illegible] sample				
8	930	625 / 626	–	626 / 627	171.66	.120 avg/23 cy.			30	30		75	52 / 60.0				28		15	15 / 20		—(about flow possible with rig) Fresh H_2O				
8		627	–	628	–	–			↓	↓			60.0	↓			↓			20	5.0					
8		628	–	629	–	–							60.0							40						
8		629	–	630	–	–							60.0							40		drained 2200 ml. LEFT DRY				
		630	70 psi	631	–								52.0							20		(211 ml/cycle avg 23 cy.) Taken gas sample				
		631*	-	632	–	–							49.3									dry				
		632*	-	633	–	–							51.5									dry (overnight also)				
		633*	-	634	170.87	.113 avg/7 cy							52													
									↓	↓		↓		↓			↓		↓	↓	↓					
		648*		649	169.20	.111 avg/15 cy.			30	30		75	51	80			28		15	20	5.0					

REMARKS: * Gas Sample for Ammonia Taken on These Cycles

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REPORT NO.
SVHSER 6185

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 10 OF ___
DATE 3-9-73
ENGINEER R Phillips
OPERATORS ___

RIG NO. 87
TYPE OF TEST Series IV Material, Series I Test
W.P.I. NO. ___
PLAN OF TEST NO. ECS 2131-6-011
SERIAL NO. Rev A
PART NO. ___

MAR	TIME	CYCLE #	FT. LEFT BED	HR ON TEST	lbs WT of CO2 BEGIN ADS	lbs ΔWT CO2 END ADS	lbs WT AIR BEGIN ADS	lbs WT AIR END ADS	MIN ADS	MIN DES	μ VAC END DES	°F AIR INLET	°F DEW PT.	°F COOLANT IN	°F COOLANT OUT	MV COOLANT ΔT	% COOLANT FLOW	"H_2O ΔP CAN	PSIA ADS PRESS	CFM ADS FLOW	mm Hg P_{CO_2} INLET	lbs CO_2 removed	% CO_2 EFF.	% H_2O removed	lbs H_2O retained	% H_2O
12	8:30	716 *		717	163.03	6.17	(.091# CO_2 avg 68cy)		30	30	-	75	dry	80	80	-	28	-	15.0	20	5			dry		
		717*		718	—	-	-	-	30	30																
		718*		719	162.76	-	(.09# CO_2 avg 3cy)								INJECTED 100 CC of NH_3 (GAS) INTO RIG											
		740		741	160.93	-	(.087 CO_2 avg 21cy)			30	17.5	75	22 dry	80	80		27		14.85	20	5	1.83		dry		
										7TH TEMP SOAK 4 HRS @ 120 °F																
		742		743	160.71 }				30	30		75	52	80	80	-	28	-	15.0	Added 7900 ml H_2O (retained 100ml for analysis)						
		758		759	158.85 }		(.116# CO_2 avg 19cy)					75	52	80	80		28		15.0		5.0	1.86	removed 6100 ml added 7900 mix			
		761		762	158.51 }																					
15		781		782	156.20		(.116# CO_2 avg 20cy)		30	30		75	52	80	80		28		14.85	removed 5750 ml, retained 100 ml for anal, replaced with 7900 ml of mix (100ml to anal)						
		784*		785	—						27								14.89		5.0					
		785*		786	—														14.92		5.0					
		786*		787	—														14.92		5.0	removed 5250, retained 100 ml for anal, replaced with 7900 ml of mix (100ml for anal)				
16		804		805	152.96																					
		805	39	806	153.45	(.11/cy)	room air **		30	30	27	75	45	80	80	-	28	.	14.93	20	5.0					
		806		807			"	"	"	"	26	75	45	80	80		28		14.93	20	5.0					
		807		808	153.42	(.115 CO_2 avg 2cy)																				
									Changed Venturi #5653 *																	
		808		809	153.10		Pumped room air		30	30	-	75	45	80	80		28		14.93	15*	5.0					
		809		810	~						-		"							15	5.0					
		810		811	152.93	(.085/cy)					24		52							10	5.0					
		811		812	152.82	(.11/cy)					24		52							10	5.0					
		814		815	152.47	-					~		52							20	5.0					
		815		816	152.36	(.11/cy)			30	30	-		52	80	80		28			20	5.0					

REMARKS: * Gas sample taken
** STORED ATMOSPHERE (CO_2 Free) DELETED - SWITCHED TO ROOM AIR

PAGE NO.

REPORT NO. SVHSER 6185

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 11 OF ___
DATE 3-16-73
ENGINEER J. Lovell
OPERATORS R. Petillo

RIG NO. 88
TYPE OF TEST Series IV Material, Series II test
W.P.I. NO. ___
PLAN OF TEST NO. ECS 2131-6-011
SERIAL NO. ___ PART NO. ___

(7)

MAR	TIME	CYCLE #	Ft LEFT ON ROLL	HR ON TEST	lbs Wt CO2 Begin Ads	lbs ΔWt CO2 End Ads	lbs Wt Air Begin Ads	lbs Wt air End Ads	MIN Ads	MIN Des	μ Vac. End Des	°F Air Inlet	°F Dew Pt.	°F Coolant In	°F Coolant Out	MV Coolant ΔT	% Current Flow	"H2O ΔP Can	PSIA Ads Press	CFM Ads Flow	mm Hg PCO2 Inlet	lbs CO2 Removed	% CO2 Cap	% H2O Removed	lbs H2O Removed	% H2O Cap
19	9:30	873		874	145.76	.113/cy (58 cycles)	ROOM		30	30	26	75	52	80	80		28		14.93	20 2850 ml	5.0 H2O removed	added 8000 mix minus 100 ml sample				
		874		875	145.22		ROOM		30	30	25	75	52	80	80		28			10	5.0	GAS SAMPLE} 20cc/min for				
		875		876	–		"		"	"	24.5	"	"	"	"		"			10	5.0	" " } 50 min Total = 1000cc				
20		895		896	143.35	.093/cy (20 cycles)	Room		"	"		"	"	"	"		"		↓	10 6250 ml	H2O removed added 8000 ml mix minus 100 ml sample					
									8TH HEAT SOAK 120°F, 4 HRS.																	
		895*		896	142.08		Room air		30	30	–	75	52	95→80	95→80		28		14.93	20	5.0					
		896* 897*		898	142.38	.15/cy (2 cy)			30	30		75	51.5	80	80		28			20						
21		912		913	140.67	.114/cy (15 cy)			30	30		75	51.5	80	80		28			20		removed 6240 ml H2O, add 8000 ml mix minus 100 ml sample				
		917		918	140.07	.120/cy (5 cy)			30	30		75	51.5	80	80		28		↓	20	↓					
		~~918~~			~~139.85~~				CHANGED VENTURI TO #5654 HI FLOW																	
		919		920	139.85		Room air		30	30	60	75	52.5	80	80		28		14.93	40	5.0	removed 5050 ml H2O, add 8000 ml mix minus 100 ml sample				
22		935		936	137.97	.118/cy (16 cy)			30	30	24	75	52	80	80		28			40						
		939 END		940	137.39	.118/cy (5 cy)			"	"		"	"	"	"		"			40						
		940		941	214.55				"	"		"	"	"	"		"			40		INTRODUCED approx 500 cc of H2S TOTAL				
		942		943	214.20				"	"		"	"	"	"		"			40						
23	7:30	958		959	212.37	.114/cy (16 cy)			30	30	28	75	52	80	80		28			40		removed 5900 ml H2O, add 8000 ml mix minus 100 ml sample				
		964		965	210.65	.29/cy (6 cy)			"	"	38	"	"	"	"		"			40						
		965		966	210.53	.12/cy (1 cy)			"	"	—	"	"	"	"		"			60						
		966		967	210.43	.11/cy (1 cy)			"	"	—	"	"	"	"		"			40						
		1029			204.31				"	"	–	"	"	"	"		"			40		Removed 1000 ml H2O - added 8000 ml H2O mix				
24		1031*		1032	204.17	↑ .125 Avg 2 cycles			30	30	28	75	52	80	80		28			40						
		1032*		1033	204.07	.25 = ↓ .10/cy (1 cy)			"	"	38	"	"	"	"		"			60						
		1033			203.12	.15/cy (1 cy)			"	"		"	"	"	"		"		↓	60	↓					

REMARKS: * Gas sample taken

PAGE NO. ___

REPORT NO. SVHSER 6185

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 12 OF
DATE 3-26-73
ENGINEER J. Revell
OPERATORS R. Petillo

BIG NO. 88
TYPE OF TEST Series IV Material, Series II Test
W.P.I. NO.

PLAN OF TEST NO. ECS 2131-6-011
SERIAL NO. PART NO.

MAN	UNITS → TIME	CYCLE	FT LEFT ON REEL	HR ON TEST	lbs Wt of CO_2 Begin Ads	lbs Δ Wt. CO_2 End Ads	lbs Wt AIR Begin Ads	lbs Wt AIR End Ads	MIN Ads	MIN Des	μ Vacuum End Des	°F AIR INLET	°F DEW POINT	°F COOLANT IN	°F COOLANT OUT	MV COOLANT ΔT	% COOLANT FLOW	"H_2O ΔP CAN	PSIA ADS PRESS	CFM ADS FLOW	MM Hg P_{CO_2} INLET	lbs CO_2 Removed	% CO_2 CAP.	% H_2O Removed	lbs H_2O Removed	% H_2O CAP.
26		1034			203.86	.16#/cy (1 cy)		ROOM	30	30	28	75	52	80	80		28		14.95	40	5.0					
		1035			203.74	.12#/cy (1 cy)			↓	↓	↓	↓	↓	↓	↓		↓		↓	60	↓					
		1036			203.62	.12#/cy (1 cy)					27									60						
		1037			203.48	.13#/cy (1 cy)					↓									↓						
		1042			202.75	.146#/cy (5 cy)																				
									150°F HEAT SOAK 12 HRS (1ST SEGMENT) START AT 10:45 PM																	
27		1043*	1044	1044	202.75			Air Room	END OF SOAK 150°F HOT GAS SAMPLE TAKEN END AT 10:45 AM																	
28		1045		1046	202.55	.100#/cy (2 cy)			30	30	27	75	52	80	80		28		14.95	40	5.0	Removed 6100 ml H_2O, added 8000 ml				
		1047		1048	202.34	.11/cy (2 cy)			"	"	"	"	"	"	"		"		↓	"	↓					
		1048		1049	202.22	.12/cy (1 cy)			"	"	←	"	"	"	"		"			"						
		1054		1055	201.49	.12/cy (6 cy)			150°F HEAT SOAK 12 HRS (2nd SEGMENT) START AT 11 PM																	
		1055		1056					END OF 12 HR 150°F SOAK HOT GAS SAMPLE TAKEN. END AT 11 AM																	
28		1056		1057	201.45			room air	30	30	10	[illegible]	52	95	95		28		14.95	40	5.0	Removed 7100 ml H_2O, added 8000 ml				
		1058		1059	201.17	.14/cy (2 cy)			"	"	28	75	52	80	80		28			40						
		1059		1060	201.05	.12/cy (2 cy)					–									"						
		1075		1076	199.13	.12/cy (16 cy)					–									40						
		1076		1077	–	–			"	"	–	"	"	"	"		"			40						
29		1077		1078	–	–					–									60						
		1078		1079	–	–					–									60						
		1081		1082	–	–					–									60						
		1082		1083	–	.12/cy (13 cy)					–									40						
		1089		1090	–	–			3d HEAT SOAK 150°F FOR 12 HRS START AT 10:45 PM 3/29/73																	
30		1090		1091	–	–			HOT GAS SAMPLE TAKEN AT END OF SOAK																	

REMARKS: * GAS SAMPLE TAKEN

PAGE NO.

REPORT NO. SWISER 6185

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

LOG OF TEST
ENGINEERING LABORATORIES

SHEET 15 OF ___
DATE 3-30-78
ENGINEER J. LOVELL
OPERATORS R. PETILLO

BG NO. 88
TYPE OF TEST SERIES IV, MATERIAL II, TEST
W.P.I. NO.

PLAN OF TEST NO. ECS 2131-6-011
SERIAL NO. ___ PART NO. ___

UNITS →				LBS	LBS	LBS	LBS	MIN	MIN	IN.	°F	°F	°F	°F	MV	%	"H2O	PSIG	CFM	mm Hg	LBS	%	%	LBS	%
TIME	CYCLE	FT LEFT ON ROLL	HR ON TEST	WT CO_2 BEGIN ADS	ABS CO_2 END ADS	WT AIR BEGIN ADS	WT AIR END ADS	ADS	DES	VAC END DES	AIR INLET	DEW POINT	COOLANT IN	COOLANT OUT	COOLANT ΔT	COOLANT FLOW	ΔP CAN	ADS PRESS	ADS FLOW	PP CO_2 INLET	CO_2 REMOVED	CO_2 CAP.	H_2O REMOVED	H_2O REMOVED	H_2O CAP
30	1091	–	1092	197.21	ROOM AIR			30	30	27	75	52	80	80		28		14.95	40	5.0					
	1092	–	1093	196.09	.12 #/cy (1 cy)														40						
	1093	–	1094	195.97						27									20						
				195.88	.09 #/cy (1 cy)																				
	1094	–	1096	195.72		ROOM AIR		30	30	–	75	52	80	80		28		14.95	40	5.0	CO_2 flooded loop - switched to Sensing				
	1095	–	1096	195.58						–															
	1111	–	1112	194.80	? .05 #/cy (16 cy)					–											CO_2 - OK				
	1114	–	1115	194.48	.16 #/cy (3 cy)					–		53													
	1115	–	1116	–						–															
	1116	–	1117	194.24	.36 ÷ .12 AVG 3 CYCLES					–															
	1117	–	1118	194.12	.12 #/cy (1 cy)			30	30	26	75	53	80	80		28			40	5.0					

REMARKS:

PAGE NO.

REPORT NO.