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HYDROGEN PEROXIDE EVALUATION

L.P.BARCLAY, Capt, USAF

TECHNICAL REPORT NO. AFRPL-TR-68-208

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AIR FORCE ROCKET PROPULSION LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA

AFRPL-TR-68-208

HYDROGEN PEROXIDE EVALUATION

L. P. Barclay, Capt, USAF

FOREWORD

This report covers the work on Project 314803107, Hydrogen Peroxide Evaluation, by the Exploratory Evaluation Branch in the Propellant Division of the Air Force Rocket Propulsion Laboratory from 1 October 1965 to 30 April 1966. The Project Engineer was Lewis P. Barclay, Capt, USAF.

The analytical work and reports of the following are gratefully acknowledged: E. I. DuPont De Nemours and Company, Inc., Food Machinery and Chemical Corporation, Shell Development Company, and Thiokol Chemical Company-Reaction Motors Division.

This Technical Report has been reviewed and approved for publication.

W. H. EBELKE, Colonel, USAF
Chief, Propellant Division
Air Force Rocket Propulsion Laboratory

ii

ABSTRACT

Hydrogen peroxide of 90 percent purity was catalytically decomposed in experimental equipment simulating the LR-99 engine gas generator system in the X-15 aircraft. The performance of peroxides produced by three different methods was evaluated. Operation at low flow rate produced heavy low-frequency pulsing in the output pressure. Both low and high flow rates produced a low-amplitude high-frequency pulsing. The consistency of the pulsing led to the conclusion that it was system-generated.

The three types of peroxide were found to perform identically. No data was generated to substantiate a change in the current hydrogen peroxide specification, MIL-P-16005E.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

vi

SECTION I

INTRODUCTION

Controversy regarding the efficiency of decomposition of various types of 90 percent hydrogen peroxide has persisted for years. Specifically, producers using the electrolytic process claim that peroxide manufactured by organic processes is inferior in its performance. Three corporations are presently manufacturing 90 percent hydrogen peroxide: FMC Corporation, by electrolysis of persulfuric acid; E. I. DuPont de Nemours & Company, by a modified anthraquinone process; and Shell Chemical Company by high pressure oxidation of isopropyl alcohol. The DuPont and Shell products are usually referred to as "organic" peroxides.

The significant analytical difference between the various peroxides pertains to the carbon content. All three processes satisfy the military specification (MIL-P-16005E) requirement of a maximum of 200 ppm carbon; FMC peroxide has a carbon content of approximately 6 ppm. DuPont peroxide approximately 15 ppm, and Shell peroxide approximately 175 ppm. It should be noted, in regard to this variation of carbon content that no catalyst degradation has been reported to date which could be attributed to carbon poisoning.

In 1961, the X-15 aircraft sustained six failures during operations with DuPont peroxide. These failures were attributed to the peroxide. The failure problem was confined to the turbopump gas generator; the auxiliary power unit and attitude-control systems were not affected. A waiver was issued to the X-15 Project Office to allow procurement of FMC electrolytic peroxide which was used exclusively in all subsequent operations. In 1964, eight catalyst packs on the X-15 aircraft failed while using electrolytic peroxide. Microphotographs showed that these failures were of the same nature as the six previous failures in that small gaps had developed between the silver catalyst m... and brass screen substrate. The X-15 Project Office attributed the ... failures to the catalyst.

1

The Propellant Division of the Air Force Rocket Propulsion Laboratory is responsible for military propellant specifications and for granting waivers thereto in regard to propellant procurement. To elucidate and help solve the X-15 problem, AFRPL undertook an in-house evaluation duplicating the operational mode on the X-15 gas generator. The test system was modeled after the generator acceptance tests and its various parts were made from LR-99 engine drawings to maximize correlation of data. Since all previous catalyst failures occurred after short operational time, the generators were run for half their rated life or until failure occurred. They were then sent to Thiokol's Reaction Motors Division where they were sectioned. Samples were made available to interested parties.

This report discusses in detail the testing procedures as well as the data obtained by AFRPL and the participating companies (RMD, DuPont, FMC and Shell).

2

SECTION II

DISCUSSION

A. General

Hydrogen peroxide decomposes in the presence of a catalyst to form
steam and oxygen. The adiabatic decomposition temperature of 90 percent
peroxide is nominally $1365°F$; however, this temperature is dependent on
the initial feed temperature of the peroxide.

The catalyst used in the LR-99 engine (X-15 aircraft) gas generator is
silver, plated on brass screens. The solubility of silver in hydrogen
peroxide causes a migration of silver from the front to rear screens, thereby
increasing the catalyst surface area. This, in turn, increases the decompo-
sition rate and leads to local increases in temperature. Catalyst temperatures
are also raised by back-flowing hot gases. The effect of increased feed
temperature is seen in Figure 1, from FMC Corporation's Hydrogen Peroxide
Rocket Manual.

At temperatures above $1430°F$ a copper-silver eutectic forms at the
catalyst/base metal interface. This eutectic has a lower melting point than
either silver or brass and its formation leads to flaking of the silver and
exposure of the brass to corrosion. Dezincification of the brass results in
zinc- and copper-rich zones at the silver/brass interface. Oxidation of the
zone occurs when the decomposition gases diffuse through the silver plate.
The brittle oxide then fractures, allowing flaking and brass corrosion as
before.

In addition to poisoning, the carbon contamination is said to be harmful
to catalysts by an increase in the adiabatic decomposition temperature through
combustion of the carbon. However, 200 ppm of carbon burning to CO_2
release only 2 BTU per pound of peroxide. The average specific heat of the
combustion products is 0.395 $BTU/lb°F$, and therefore, the temperature
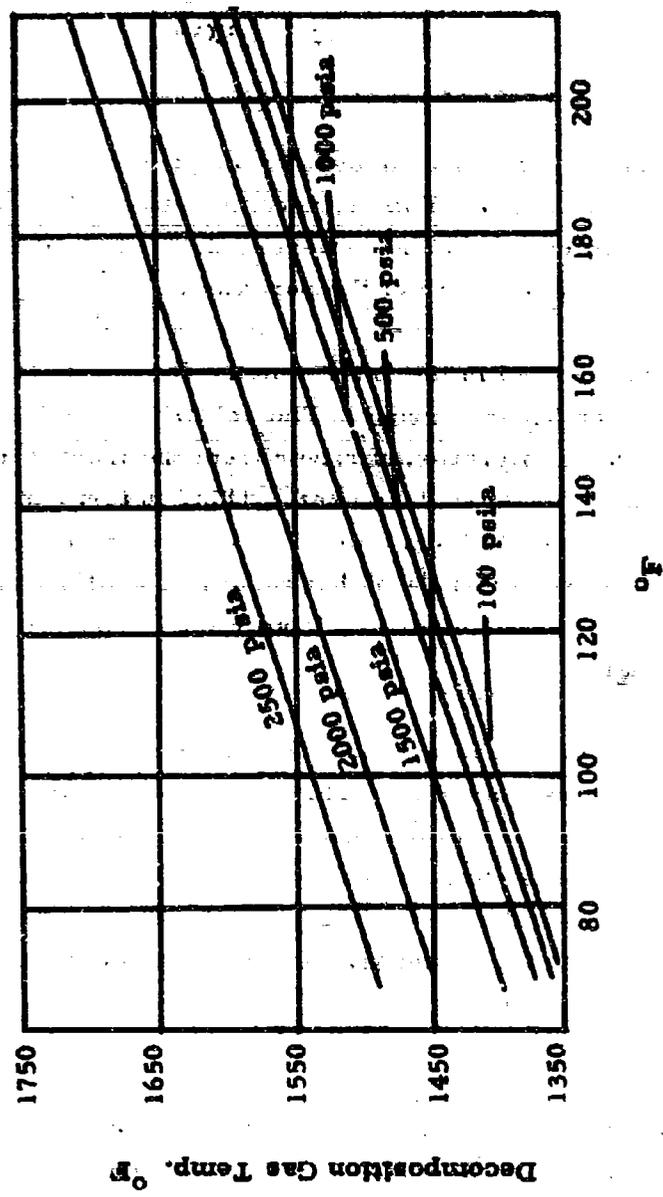
Figure 1. Effect of Feed Temperature and Reaction Pressure Upon the Decomposition Temperature of Becco 90 percent H_2O_2. [J. McCormick, Hydrogen Peroxide Rocket Manual]

4

increase due to combustion of the maximum allowable carbon may be calculated as follows:

$$T = \frac{H}{C_p} = \frac{2 \text{ BTU/lb}}{0.395 \frac{\text{BTU}}{\text{lb}^\circ\text{F}}} = 5^\circ\text{F}$$

A temperature increase of only 5°F will not harm the silver catalyst screens. Figure 2 shows the above in greater detail.

B. Equipment.

The test system was designed to simulate the operational system in the X-15/LR-99 turbopump. Key components were fabricated from LR-99 engine drawings, including cavitating venturis for critical flow control and a turbine nozzle simulator to create the necessary back pressure and gas flow characteristics.

The system is schematically indicated in Figure 3. The actual system is shown in Figures 4, 5, and 6. The tank shown in Figure 6 is one of four in the environmental box which was used to maintain the peroxide in the desired temperature range of 85 to 90°F. A heating coil and insulation were wrapped on the run lines.

Teflon and stainless steel were the only materials used in contact with the peroxide. All components were subjected to a cleaning procedure involving sequential treatment with a degreaser, distilled water, 70 percent nitric acid, distilled water, and 90 percent peroxide. After the system was assembled, the nitric acid, distilled water, and 90 percent peroxide were again used. The entire system remained passive during test operations and no problems due to contamination were encountered.

Instrumentation was passivated in the same manner as the rest of the system. Thermocouples, pressure transducers and flowmeters were changed once a month or as required.

5
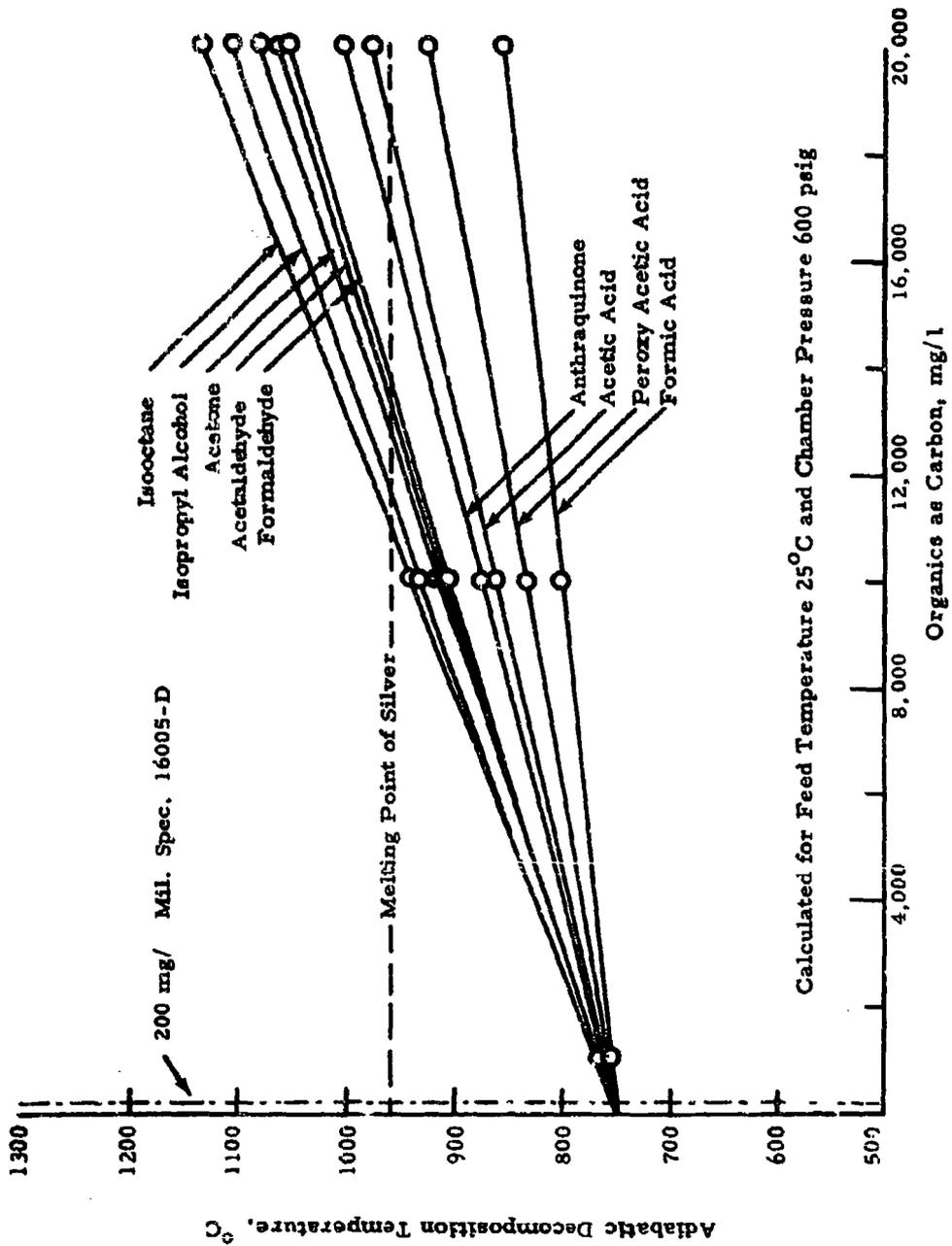
Figure 2. Increase in Adiabatic Decomposition Temperature Due to Organic Compounds in 90 percent H_2O_2. [Calculations by Shell Chemical Co]

6
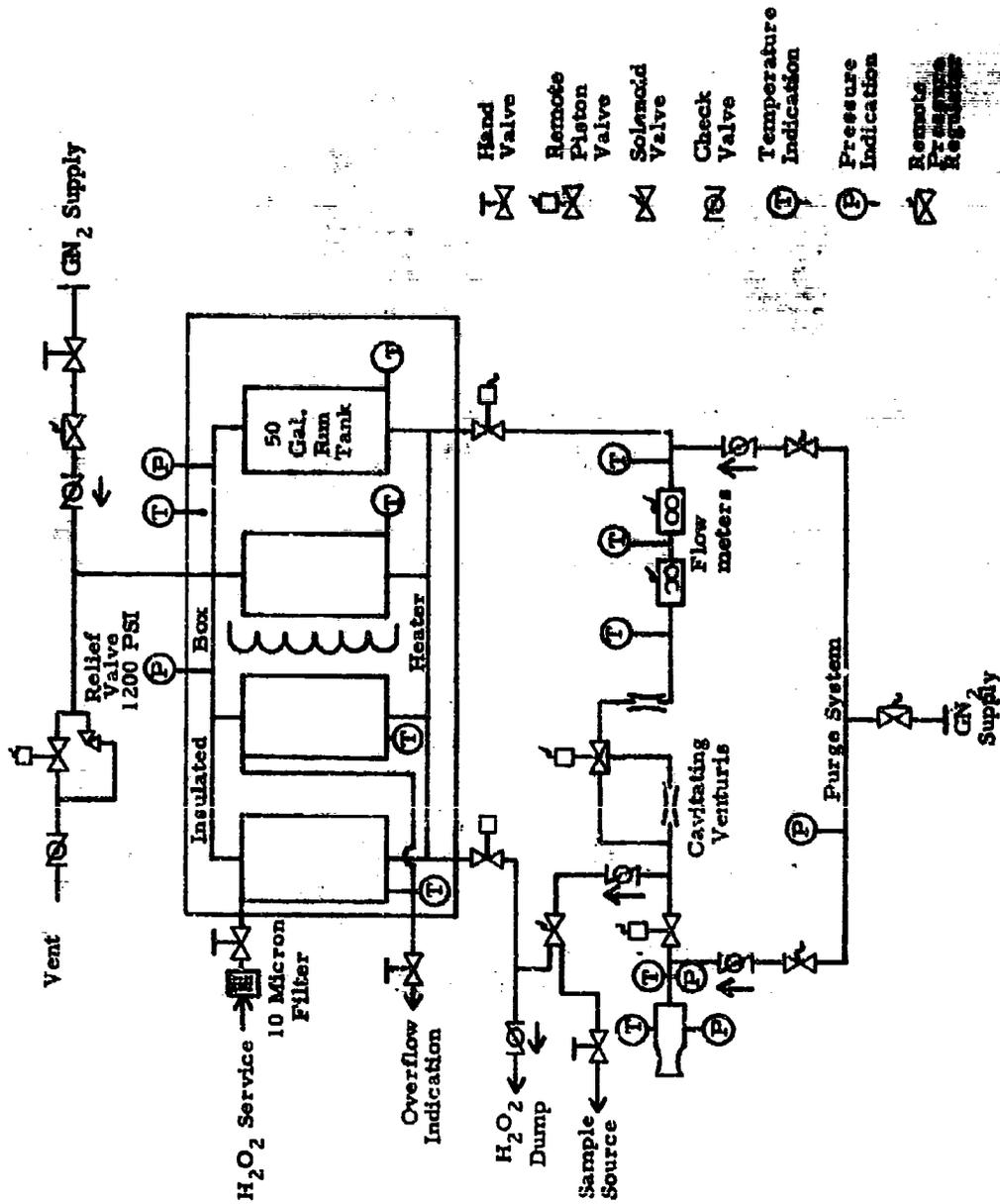
Figure 3. Test System Flow Diagram.

7
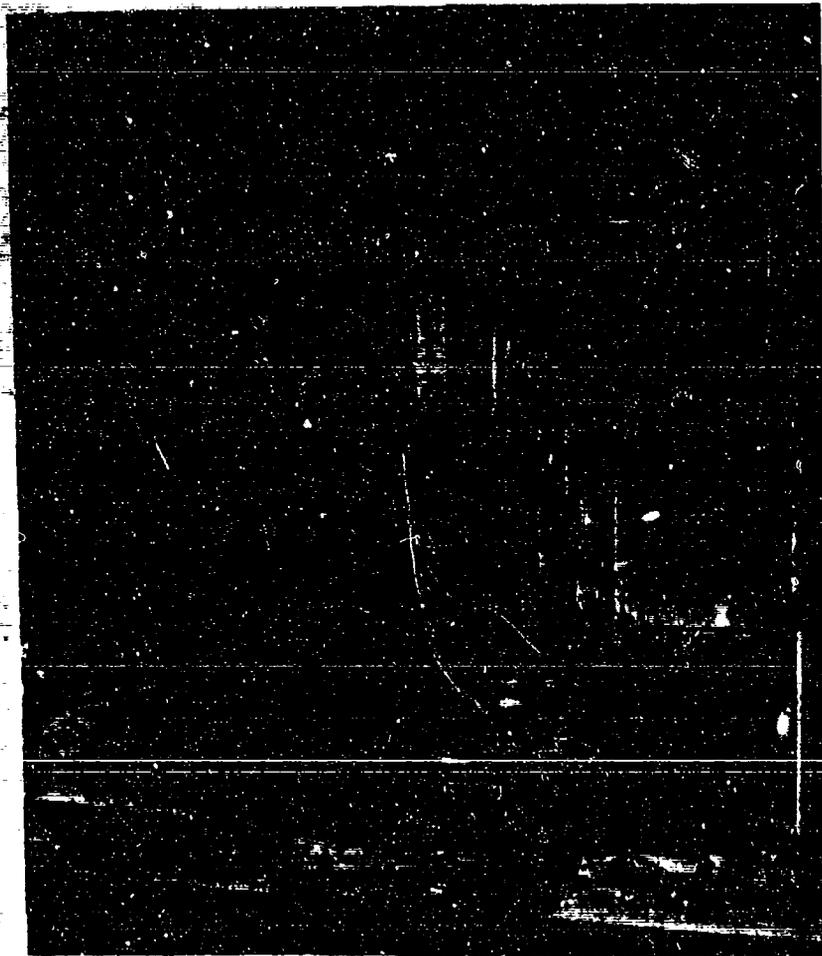
Figure 4. Front View of Hydrogen Peroxide Test System.

Figure 5. LR-99 Gas Generator and Turbine Nozzle Simulator.
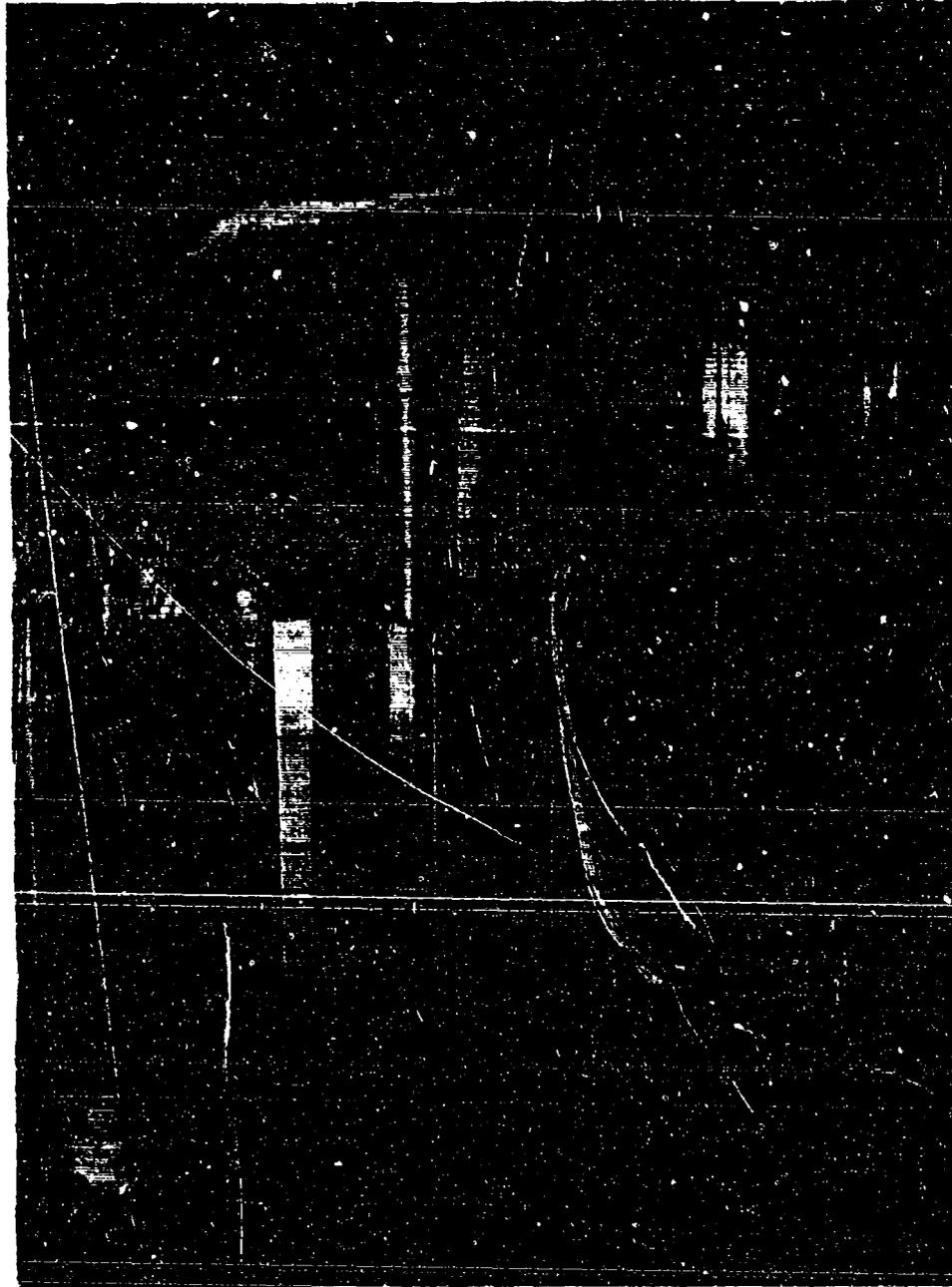
Figure 6. Hydrogen Peroxide Run Tank Inside-Temperature-Conditioning Box.

C. Procedures.

Test procedures simulated operating conditions on the X-15 aircraft. Although the LR-99 engine gas generator is rated at 2 hours operational lifetime, the X-15 experienced a number of failures in 10 minutes or less. It was therefore decided to run three generators well over this period. Generator S/N 131 used peroxide produced by isopropyl alcohol oxidation for 60 minutes and generators S/N 141 and S/N 111 used peroxide produced by the anthraquinone process for 50 and 34 minutes respectively. A fourth generator, S/N 009, which already had 97 minutes of satisfactory operation on the X-15 aircraft, was run in a series of baseline tests with electrolytic peroxide. All peroxide previously used in this generator had been produced electrolytically.

Each test "run" consisted of 40 seconds firing at 1.5 to 1.7 lb/sec flow rate, and 80 seconds firing at 7.7 to 8.0 lb/sec flow rate. These test parameters correspond to the idling and full-thrust modes of the LR-99 engine and represent the average fractions of run life in each mode. The peroxide was preheated to 85 to 90°F before each run to duplicate X-15 aircraft operating conditions.

The sequence of operations for each day was as follows:
1. Peroxide temperature checked.
2. Run lines heated to 85 to 90°F.
3. Run lines flooded.
4. Line heater turned off (affected flowmeters).
5. Tank pressure set at 900 psi.
6. Test performed.
7. Generator purged with nitrogen until the exhaust thermocouples indicated ambient temperatures.
8. Digital data tape changed and the instrumentation recalibrated.
9. Tanks vented.
10. Tanks refilled. (All peroxide was passed through a 10-micron filter and then allowed to stand overnight to bring it to the required temperature.)

11

D. Data Reduction.

Data was recorded on a Systems Engineering Laboratories analog to digital unit (SEL 600). Chamber pressure, chamber temperature and control data were recorded by oscillograph and strip charts. Pressures were recorded at 800 samples/second. The data was computer-reduced and displayed by Telecomputing Services Incorporated (now Computing and Software, Inc.) under Air Force contract.

The data display included a general printout of all samples reduced to a 1-second time average for easier reading. Since time averaging camouflages the existence of pressure oscillations, the exhaust pressures were also mechanically plotted and oscillograph recorded. The two displays were in excellent agreement.

The Appendix gives typical values of data for each run.

12

SFCTION III

RESULTS AND INTERPRETATION

A. AFRPL Program.

The primary objective during the tests was to determine what operating conditions caused catalyst failure. Reaction Motors Division of Thiokol Chemical Co., Inc., and the X-15 Project Office had previously agreed that catalyst failure would be indicated by a decomposition temperature less than 1300° F and/or a catalyst-bed pressure drop greater than 150 psi during full-thrust run conditions. The flow envelope as defined by RMD specified pressure drops of 44 psi maximum, and 8 psi minimum at flow rates of 1.7 lb/sec and pressure drops of 116 psi maximum and 42 psi minimum at flow rates of 7.8 lb/sec. These flow rates were achieved in accordance with the prescribed limits (low rate, 1.5 to 1.7 lb/sec; high rate, 7.7 to 8.0 lb/sec).

The highest pressure drops measured on DuPont and Shell peroxides were approximately 110 psi. Decomposition temperatures were almost always above theoretical, presumably due to the preheating of the liquid peroxide by back-flowing gases. The generator using FMC electrolytic peroxide performed well outside the design envelope, reaching pressure drops drops of 150 psi several times. This unit had 97 minutes prior use on the X-15 and the Project Office indicated that this performance was satisfactory even though it claimed a 150-psi pressure drop defined failure. Its decomposition temperatures were similar to those of the other units.

Chamber pressure oscillations were observed during all runs. The oscillations during the high flow rate were of relatively high frequency (70 to 120 Hz) and low amplitude (1 percent and less of average pressure). Since the propellant turbopumps on the X-15 could not respond to high frequencies, these oscillations were not considered harmful. However, at the low flow rate, a lower frequency (7 to 10 Hz) was superimposed on the high frequency. Amplitudes were 10 to 25 percent of the average pressure.

An analysis by RMD indicated that the turbopumps could respond to this oscillation in such a way as to initiate automatic shutdown of the LR-99 engine. Since this type of oscillation usually accompanies termination of service life, it was a source of concern during the tests. The oscillation was consistent in nature and catalyst performance was not noticeably degraded, but attempts were made to isolate the source. Pressure measurements taken along the run lines showed that the oscillation was completely damped out upstream by the venturis, whereas downstream it remained constant both at the injector and in the chamber. The frequency was independent of position, but the highest amplitudes were reached at a "T" fitting which joined the high- and low-flow branches below the cavitating venturis. Inasmuch as flows were oriented such that the low flow rates moved straight and the high flow rates made a 90 degree turn, it was theorized that the highly turbulent flow should cause the most severe oscillation. This was not the case, however, and no satisfactory explanation was found. A number of attempts were made to stop the oscillation but none were successful.

It should also be noted that usually the first test of each day showed a higher amplitude of oscillation than the second. The third run of the day, performed after a 1-hour interval, was about as violent as the first, while the fourth run would be similar to the second. This led to consideration of the possibility that the generator did not reach ambient temperature between some of the tests; however, temperatures in the chamber and temperatures on the outer surface both checked at ambient before every test. A series of tests were made with each generator in which the flow rate was cycled between the high and low values. In every case the first low-rate portion showed the usual 7 to 10 Hz plus 70 to 100 Hz, but the succeeding low-rate portion showed a single higher frequency (28 to 50 Hz). This reinforced the conclusion that the problem was system-originated. The oscillation was consistent and did not degrade generator performance, therefore, it was not considered in the final data analysis.

The only problem encountered with the peroxide was the clogging of the filter by the DuPont product. A check revealed visible particles,

14

aluminum oxide, mixed with peroxide in the bottom 3 inches of the drums.
The bulk of the material was within the specification and when the last
3 inches of peroxide were left in the drum no further problem was encountered.

No catalyst pack failed in this test program. In comparing the packs
using organic peroxides with the pack using electrolytic peroxide, and
allowing for the greater operational time on the latter, no differences in
performance were observed. Extrapolation of the data indicates that the
catalyst packs using organic peroxides develop the same pressure drops
and operating temperature as the pack using electrolytic peroxide. It should
be pointed out that the catalyst failures which prompted this investigation
occurred in 10 minutes or less of use time whereas all catalyst packs used
in these tests lasted much longer.

B. Contractor's Reports.

At the conclusion of the AFRPL tests, the three generators operated
with organic peroxides were sent to Reaction Motors Division (Thiokol) to
be sectioned and samples of the screens were given to RMD, DuPont, FMC
and Shell for analysis. The fourth generator was returned to the X-15
Project Office. All of the referenced companies provided reports of their
findings; they are consolidated in the following paragraphs.

The RMD report is a thorough discussion of the three generators which
they sectioned, and RMD data concerning generators run with FMC peroxide.
It contains more specific statements than the others concerning generators
and the significance of various observations of the test catalyst.

All four investigations revealed areas where the silver had been
stripped from the screen. In the upper screens this stripping is primarily
due to the high-velocity liquid peroxide injection, and the stripping cor-
responds to the injection pattern. Silver losses in the lower screens
occurred as random flaking or spalling. RMD, Shell and DuPont photo-
graphed, at high magnification, sites of silver/copper eutectic formation.

These seem to have occurred randomly throughout the catalyst packs. Shell noted that the eutectic formation was light. More widespread was the oxidation of the zinc and copper strata which was brought about by the dezincification of the brass. The oxygen apparently diffuses through the silver plate without difficulty. RMD, Shell and DuPont presented high-resolution photographs of the copper oxide layer showing it laced with cracks. FMC photographs showed the absence of silver over parts of the catalyst wire, but no attempt was made to analyze the exposed material (which was probably brass, as FMC assumed, since an exposed eutectic or oxide would erode readily).

The assessment of catalyst degradation appeared to be a matter of intrepretation as seen in the contrasting reports from FMC and RMD. FMC stated in its report: "However, the serious damage suffered with the organic process peroxide appears to be in excess of that usually encountered with electrolytic H_2O_2." The RMD report, on the other hand, made this statement: "Examination revealed that there were no significant differences between the beds and that the catalyst screens were in good condition. Silver-plated brass screen deterioration was minor and randomly distributed."

The screen deterioration described above can be considered in better perspective if reviewed in the light of RMD's report. The data shows that catalyst screens suffer identical deterioration when heated in a furnace in air to temperatures of $1150^\circ F$ and 1410 to $1450^\circ F$ for 15 minutes. This clearly demonstrates that catalyst degradation is characteristic of the catalyst material and the thermal environment. The corrosion effects induced by peroxide aggravate the problem, but the relative magnitude of the peroxide versus the thermal effects in the deterioration process renders chemical differences between the peroxide types insignificant.

Both RMD and FMC analyzed for carbon; FMC reported 0.006 percent to 0.015 percent carbon, RMD reported carbon content of less than 0.016 percent.

16

FMC presented evidence that considerably less carbon is deposited on the screens when electrolytic peroxide is used. This is to be expected. Yet the peroxide obtained by oxidation of isopropyl alcohol contains a much larger amount of carbon (175 versus 6 ppm) and no catalysts have failed during its use. Calculations have shown that the carbon is not present in large enough quantities to burn the catalyst (Figure 2). In addition, there has been no evidence presented to date indicating that any catalysts using peroxide from the current specification have been poisoned, and the FMC report specifically stated that no poisoning was evident in the catalyst packs used in this program. While certain carbon compounds may be catalyst poisons, none of these compounds appear to occur in peroxide as currently produced.

Various residue materials were found on the catalyst screens, primarily the oxides of silver, copper, zinc and tin. The first three are to be expected in view of the catalyst and screen erosion. As for tin, it is present in the peroxide as a stabilizer. None of these materials are present in great enough quantity to cause trouble, although large amounts could conceivably lead to high bed-pressure drops and decreased catalyst activity. The higher pressure drops noted in the generator using electrolytic peroxide could have been caused by accumulation of these oxides, since it had been used for a much longer period than the other generators.

In summary, the analyses made by RMD, DuPont, FMC, and Shell all indicate that catalyst failure in the LR-99 engine gas generator is due to the physical construction of the catalyst rather than the type of peroxide used as the propellant.

SECTION IV

CONCLUSIONS

1. No significant differences were observed in the performances of hydrogen peroxides produced by the anthraquinone, electrolytic and isopropyl alcohol oxidation processes when used with a silver-type catalyst.

2. No evidence was found to indicate a need for a change in the requirements of the H_2O_2 procurement specification MIL-P-16005E.

3. Degradation and failure of silver-plated brass screen catalysts are primarily due to temperature effects. However, the degradation is aggravated by the corrosive high-velocity flow of decomposing hydrogen peroxide.

4. The modes of catalyst degradation are (1) oxidation at the silver/brass interface and subsequent spalling of the silver plate, (2) formation of low-melting-point eutectic at the silver/brass interface, (3) erosion and corrosion at the brass screens wherever exposed, (4) dissolution of the silver in hydrogen peroxide with replating downstream, (5) plugging of the catalyst pack by erosion products, (6) melting of the silver due to increased decomposition rate brought about by Mode 4, (7) increased catalyst temperatures due to preheating of the liquid hydrogen peroxide by recirculating gases, (8) weakening of the screens at pressure points and (9) blistering of the silver plate due to high temperatures.

18

SECTION V

RECOMMENDATIONS

1. Air Force procurement of 90 percent hydrogen peroxide should be made only on the basis of cost and Specification MIL-P-16005E; the latter adequately defines the quality requirements.

2. The method of production of 90 percent hydrogen peroxide should be deleted from the Federal Stock Catalogue. The use of separate Federal Stock Numbers to distinguish between electrolytically and organically produced hydrogen peroxide creates confusion and a false impression that performance differences exist among the commercially available peroxides.

3. Since the degradation modes of the silver/brass catalyst are peculiar to the brass substrate, the use of a nickel or nickel alloy substrate should be considered.

APPENDIX

SUMMARY OF DATA OBTAINED FROM THE

AFRPL TEST SERIES

APPENDIX

SUMMARY OF DATA OBTAINED FROM THE AFRPL TEST SERIES.

The following tables show typical test data for each generator used. They represen only a fraction of the total data recorded.

Table I. Typical Data From Test Gas Generator S/N 141 Being DuPont Furnish

Run	Exhaust Temp °F	Low Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	High Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	Flow Ratio Lb/Sec Low / High
1	1365	20	80	7	94	80	0.6	1.69/7.8
2	1361	21	80	7	94	75	0.6	1.69/7.8
3	1390	20	70	5	84	70	0.6	1.69/7.1
4	1413	24	80	6	94	80	0.5	1.70/7.8
5	1415	23	80	5	98	70	0.6	1.70/7.8
6	1365	23	70	7	95	90	0.6	1.70/7.8
7	1415	23	80	6	97	80	0.6	1.70/7.8
8	1418	24	70	7	97	90	0.6	1.7/7.8
9	1410	24	8-70	8	97	100	0.7	1.7/7.8
10	1400	23	8-70	9	97	110	0.6	1.7/7.8
11	1410	24	8-70	13	100	90	0.6	1.7/7.9
12	1416	24	7-65	9	101	110	0.6	1.7/7.8
13	1405	24	9-70	10	101	120	0.6	1.7/7.8
14	1411	25	7-70	9	102	100	0.6	1.7/7.8
15	1423	25	10-60	30	103	100	0.6	1.7/7.8
16	1422	25	9-80	10	103	100	0.7	1.7/7.8
17	1415	25	9-70	8	103	110	0.8	1.7/7.8
18	1422	25	8-70	11	104	100	0.8	1.7/7.8
19	1425	27	9-70	12	107	100	0.8	1.7/7.8
20	1427	26	8-70	28	105	100	0.8	1.7/7.8
21	1410	25	8-60	10	104	98	0.8	1.7/7.8
22	1415	26	7-50	9	105	98	0.8	1.7/7.8
23	1405	25	8-50	9	105	124	.0	1.7/7.8
24	1416	26	8-60	9	107	80	0.8	1.7/7.8
25	1415	26	8-60	9	105	100	0.9	1.7/7.8
26	1423	26	9-60	9	107	100	0.8	1.7/7.8
27	1422	27	8-60	10	108	80	0.8	1.7/7.8
28	1429	25	8-60	35	105	120	1.0	1.7/7.8
29	1438	25	8-50	10	103	100	0.8	1.7/7.8

Table II. Typical Data From Test Gas Generator S/N 111 Using DuPont Peroxide

Run	Exhaust Temp °F	Low Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	High Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	Flow Rate Lb/Sec Low / High
1	1388	18	---	5	78	---	0.6	1.68/7.7
2	1392	20	---	9	83	---	0.7	1.7/7.8
3	---	21	---	10	82	---	0.6	1.7/7.8
4	---	22	---	15	86	---	0.8	1.68/7.74
5	---	22	60	15	87	110	0.6	1.7/7.8
6	1380	22	9-90	20	76	100	0.7	1.7/7.8
7	15°°	23	60	14	79	105	0.6	1.7/7.8
8	---	23	9-75	22	79	100	0.7	1.7/7.8
9	1333	23	70	14	84	100	0.6	1.7/7.8
10	1402	24	9-70	20	86	115	0.6	1.7/7.8
11	1407	23	9-70	13	86	105	0.7	1.7/7.8
12	1417	24	9-80	23	91	105	0.7	1.7/7.8
13	1413	23	9-70	14	87	120	0.7	1.7/7.8
14	1467	24	9-80	25	90	120	0.6	1.7/7.8
15	1420	24	9-70	15	88	110	0.8	1.7/7.8
16	1417	25	7-80	22	97	115	0.8	1.7/7.8
17	1420	25	10-70	16	94	120	0.8	1.7/7.8

Table III. Typical Data From Test Gas Generator S/N 131 Using Shell Porosim

Run	Exhaust Temp °F	Low Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	High Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	Flow Rate Lb/Sec Low / High
1	1403	18	10-110	24	78	115	0.6	1.65/7.7
2	1402	20	8-60	5	82	120	0.6	1.69/7.8
3	1396	22	9-70	10	83	70	0.6	1.7/7.8
4	1400	22	7-90	6	86	70	0.6	1.7/7.8
5	1400	22	7-70	6	80	60	0.6	1.7/7.8
6	1526	23	3-8-60	13	79	90	0.8	1.7/7.3
7	1400	23	7-60	14	78	90	0.6	1.7/7.8
8	1404	23	9-70	14	78	50	0.6	1.7/7.8
9	1410	24	8-70	14	81	90	0.6	1.7/7.8
10	1412	24	9-70	14	81	120	0.6	1.7/7.88
11	1400	24	8-60	15	81	120	0.5	1.7/7.88
12	1408	25	1-8-70	15	81	100	0.6	1.7/7.87
13	----	25	7-70	15	80	120	0.8	1.7/7.8
14	1388	25	8-70	19	80	90	0.6	1.7/7.85
15	1390	25	8-70	17	80	100	0.6	1.7/7.84
16	1400	26	7-70	15	80	80	0.7	1.7/7.84
17	1395	27	8-65	20	81	140	0.8	1.7/7.83
18	1375	25	7-60	14	81	90	0.7	1.7/7.84
19	1405	26	7-65	27	81	110	0.6	1.7/7.84
20	----	20	7-65	16	81	80	0.7	1.7/7.85
21	1400	26	7-70	21	83	130	0.7	1.7/7.94
22	1377	26	7-65	16	83	100	0.8	1.7/8.00
23	----	26	8-70	20	85	100	0.7	1.7/7.95
24	----	26	8-65	20	89	90	0.7	1.7/7.98
25	----	26	7-55	25	90	120	0.6	1.7/7.82
26	----	26	7-60	13	88	90	0.6	1.7/7.85
27	1400	26	7-60	18	90	100	0.6	1.7/7.82
28	----	26	8-60	13	91	100	0.6	1.7/7.83
29	1395	26	7-70	25	87	110	0.8	1.7/7.84

Table IV. Typical Data From Test Gas Generator S/N 009 Using FMC Peroxide

Run	Exhaust Temp °F	Low Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	High Flow ΔP PSI	Chamber Pressure Frequency Hz	Oscillation Amplitude %	Flow Rate Lb/Sec Low/High
1	1426	31	9-90	12	130	110	0.7	1.7/7.83
2	143?	33	2-8-90	9	131	140	0.7	1.7/7.83
3	1432	34	8-90	7	123	110	0.7	1.7/7.84
4	1439	34	9-80	14	138	80	0.7	1.7/7.79
5	1397	32	8-90	15	147	100	0.9	1.7/7.84
6	1397	33	1-8-90	10	149	110	0.8	1.7/7.85
7	1409	33	1-9-90	10	150	100	0.7	1.7/7.85
8	1407	33	1-8-90	10	149	100	0.7	1.7/7.88
9	1405	33	1-9-80	11	150	90	0.7	1.7/7.87

Table V. Typical Data From Cycling Tests

Run	First Cycle Low Flow		First Cycle High Flow		Second Cycle Low Flow		Second Cycle High Flow	
	Frequency Hz	Amplitude Percent	Frequency Hz	Amplitude Percent	Frequency Hz	Amplitude Percent	Frequency Hz	Amplitude Percent
DuPont								
S/N 141-31	9-55	12	110	0.4	38	9	100	0.8
141-32	9-55	1	90		38	8	90	0.9
141-33	9-55	12	110	0.9	28	10	90	0.8
DuPont								
S/N 111-18	9-70	15	120	0.9	32	17	90	0.8
111-19	8-70	13	120	0.8	13-37	14	100	0.8
111-20	8-70	24	100	1.0	13-37	17	100	0.8
Shell								
S/N 131-31	6-70	25	100	1.0	32	24	100	0.8
131-32	9-60	17	100	0.8	34	22	80	0.8
131-33	8-60	18	110	0.8	32	24	120	0.7
FMC								
S/N 009-1	10-80	18	100	0.9	56	2	100	0.6
009-11	1-10-80	9	100	0.7	51	3	115	0.8
009-..	1-7-80	9	100	0.7	49	3	105	0.7

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13. ABSTRACT

Hydrogen peroxide of 90 percent purity was catalytically decomposed in experimental equipment simulating the LR-99 engine gas generator system in the X-15 aircraft. The performance of peroxides produced by three different methods was evaluated. Operation at low flow rate produced heavy low-frequency pulsing in the output pressure. Both low and high flow rates produced a low-amplitude high-frequency pulsing. The consistency of the pulsing led to the conclusion that it was system-generated.

The three types of peroxide were found to perform identically. No data was generated to substantiate a change in the current hydrogen peroxide specification, MIL-P-16005E.

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